To Enhance Student Knowledge and Skills in Manufacturing Technology Laboratory through PBL and OBE

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Abstract: The development of modern technology in engineering education inspires students to acquire new knowledge and skills to understand the course better. The current teaching is derived from the conventional teaching methods with innovations and advanced technology-enabled techniques. Project-based learning (PBL) is a technique to solve challenging authentic, curriculum-based, and interdisciplinary problems. The PBL determines the effectiveness of learning for both teachers and students. The Outcome-Based Education system (OBE) is a student-centric teaching and learning methodology in which the course delivery and assessment are planned to achieve stated objectives and outcomes. This paper attempts to develop the course content, delivery, and evaluation through an OBE and validate the Manufacturing Technology laboratory course's effectiveness using a PBL approach.

The experiments and course projects are designed and delivered to design and fabricate a table clamp at the end of the course, demonstrating thorough, in-depth knowledge about the course acquired through conduction and practices.

Students designed and fabricated the table clamp through the PBL approach, evidenced through the feedback received against the course design and delivery effectiveness. By applying PBL techniques for the Manufacturing Technology laboratory course, students acquired new knowledge, complex problem-solving, communication, and higher-order thinking skills. The whole exercise also enabled the course instructor to achieve program outcomes 3, 4, and 5.

Keywords: Project-based Learning, Outcome-Based Education system, curriculum-based, complex problem-solving, higher-order thinking skill

1. Introduction

The engineering education approach in India remains the same as that of conventional practices at an early age. This approach may not create enthusiasm, interest, higher-order thinking, communication skills, etc., towards the present generation of engineering students. In this modern technology era, the conventional engineering education method has to reshape the current emerging learning process to develop higher-order thinking, communication, and complex problem-solving skills for engineering students [1].

The conventional way of conducting laboratories and assessing or examining them proves to be less effective in the challenge and change-driven world. The competitiveness is growing day by day, and the students should empathize with it to adjust to the working environment after the completion of

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education. To make this possible, the curriculum is expected to be more practical than theories overridden, which helps the student learn the real-world application and use it for his ideal creativity [2-3].

The engineering courses in India's engineering institutions need to be improved for new competencies and interdisciplinary technology development. Research in Engineering is a possibly important cornerstone for paving the path to breakthroughs in the engineering. It is known to be the primary source of knowledge locally, regionally, nationally, or internationally. Modern research is not only about learning processes but educational techniques as well. Numerous leading institutes in India have already taken steps toward empowering students with the required skills and knowledge for optimum impact [4].

During the past decades, projects were introduced in the curriculum. In engineering education, introducing projects is not a revolutionary or new idea in the curriculum structure. However, these projects evolved under the convention or etiquette teaching method. Project-based learning (PBL) has gained more weightage and a more significant foothold in the classroom, where students and teachers participate and engage themselves more effectively and efficiently. The project-based learning technique motivates the students to be involved entirely in the course and dig more realistic complex problems that resemble our real-life examples. It also creates a challenging and new thought process about the course. Project-based learning goes beyond the teacher's and students' creativeness. Well-designed course projects inspire students towards higher-order thinking and complex problem-solving. When students connect to project-based learning, encourage them to acquire new ideas or knowledge, brainstorming, complex problem solving, and higher-order thinking skills about the project and the course. Students can question 'why' for every aspect of their learning.

Engineering educational institutions or engineering educational systems aim to deliver the student community's learning skills and techniques. Flexibility in engineering education and engineering practices is required for the student community. Modern teaching techniques, styles, or methods have versatility in engineering education compared to traditional teaching methods. Few engineering institutions have adopted such flexibility in their curriculum. The institutions that have taken the flexibility in their curriculum get better results, while others don't. In general, the flexibility-adopted institutions become smart, learn new tools, and think and do smartly and effectively. They quickly transform themselves into modern tools and revolutions in industry. In contemporary teaching, students have the flexibility to learn specific courses. The curriculum can be designed based on the present industry revolutions or modern technology innovations, where students can develop their current skills. To adopt this facility, an institution or facilitator must create such an environment to offer to the student community to attend specific courses or topics to attain the course outcomes. Outcome-based education (OBE) creates clarity in the curriculum that students can accomplish at completing the course. The outcome-based education system can measure student performance at every step through continuous assessment [5-9].

This article attempts to impart higher-order thinking, complex problem solving, and communication skills through project-based learning techniques in the manufacturing technology laboratory course.

2. Methodology

The concept began with improving the students' interest in the laboratories and using available machines/equipment. They were provided with sufficient hands-on experience to have a better understanding.

To make this happen, the laboratory curriculum was divided into two major parts and four distinct sub-phases. Figure 1 shows the curriculum structure for the manufacturing technology laboratory.

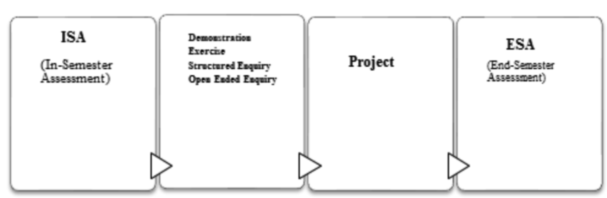


Fig. 1 : Curriculum Structure for Laboratory.

Demonstration: In this phase, the Instructor will demonstrate the experiment, including the machine, tools, limitations, applications. Two demonstrating experiments were assigned, and a weightage of 20% (20 Marks) is distributed to this phase. The students need to understand the machines/equipment and study their usage and safety norms for proper usage before working on them. At the end of this phase, students acquire knowledge about material removal operations and evaluate mechanical properties such as hardness, tensile, and impact strength as per the ASTM standard.

Exercise: In this phase, the Instructor explains the experiments in detail, such as designing components and their machining operations. At the end of the investigation, students need to conclude based on their acquired knowledge. In this exercise phase, different machining operations were discussed, and students learn the knowledge about machining operations required to machine the components for table clamping devices. For this exercise phase, a weightage of 30% (30 Marks) is assigned.

Structured Enquiry:

In this phase, the students assemble the parts and complete the assembly. Here, the Instructor explains a problem statement, required materials, and machining information. Students need to find the solution and create the component or final assembly without any course instructors' assistance. For this phase, a weightage of 10% (10 Marks) is assigned. This particular phase shall address PO2.

Open-ended Enquiry:

In this phase, the Instructor explains the problem statement. Students are expected to select the list of components required and develop a solution to create a part without any assistance from the course instructors. Students manufacture the components individually by applying the concept of design for manufacturing in SOLID WORKS software. For this phase, a weightage of 10% (10 Marks) is assigned. This particular phase shall address PO3, i.e., design and development of solutions and exposure to modern tools usage PO5.

Project:

This phase is final and the most important, where students were evaluated at the end of the semester, called ESA (End-Semester Assessment). The students are teamed up as four, and they were allowed to develop a product (table clamp) using the techniques learned through the above phases. The student is expected to select a product and design the same using CAD modeling software SOLID WORKS learned in the previous semester or as a part of this laboratory (as required). These modeling drawings were used to validate the components for the final assembly of the product. Three to four weeks were assigned for this project. In the project, a table clamp was given as a theme of the project for a batch of students, and they could perform all the machining operations required to build. And finally, the product is evaluated based on the rubrics.

Students are expected to design and fabricate the component offered as part of the course (table clamp). The students have to execute the same through the PBL approach. The course aims to ensure students acquire new knowledge, complex problem-solving, communication, and higher-order thinking skills. This exercise also enables the course instructor to achieve program outcomes 1 to 5, as listed below.

Program Outcomes are:

1. Engineering knowledge: Apply mathematics, science, engineering fundamentals, and an engineering specialization to solve complex engineering problems.

2. Problem analysis: Identity, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate public health and safety and cultural, societal, and environmental considerations.

4. Conduct investigations of complex problems: Use research-based knowledge and research methods, including design of experiments, analysis, interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling to complex engineering activities to understand the limitations.

3. Results and Discussion

The Manufacturing Technology laboratory course was offered to the engineering students of the fourth semester. When the students were in the third semester, they learned about Manufacturing Technology and CAD modeling software (SOLID WORKS) as an individual course. In the context of their knowledge gained in the manufacturing processes, materials, and SOLID WORKS software, the course instructor or teacher designed the course plan to implement the physical product at the course project's end. Table 1 depicts the design experiments/jobs planned to meet the Manufacturing Technology laboratory course requirements.

The laboratory course is designed so that the exercises or experiments were intended to gain preliminary machining skills such as turning, facing, step cutting, drilling, taper turning, and threading operations. During the machining process, the students able to acquire knowledge of dimensioning and tolerances. The course is also designed to understand and learn design and analytical skills. The design and analytical competencies were obtained through CAD modeling software (SOLID WORKS) and material testing exercises. The mechanical

Table 1 : List of experiments/jobs planned to meet the requirements of the Manufacturing Technology laboratory course.

Category: Demonstration		**Total Weightage: 20 Marks**		**No. of lab sessions per week: 2**
Expt. / Job No.	**Experiment/ Job Details**	**No. of Lab Session(s) per batch (estimate)**	**Marks/Experiment**	**Correlation of Experiment with the theory**
1.	Material Removal Operations	1	10	
	Learning Objectives: The students should be able to: 1. Demonstrate various operations like Facing, Turning, threading on a workpiece using a Lathe machine. 2. Perform operations like drilling holes on a given work material using Drilling Machine. 3. Perform a Tapping operation on a given slab of metal. 4. Demonstrate grinding operation on a given metal cube to achieve predefined dimensions. 5. Demonstrate taper turning operation on a circular bar			Introduction Turning, Shaping, Planing Machines, Milling Machines, Drilling and Grinding Machines
2.	Material Testing	1	10	
	Learning Objectives: The students should be able to: 1. To calculate various stresses acting on a circular bar subjected to axial loading using UTM and plot a graph by taking the readings. 2. To calculated the Impact strength of a given material using Charpy and Izod testing machine. 3. To calculate the Hardness of a given material			Introduction Turning, Shaping, Planing Machines, Milling Machines, Drilling and Grinding Machines
Category: Exercise		**Total Weightage: 30 Marks**		**No. of lab sessions per week: 6**
Expt. / Job No.	**Experiment/ Job Details**	**No. of Lab Session(s) per batch (estimate)**	**Marks/Experiment**	**Correlation of Experiment with the theory**
3.	Fabricate the Parts for Table Clamping Device	6	30	
	Learning Objectives: The students should be able to: 1. To machine a given raw metal sheet to actual dimensions. 2. Perform drilling operations at suitable locations. 3. Mark the workpiece before going for manufacture. 4. Taking measurements at every step of operations using Vernier Callipers. 5. Perform welding operation on hinges to achieve the perfect right angle. 6. Fill the machining time calculation chart. 7. Performing threading on a circular bar to a given pitch. 8. Fill operation chart and inspection reports.			Introduction Turning, Shaping, Planing Machines, Milling Machines, Drilling and Grinding Machines, CNC Machine Tools, Metrology and Inspection
Category: Structured Enquiry		**Total Weightage: 10 Marks**		**No. of lab sessions per week: 1**
Expt. / Job No.	**Experiment/ Job Details**	**No. of Lab Session(s) per batch (estimate)**	**Marks/Experiment**	**Correlation of Experiment with the theory**
4.	Assembly of parts Learning	1	10	
	Learning Objectives: The students should be able to: 1. Ensure all the parts are ready for assembly. 2. Make sure all the parts are within the defined limits 3. Prepare a process chart to ensure smooth flow of assembly 4. Write the specification of the assembly.			Introduction Turning, Shaping, Planing Machines, Milling Machines, Drilling and Grinding Machines, CNC Machine Tools, Metrology and Inspection
Category: Open Ended		**Total Weightage: 10 Marks**		**No. of lab sessions per week: 1**

Expt. / Job No.	Experiment/ Job Details	No. of Lab Session(s) per batch (estimate)	Marks/Experiment	Correlation of Experiment with the theory
5.	DFM (Design for Manufacturing) using Solid works Learning outcomes	1	10	
	Learning Objectives: The students should be able to: 1. Ensure all the parts can be manufactured without any difficulties. 2. Ensure the dimensions given and the machine selected can operate. 3. Visualize all the parts and remember the location of each link in the assembly. 4. Identify alternate dimensions to any failing part and correct without performing machining operations. 5. Select a suitable machine to perform specific operations.			Introduction Turning, Shaping, Planing Machines, Milling Machines, Drilling and Grinding Machines, CNC Machine Tools, Metrology and Inspection, Comparators and Angular Measurement Devices and Advanced Metrology

behavior such as Hardness, tensile strength, and impact strength of the material was carried out during this course. Finally, the students have to assemble all the different parts of the table clamp and perform joining operations such as welding during assembly. The final product was submitted to the course instructor for the final evaluation. The evaluation or assessment will be carried out based on the rubrics.

During the course design, the Instructor designed the rubrics to assess the student's performance. At the beginning of the course, the course instructor shares the experiments and rubrics with the students. The rubrics for evaluating the student's performance in each experiment are designed to understand their role during the conduction of the experiments.

Table 2 shows the rubric to assess student performance during the experiment's conduction for the Manufacturing Technology laboratory course. The

Table 2: Rubric to assess student performance during the experiment's conduction for the Manufacturing Technology laboratory course.

Demonstrate

	Not Competent 0-4	Competent 5-7	Highly competent 8-10
Ability to follow directions	A student is not able to follow directions for any of the tasks.	A student can follow moderately but didn't listen to the Instructor.	A student can follow all the directions as given by the Instructor.
Level of needed assistance	A student is unable to complete the task without significant assistance	A student can complete the job with moderate assistance	A student can complete the task without assistance
Application of safety practices	Student failed to follow a significant number of safety rules	A student attempted to follow safety rules but was unable to meet several	A student followed all the safety rules as per the Lab manual.
Clean-up and tool return	A s tudent did not clean assigned area or return tools	A s tudent cleaned partially but did not return all the tools	A s tudent cleaned his assigned area and produced all the given tools

Exercise

	Not Competent 0-10	Competent 11-20	Highly competent 21-30
Total time is taken to complete the Job	A student is not able to complete the job in the allotted duration.	A student can complete the Job but take more time.	A student can complete the job well before the allotted time.
Job Failure	A student took a new workpiece due to over machining.	A student can complete the Job but has defects.	A student can complete the task without any flaws.
Accurate dimensions/Surface finish	Most of the major dimensions are failing to meet the drawing. A rough surface finish in most of the faces.	Most of the dimensions are accurate. Moderate surface finishes, but irregular areas can be observed.	All the dimensions are accurate as per the drawing, and all the faces have a mirror-like finish.
Operation Sheet	Not Performed	The sheet is prepared with some mistakes	The complete sheet is in sequence with no mistakes.

Structured Enquiry

	Not Competent 0-4	Competent 5-7	Highly competent 8-10
Availability of machined parts	Most of the parts were missing due to some reasons	Most of the essential components are ready.	All the parts are ready and are in good condition.
Assembly procedure	The procedure is written in a random manner	Sequences of operations are composed with few mistakes	All functions are written in series with no errors.
Final Assembly	Few parts are connected, but most have failed	A primary assembly is performed.	The complete assembly is ready with no clearances.
Performance	A significant function of the assembly is not working.	Partial movement can be seen.	All the movements of the assembly can be captures without jerks.

Open-end Enquiry

	Not Competent 0-4	Competent 5-7	Highly competent 8-10
DFM using Solid works software	DFM is performed but with irrelevant comments	Performed but few mistakes in commenting	DFM is applied to all the parts with relevant comments of each.
Motion Study using Solid works software	Motion study is tried but no outcome	Performed with partial errors	Perfect motion simulations can be captures with no errors
Drafting	Few parts have been drafted.	All parts are drafted with few errors.	Complete drafting is performed with no mistakes.
Viva	Few questions were answered correctly	Most of the answers are correct.	All the answers are found to be accurate.

Project

	Not Competent 0-5	Competent 6-15	Highly competent 15-20
Manufacturing Report	Most of the critical content is missing.	The report is complete, but comments on operations are not appropriate.	The report is up to the mark , meeting all the standards.
Powerpoint presentations	Content is shown haphazardly with low communication skills.	Presentation with a lack of communication skills.	The excellent presentation, along with communication skills, is presented.
Machining time calculations	The partial calculation is done.	The calculation is done, but steps/units are missing	All the calculations are done.
Viva	Few questions were answered correctly	Most of the answers are correct.	All the answers are found to be accurate.

rubrics give the students a clear picture of their role, involvement, and strive in the study. Based on the rubrics, students can motivate and prepare for the experiments. Students can develop and discuss or clarify any doubts about the experiments before attending the laboratory or class. The rubrics encourage the student's involvement, communication skill, problem-solving skills, and higher thinking skills.

The above rubrics are designed based on the standard student assessment evaluation structure. Table 3 shows the ISA student assessment structure (In-Semester Assessment) and ESA (End-Semester Assessment). The weightage of 80% (80 Marks) is allotted for ISA, and 20% (20 Marks) is assigned to ESA. The weightage of 80% (80 Marks) is again divided into five subdivisions, as explained in detail in the above sections. The 10% weightage (10 Marks) is allotted for conducting viva voce or quiz based on their learning skills during the experiment. The 20% weightage (20 Marks) assesses or evaluates the student project at the end of the course.

Table 3: Students Assessment through ISA (80%) + ESA (20%)

Type of Evaluation	Types of laboratory work	Assessment				
		Aim	Material	Method	Output	Weightage in Marks
In-Semester Assessment (80%)	Demonstration	Given	Given	Given	Given	20
	Exercise	Given	Given	Given	Open	30
	Structured Enquiry	Given	Given	Open	Open	10
	Open-Ended	Given	Open	Open	Open	10
	Quiz/Viva	-	Given	-	Open	10
End-Semester Assessment (20%)	Project	Open	Open	Open	Open	20
					Total	**100**

During the course project's execution (table clamp), the students design the table clamp in SOLID WORKS software based on the dimensions prescribed at the beginning of the project. The material selection and analysis were carried out in the software to qualitative the result at the end. Figure 2 shows the clamp design designed by the students using solid modeling software (SOLID WORKS). Ten different parts are available in this design total, and students have to create these different parts and assemble them to complete the modeling. Those ten other parts need to join is, as shown in figure 2. The isometric view of the clamp's final design after assembly is shown in figure 2, and a side view top view of the model can be observed.

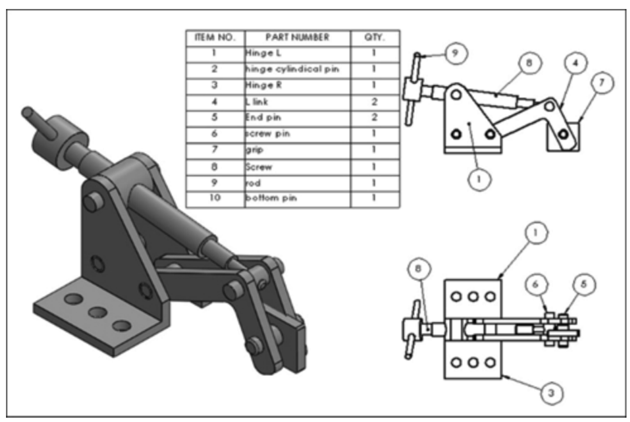


Fig. 2 : Table Clamp design using solid modeling software (SOLID WORKS).

Figure 3 shows the table clamp manufactured by the students as a part of their course project. During this project, students undergo different machining and joining operations. It depicts that the students acquired adequate knowledge about design, materials

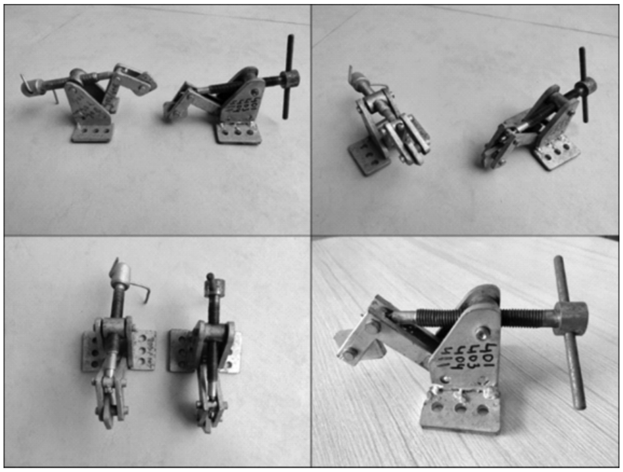
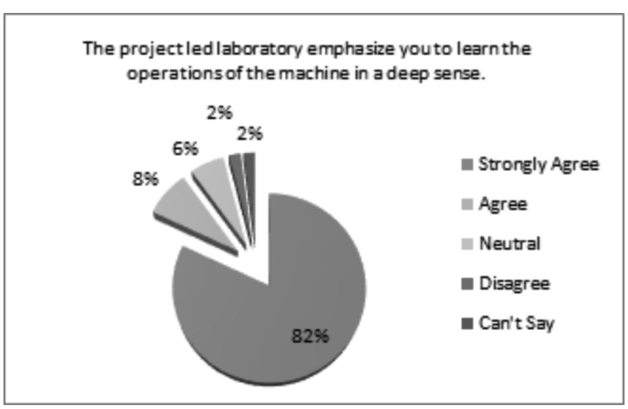
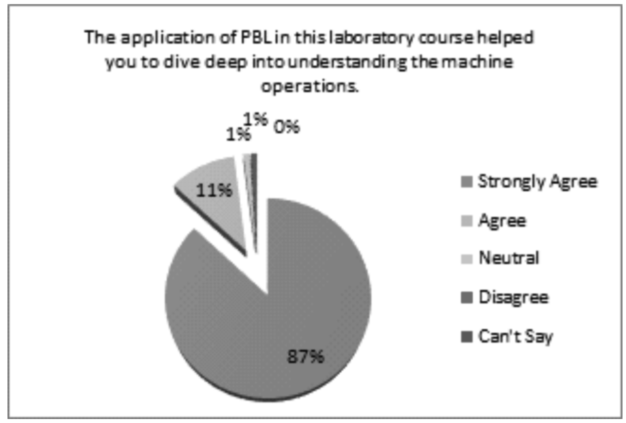


Fig. 3 : Table Clamps manufactured by the students as part of the course project.

property, machining, and joining processes. From the figure, it is also observed that the students developed the table clamp product. The students' acquired skills such as communication, complex problem solving, and higher-order thinking also expanded the entrepreneurial skills. Students' motivation and confidence levels have been designed with these laboratory exercises and course projects, evidenced in this course.

The student survey was organized to validate the application of PBL, determine students' knowledge and their interest and skills acquired. A survey was conducted with a sample size of 50 students using a questionnaire technique, which involved three questions relating to the execution. The feedback received from them was plotted in SPSS software. Figure 4 depicts the Pie charts explaining the students' interest, involvement, and skills towards the





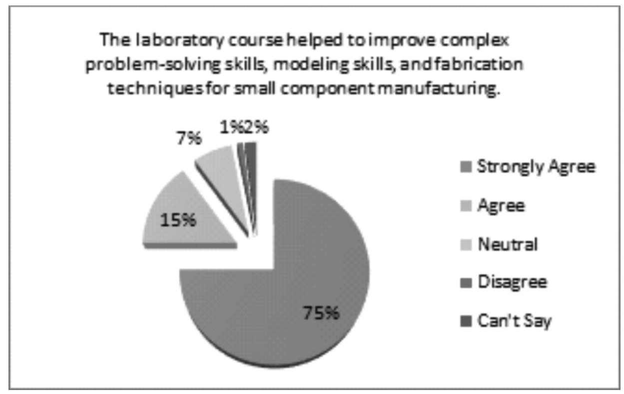


Fig. 4 : Pie charts explaining the student's interest, involvement, and skills in the laboratory.

** [These results are for a sample size of 50 and may vary on the sample size, and the scale of analysis may change]

laboratory. Students strongly agreed to all the three questions raised to understand their appeal, engagement, and skills gained in the laboratory course. The Pie charts explained the student interest, commitment, and skills acquired during experiments and projects and motivate the faculty or Instructor to engage, conduct properly, and deliver the course most effectively. Student feedback encourages the faculty or Instructor to adopt and apply for other relative courses.

Challenges:

When we talk of the PBL approach, In the field of the sciences, workgroups comprise from 5 to 8 students, while it is recommended to have just 3 or 4 in the area of engineering. Once each teaching module is finished, groups are randomly reconfigured to work productively with different people. With such a small group size, the total number of teams becomes enormously high, making it difficult for the course instructor to focus on ensuring productivity. In this investigation, we had a total of 14 groups.

The teacher takes on the role of facilitator or tutor, challenging the students to question their thinking and find the best approach towards understanding and resolving the problem. As the course progresses, the students become able to take on this role themselves and make the exact demands of each other. This essentially requires a good ecosystem of peer learning, which is relatively weak in our current scenario.

Generating appropriate problems lies at the core of learning and developing organizational skills. Hence, the course instructor needs to have strong support and mentoring from the competent faculty among the senior group to create relevant issues.

4. Conclusions

The Manufacturing Technology laboratory course was introduced to the Undergraduate students studying the fourth semester. They were made to have an immersive, hands-on experience of the machining processes. The course aimed to ensure students acquire new knowledge, complex problem-solving, communication, and higher-order thinking skills, and the same was realized as evidenced through the feedback results.

The projects assigned comprised mainly discovering solutions for the present industrial problems, execute the project in collaboration. As the projects included various activities, it has been observed that students' participation was far better. The feedback received from the students and the level of the components manufactured shows their motivation level and their commitment to completing the task on time, which was quite challenging, given the time constraints and their workload in the semester. Finally, Outcome-based education has influenced developing the course content and its delivery, so also successful implementation. In this investigation, the whole exercise enabled the course instructor to achieve program outcomes 3, 4, and 5 to a higher degree.

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