Attainment of Program Outcome '3b' of ABET through Laboratory Experiment for the Undergraduate Program

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Abstract— **The engineering education has gone through several re-engineering efforts under various names. Some of the popular names in the past have been sustainable engineering and concurrent engineering. While each of these names has a different flavor to it, the underlying principle of effective engineering education has been its ability to provide practical and functional learning opportunities to students. Experiential learning, which encompasses all types of practice-based learning opportunities, is the founding principle of a successful engineering education model. This paper presents an approach to enhance active and collaborative learning in 'Metal Cutting' laboratory by the undergraduate students of V Semester Industrial & Production Engineering using the concept of "Design of Experiments", to study the effects of various parameters on machining performance. The paper also describes the assessment of program outcome '3b' of ABET criteria through laboratory experiment.**

*Keywords— **Design of experiments, Program outcome '3b', open ended experiment.***

I. INTRODUCTION

It has been well documented that humans learn better through a combination of hearing, seeing, and hands-on experience than through just hearing and seeing alone. Despite these findings, the majority of college instruction is through lecture. This exercise seeks to improve the quality of education for students in understanding the subject concepts clearly by allowing them to test theoretical structural concepts in a hands-on, lab environment that parallels their statics lecture class. There are many studies and literature showing that students learn better when they are physically engaged in the learning process. Despite these facts, studies also show that the average instructor spends about eighty percent of his time lecturing to students. Instructors must learn "how to increase the productivity of their teaching" to allow students to learn and retain more. The result will be students not only have a higher level of understanding of concepts, but who are also able to move on to complex problem solving capability more quickly than in traditional educational environments [1].

Under these circumstances, identifying the problem in an industry or identifying the factors which affect the process play vital role [2].

Outcome '3b' of Accreditation Board for Engineering and Technology (ABET) states that engineering graduates must have "an ability to design and conduct experiments, as well as to analyze and interpret data". The ability to conduct experiments, analyze and interpret data has been addressed by traditional laboratory courses, whereas the ability to design an experiment presents a new challenge. Previous to this initiation, in our regular laboratory courses, the students were used to conduct the experiments conventionally i.e., they record the responses during machining operation and this experiment was at the exercise level. An attempt has been made in this paper to bridge the gap between theory and practice as well as making students industry ready through an experiential learning in the 'Metal cutting' laboratory for undergraduate students of Industrial and Production Engineering program. The students also have used the statistical approach in this experiment, by which they are exposed to the design of experiments (DOE) technique as well as statistical tool. Through this experiment, students are involved in a team and conducted an open ended experiment to study the effects of various process parameters on performance of cutting tool in machining process. Further, the students have analyzed the cutting forces and power consumption in turning operation for selected cutting parameters. This will help them to understand the variation in the cutting forces as well as power consumption for identified cutting conditions for a work-tool combination. This activity also helps to assess the students for the attainment of program outcome '3b' of ABET criterion.

II. OBJECTIVES

- To help the students in acquiring deeper understanding of the experimental process and the use of statistical methods.
- To design, conduct, analyze and interpret the experimental results for attaining the program outcome '3b' of ABET criterion.

- To statistically analyze the experimental results using statistical software for studying the effects of various cutting parameters on machining performance.

III. METHODOLOGY

The students in a team were given an open ended problem to analyze the effects of process parameters on the performance of turning operation. The students need to perform the above activity using the following steps to address the program outcome '3b' of ABET criterion:

- Planning or designing the experiment
- Conducting experiment
- Analyzing the experimental data
- Interpreting the experimental results

A. Planning or designing the experiment

The students identified three major cutting parameters such as cutting speed, feed and depth of cut, which affect the two responses, namely, cutting force and power consumption during turning operation. Table I illustrates the process parameters and their levels identified by one of the teams.

Machine used: Centre lathe

Tool material: Carbide tool (K10)

Work piece material: Aluminium of diameter 24mm

Based on experimental plan, 2^3 (3 factors and 2 levels) factorial design have been formulated, which is represented in Table II.

TABLE I. IDENTIFIED PARAMETERS AND LEVELS

Parameters	**Levels**	
	1	2
Cutting speed (m/min)	75.39	105.56
Feed (mm/rev)	0.250	0.355
Depth of cut (mm)	0.5	1.5

TABLE II. EXPERIMENTAL DESIGN

Trial No.	Run Order	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
1	21	75.39	0.250	0.5
2	17	105.56	0.250	0.5
3	15	75.39	0.355	0.5
4	20	105.56	0.355	0.5
5	11	75.39	0.250	1.5
6	10	105.56	0.250	1.5
7	22	75.39	0.355	1.5
8	8	105.56	0.355	1.5
9	12	75.39	0.250	0.5
10	1	105.56	0.250	0.5
11	4	75.39	0.355	0.5
12	7	105.56	0.355	0.5
13	6	75.39	0.250	1.5
14	18	105.56	0.250	1.5
15	23	75.39	0.355	1.5
16	14	105.56	0.355	1.5
17	16	75.39	0.250	0.5
18	24	105.56	0.250	0.5
19	5	75.39	0.355	0.5
20	3	105.56	0.355	0.5
21	19	75.39	0.250	1.5
22	2	105.56	0.250	1.5
23	13	75.39	0.355	1.5
24	9	105.56	0.355	1.5

B. Conducting experiment

Based on the experimental plan, the students conducted experiments as per full factorial design (FFD) of 2^3 with 3 replications under each experimental combination. The cutting force (Fc) was measured using lathe-tool dynamometer and has been recorded for each experimental. The power consumption is computed by [3]:

$$Power\ consumption = \frac{Fc \times v}{60} \quad in\ Watts$$

Where,

$$v = \frac{\pi D N}{1000} \quad in\ m/min$$

v = Cutting speed in m/min

D = Diameter of work piece in mm

N = Spindle speed in RPM

The responses are summarized in Table III.

TABLE III. PARAMETER SETTINGS AND RESPONSES

Cutting speed (m/min)	Feed (mm/rev)	DOC (mm)	F_C (N)	Power consumption (W)
75.39	0.250	0.5	107.91	135.59
105.56	0.250	0.5	98.1	172.59
75.39	0.355	0.5	127.53	160.24
105.56	0.355	0.5	127.53	224.37
75.39	0.250	1.5	225.63	283.50
105.56	0.250	1.5	215.82	379.70
75.39	0.355	1.5	304.11	382.11
105.56	0.355	1.5	274.68	483.25
75.39	0.250	0.5	107.91	135.59
105.56	0.250	0.5	107.91	189.85
75.39	0.355	0.5	127.53	160.24
105.56	0.355	0.5	127.53	224.37
75.39	0.250	1.5	225.63	283.50
105.56	0.250	1.5	225.63	396.96
75.39	0.355	1.5	304.11	382.11
105.56	0.355	1.5	264.87	465.99
75.39	0.250	0.5	107.91	135.59
105.56	0.250	0.5	107.91	189.85
75.39	0.355	0.5	117.72	147.92
105.56	0.355	0.5	127.53	224.37
75.39	0.250	1.5	225.63	283.50
105.56	0.250	1.5	215.82	379.70
75.39	0.355	1.5	304.11	382.11
105.56	0.355	1.5	264.87	465.99

C. Analyzing the experimental data

Using the experimental results of Table III, the students analyzed the data for identifying the significance of the process parameters on the proposed machining performance during turning operation using statistical software MINITAB. Tables IV to VII present the significance of process parameter and analysis of variance (ANOVA) for cutting force (Fc) and power consumption respectively for 95% confidence interval. Figs1 and 2 depict the pie charts showing the importance of each process parameter and their interactions for cutting force and power respectively. Students also used MINITAB software to draw pareto charts (Figs. 3-4), main effect plots (Figs. 5-6) and interaction effect plots (Figs. 7-8) for the experimental results of Table III.

TABLE IV. ESTIMATED EFFECTS AND COEFFICIENTS FOR F_C

Term	Effect	Coef	SE Coef	T	P
Constant		185.164	0.8175	226.50	0.000
Cutting speed	-10.628	-5.314	0.8175	-6.50	0.000
Feed	41.692	20.846	0.8175	25.50	0.000
DOC	138.158	69.079	0.8175	84.50	0.000
Cutting speed*Feed	-5.723	-2.861	0.8175	-3.50	0.003
Cutting speed*DOC	-10.628	-5.314	0.8175	-6.50	0.000
Feed*DOC	22.072	11.036	0.8175	13.50	0.000
Cutting speed*Feed*DOC	-8.992	-4.496	0.8175	-5.50	0.000

TABLE V. ANALYSIS OF VARIANCE FOR F_C

Source	DF	Seq SS	Adj MS	F	P
Cutting speed	1	678	678	42.25	0.000
Feed	1	10430	10430	650.25	0.000
DOC	1	114525	114525	7140.25	0.000
Cutting speed*Feed	1	196	196	12.25	0.003
Cutting speed*DOC	1	678	678	42.25	0.000
Feed*DOC	1	2923	2923	182.25	0.000
Cutting speed*Feed*DOC	1	485	485	30.25	0.000
Pure Error	16	257	16		
Total	23	130171			

TABLE VI. ESTIMATED EFFECTS AND COEFFICIENTS FOR POWER

Term	Effect	Coef	SE Coef	T	P
Constant		277.876	1.347	206.25	0.000
Cutting speed	77.081	38.541	1.347	28.61	0.000
Feed	61.430	30.715	1.347	22.80	0.000
DOC	205.658	102.829	1.347	76.32	0.000
Cutting speed*Feed	1.853	0.927	1.347	0.69	0.501
Cutting speed*DOC	18.710	9.355	1.347	6.94	0.000
Feed*DOC	31.023	15.511	1.347	11.51	0.000
Cutting speed*Feed*DOC	-8.011	-4.005	1.347	-2.97	0.009

TABLE VII. ANALYSIS OF VARIANCE FOR POWER

Source	DF	Seq SS	Adj MS	F	P
Cutting speed	1	35649	35649	818.29	0.000
Feed	1	22642	22642	519.73	0.000
DOC	1	253771	253771	5825.11	0.000
Cutting speed*Feed	1	21	21	0.47	0.501
Cutting speed*DOC	1	2100	2100	48.21	0.000
Feed*DOC	1	5774	5774	132.55	0.000
Cutting speed*Feed*DOC	1	385	385	8.84	0.009
Pure Error	16	697	44		
Total	23	321040			

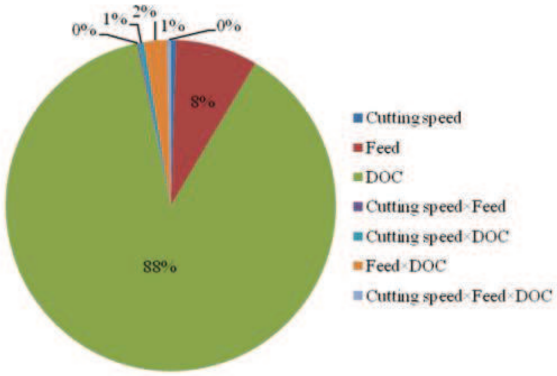

Fig. 1. Percentage Contribution for F_C

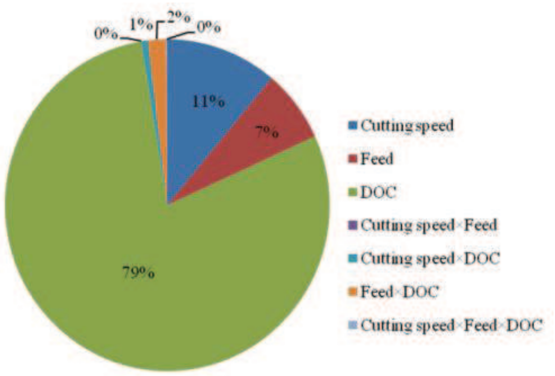

Fig. 2. Percentage Contribution for Power Consumption

D. Interpreting the experimental results

Through main effect and interaction effect plots, students analyzed the experimental results. It was observed that the depth of cut was the most significant factor, which affects the cutting force as well as power consumption. The cutting speed affects the cutting force inversely and is directly proportional to the power consumption. It was also noted that cutting speed has negative effect on cutting force; whereas, both feed and depth of cut have positive effects on cutting force. From the experimental results and subsequent analysis, it was seen that all the three identified factors have positive effects on power consumption. The interaction between cutting speed and feed, cutting speed and depth of cut ware observed on cutting force. But there is negligible interaction between feed and depth of cut. It was seen that there is no interaction between cutting speed and feed, cutting speed and depth of cut on power. However, there is negligible interaction between feed and depth of cut on power. After analyzing the experimental results, the students interpreted the experimental results for the trends observed in cutting force and power consumption during tuning operation of aluminium work material and arrived the inferences. Finally, the conclusions were discussed.

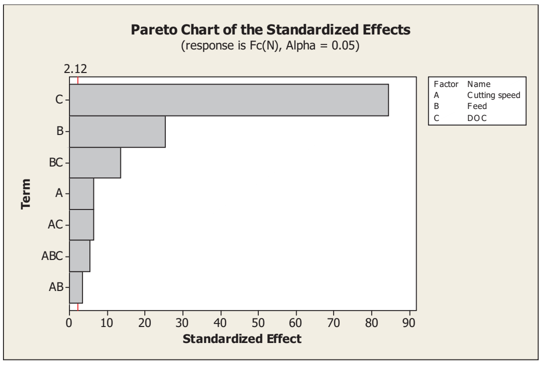

Fig. 3. Pareto chart for F_C

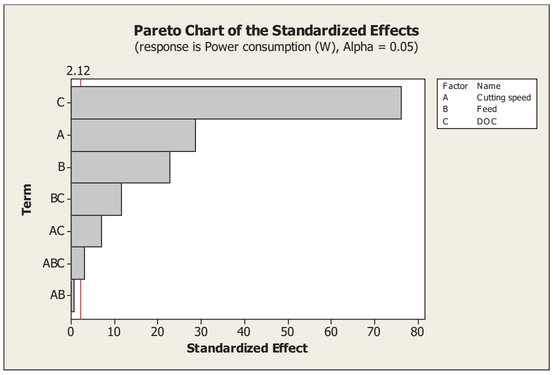

Fig. 4. Pareto chart for Power consumption

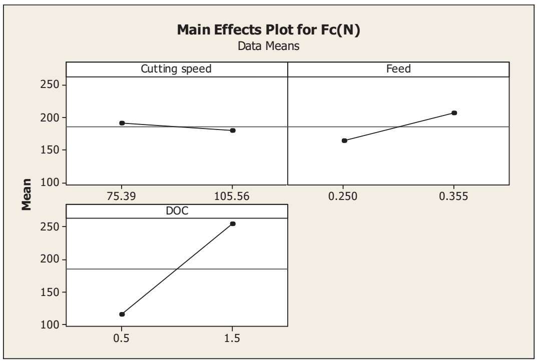

Fig. 5. Main effects plot for F_C

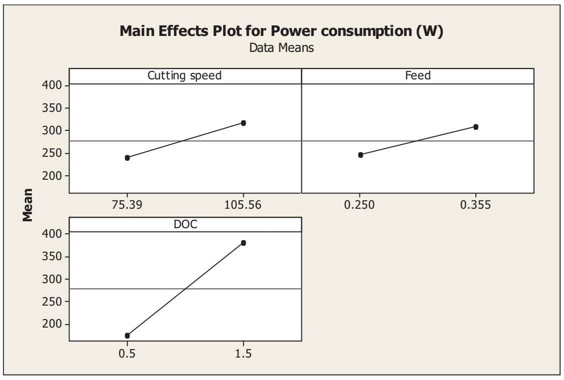

Fig. 6. Main effects plot for Power consumption

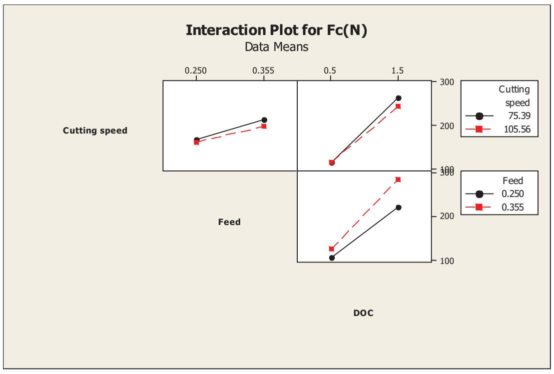

Fig. 7. Interaction plot for Fc

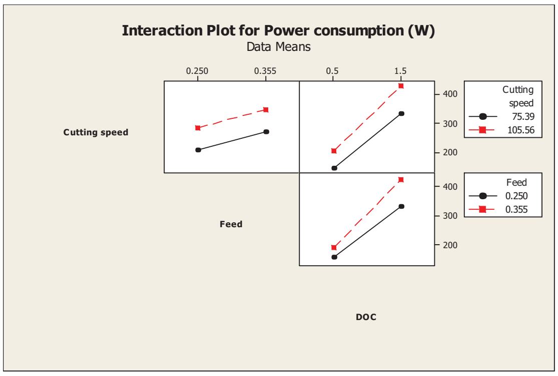

Fig. 8. Interaction plot for Power consumption

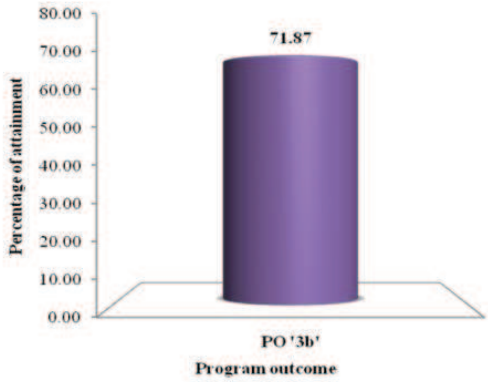

Fig. 9. Overall attainment of PO ‘3b’

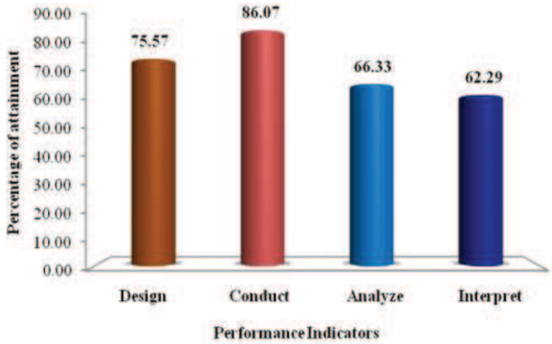

Fig. 10. Attainment of program outcome

IV. Assessment

Assessment has been done by the concerned faculty for the attainment of program outcome ‘3b’ of ABET criterion. The following performance indicators (PIs) for the outcome were identified for the above activity and each indicator was evaluated through the assessment rubrics.

- Design an experiment to verify the conceptual understanding.
- Conduct (or simulate) an experiment and report the results.
- Analyze a set of experimental data.
- Interpret the data.

Students were evaluated for each of the performance indicators through demonstration, presentation and viva-voce examination. Fig. 9 exhibits the overall attainment outcome addressed and Fig. 10 gives the % attainment for each performance indicator (PI). The overall class attainment of program outcome ‘3b’ was found to be 71.87%.

Each indicator of the outcome attainment was analyzed critically by the concerned faculty and the action was initiated for further improvement.

V. Conclusions

In this paper, an attempt has been made to address ABET ‘3b’ program out come for undergraduate students of Industrial and Production Engineering through open ended laboratory experiment. The students were explored to plan the experiments through design of experiments (DOE). The experimental results were then statistically analyzed using statistical software. By analyzing the plots and subsequently interpreting the results; the students could acquire deeper understanding of the machining behavior through experiential learning.

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