125 YEARS AT THE HEART OF ENGINEERING EDUCATION
ASEE
2018 ASEE ANNUAL CONFERENCE & EXPOSITION
JUNE 24-27, 2018
SALT PALACE CONVENTION CENTER
SALT LAKE CITY, UT

Paper ID #22436

Teaching Manufacturing Technology through 'Learning by Doing' Approach

Dr. Zareena Gani, ADMC, Higher Colleges of Technology, UAE

Dr. Zareena Gani started her career in Engineering with a degree in Mechanical engineering from MK University, India. She has over 20 years of experience in both academia and industry. She has worked as a Design and Manufacturing engineer in Singapore before joining National University of Singapore from which she obtained her M.Eng degree. She also has worked in Singapore Institute of Manufacturing Technology (A*STAR) as a Research Fellow before moving to Canada. She gained exposure with the Canadian tool making industry while she worked in Profine Molds and her keen interest in research brought her back to school. She obtained her Ph.D. from McMasters University in Canada as an NSERC scholar. After graduation, she moved to United Arab Emirates in 2011 and joined Higher Colleges of Technology. Dr. Zareena has published her research findings in many reputed international journals and conferences.

Dr. Sangarappillai Sivaloganathan, United Arab Emirates University

Dr Sangarappillai Sivaloganathan – Siva is a Srilankan by birth and a citizen of the United Kingdom. His experience in Sri-lanka started with an year's post-graduate apprenticeship in the manufacturing shops of the Government Railway and nine years in the Cement Industry. He graduated as a Mechanical Engineer from University of Srilanka, and obtained his Masters from the University of Aston and PhD from City University of London, both in the UK. He started his career in the UK as the Senior Research Assistant at the SERC Engineering Design Centre. He joined Brunel University in 1995 where he worked for 18 years before joining United Arab Emirates University in August 2011. During his stay at Brunel he has worked with many British industries. Dr Sivaloganathan is a keen researcher in Design and was the Convenor for the International Engineering Design Conferences in 1998 and 2000. He has been a regular participant of the ASEE annual conference during the past few years. He has published more than 85 papers in reputed journals and conferences.

Mr. sajeev karai, Higher Colleges of Technology

i am working as a Lab Instructor

Mr. Huned Bohari Bohari, HCT

Teaching Manufacturing Technology through “Learning by Doing” approach

Abstract:

Machining processes have many parameters that affect the performance, accuracy and the surface quality of the finished product. It is the responsibility of the teaching instructor to give the necessary understanding and ability to use the knowledge in the various manufacturing process such as shaping, moulding, material removal process, advanced machining techniques and additive manufacturing process to get them readily employable in the local industries. In order to enhance the student understanding of the course, the delivery methodology and the assessment strategies were designed to include practical / workshop sessions. In these session, the students were trained on basic skills to operate conventional lathe and milling machines. The students were then exposed to witness the effects of various cutting parameters on the surface finish and tool life produced in different workpiece materials. The students were also exposed to G&M code generation for CNC machining, Solidworks modelling for 3D printing. The results were significantly better and the students were enthusiastic and fully engaged with the work. This paper describes all these in detail, the method of assessment, the results and the students' feedback.

Keywords: Learning by doing, Machining, hands-on skill, Advanced manufacturing

1. Introduction

In today's global economy, a strong manufacturing base is required for any nation to have a strong economy in order to provide high living standards for its people. As UAE continues to pursue a strategy of diversifying its economy from non-oils sectors to high technology and high growth sectors the demand for qualified mechanical engineering graduates are in rise.

Students graduating with the “Bachelors in Applied Science (BAS)” degree in Mechanical Engineering are required to acquire certain set of hands-on-skills in addition to the engineering knowledge, in order to be readily employable as technicians, technologists or supervisors. To fulfil these requirements, manufacturing engineering instructors are required to have adequate experience in industrial practice in addition to academic experience and educational qualifications, to teach the real life shop-floor scenario.

Manufacturing Technology is being taught as a core course in undergraduate Mechanical Engineering program. The course outline and the syllabus cover a wide range of topics including various manufacturing techniques such as metal casting, polymer moulding, metal cutting; and Design for Manufacturing and Assembly (DFM/A). Proactively engaging the students while covering all the Course Learning Outcomes (CLOs) with lectures and meeting the requirements of accreditation bodies within the stipulated time were challenging for both students and instructors. This article explains how these challenges in engineering education and delivery of skills were effectively addressed with the “Learning by Doing” paradigm while keeping in pace with advanced manufacturing technologies such as 3D printing.

2. Literature Review

Recent interest in improving pedagogical approaches in science, technology, engineering, and mathematics (STEM) fields has stimulated research in many universities. Several educational methodologies are reviewed in the context of manufacturing and through the lens of sustainability. It is found that there is a need to identify and understand the STEM educational challenges, and to assess the usefulness of existing methodologies using case-based analyses. A framework encompassing four steps: defining the learning outcomes, creating instructional resources, creating active learning resources, and creating a summative assessment mechanism was developed. (1)

David A. Whetten has articulated successful teaching - learning in higher education in the following Table 1 adapted from Barr and Tagg. (2)

Factor	Teaching Focus	Learning Focus
Orienting Questions	What do I want to teach? How can I cover the designated course material?	What do students need to learn? How can we accomplish specific learning objectives?
Teacher’s role	Provide / deliver instruction. Transfer knowledge to students. Classify and sort students.	Produce learning. Elicit student discovery and construction of knowledge. Develop each student’s competencies and talents
Success criteria	Teacher’s performance Input, resources	Student’s performance Learning, student-success outcomes
Assumption about teachers	Any expert can teach	Teaching is complex and requires considerable training.

Table 1: Recent Paradigm shift in Higher Education

Evaluating the factors on “Learning Focus” instead of “Teaching Focus” would provide a platform to adapt new teaching - learning methodologies.

Freeman et al. compares traditional passive learning with active learning in which the former is *teaching by telling* and the later includes approaches as diverse as occasional group problem-solving, worksheets or tutorials completed during class and provided evidence that active learning can improve undergraduate STEM education. (3) Traditionally, education in engineering has been based on one-way communication where the students were only receiving information from the teacher but not interacting in the learning process. In collaborative learning, continuous assessment, teamwork, *increased practical classes*, etc., has given a substantial change in teaching, leading to improved student learning process. (4).

Concepts related to manufacturing processes are completely new and tough for the students at engineering degrees. This fact affects the assimilation process of the manufacturing concepts that should be learnt in order to pass the corresponding manufacturing courses. Results of a study to investigate the students' conceptual understanding related to basic mechanical concepts at different undergraduate and graduate courses showed that the conceptual understanding of younger students does not differ from those graduated, and if these misunderstandings are not detected and corrected, they will interfere in their future reasoning throughout their career. It has been proven that conceptual understanding and knowledge retention were much better when active learning strategies are applied. (5)

According to Rentzos L. et al, the "factory-to-classroom" concept of the Teaching Factory aims at transferring the real production/manufacturing environment to the classroom. The real life production site needs to be used for teaching purposes in order to enhance the teaching activity with that of the knowledge, existing in the processes of every day industrial practice. Towards this direction, delivery mechanisms that will allow the students in a classroom to apprehend the production environment, in full-context, need to be defined and developed. (6)

Chryssolouris.G. et al., reviewed related publications and concluded that to effectively address the emerging challenges for manufacturing education and skills delivery, the educational paradigm in manufacturing needs to be revised. Many educational institutions have tried to bring their educational practice closer to industry also with the concept of "Learning Factory". A drawback of this approach may be that the dedicated equipment, which is installed on the academic settings, may at some point become obsolete. (7)

With the advancement of manufacturing technologies adapted by industries, academic institutions are required to adapt those technologies in their curriculum to be in par. One such latest advancement in manufacturing is the 3D printing technology.

3D modelling and related techniques are emerging core competencies due to the increasing popularity of 3D printers. Popularization of CAD / CAM and implementation of CNC and robotic arms has played a significant role in reducing manufacturing costs and improving production efficiency. As these modern techniques become increasingly mature, new technologies for rapid prototyping such as stereolithography or 3D printing technology receive increased attention (8).

Manogharan et al. postulated that integration of subtractive and additive manufacturing processes can aid advanced manufacturing by realizing low cost, rapid manufacturing of high precision, tailored products, along with elimination of restrictions and tooling assumptions associated with conventional manufacturing processes. New, low-cost additive manufacturing equipment can complement automated machine tools to expand the student design and manufacturing space. Student understanding of hybrid manufacturing, or the integration of subtractive and additive processes, can be fostered, while offering the opportunity to explore the existing technical and sustainability challenges of manufacturing processes. (9)

This article evaluates "Learning-by-Doing" which involves active and collaborative learning approach with both traditional and advanced state-of-the-art machine shop facilities.

3. Teaching- Learning approach

Machining is one of the most important manufacturing processes. The Industrial Revolution and the growth of the manufacturing-based economies of the world can be traced largely to the development of the various machining operations. (10) Machining processes have many parameters that affect the performance, accuracy and the surface quality of the finished product. Most of these parameters would mean very little to someone who just reads or listens about machining without actually seeing them in action. Conventional lectures with power point presentations followed by quizzes would at best make them to memorize them and repeat when asked.

In order to enhance the student understanding of the course, the delivery methodology and the assessment strategies were designed to include practical / workshop sessions. Thus, the primary focus of this course delivery was shifted from lecture based approach to "learning by doing" approach. Unlike certain countries that introduces machining operations in secondary schools, prior knowledge on these machines in the students' enrolled in this course was very limited. Basic machining operations such as turning, milling, drilling were introduced with a brief workshop session to help students identify the types of machines, machine parts such as work-holding devices, tool holders, workpiece and the machine controls.

3.1 Conventional Machining

The introductory workshop session was found useful in the classroom sessions that followed, where the lectures were focused on elaborating various metal removal process. Students could easily recall the operations that could be performed in a lathe, mill or drill, the limitations of each machine, difference between solid cutting tools, inserts, single-point and multi-point cutting tools, just to name a few. The importance of cutting parameters such as machinability of material, cutting tool material, cutting speed and spindle speed, depth-of-cut, feed rate, tool geometries and chip control were introduced. Other parameters such as tool life including types of tool wear, importance of coolant and its types; cutting force, surface roughness, roughing and finishing operations were also introduced.

In these session, the students were trained in the basic skills to operate conventional lathe and milling machines. The students were then exposed to witness the effects of the type of cutting tools, tool life, cutting fluids and selection of tools and cutting parameters such as cutting speed, feed and depth of cut on the surface finish produced. By using different workpiece materials, they were able to see the effects of varying these parameters on the finished quality of the work.

Machining was performed on different workpiece materials such as, Brass, acrylic, Aluminum and Copper with HSS tools and coated carbide tools, with and without cutting fluids and with varying cutting parameters i.e. spindle speed, feed rate and depth of cut and also with sharp tools and worn tools. Tool wear and surface finish were measured for each input and output parameter combination.

Figure 1: Microscopic images of (a) New tool, (b) Tool wear w/o coolant, (c) Tool wear with coolant

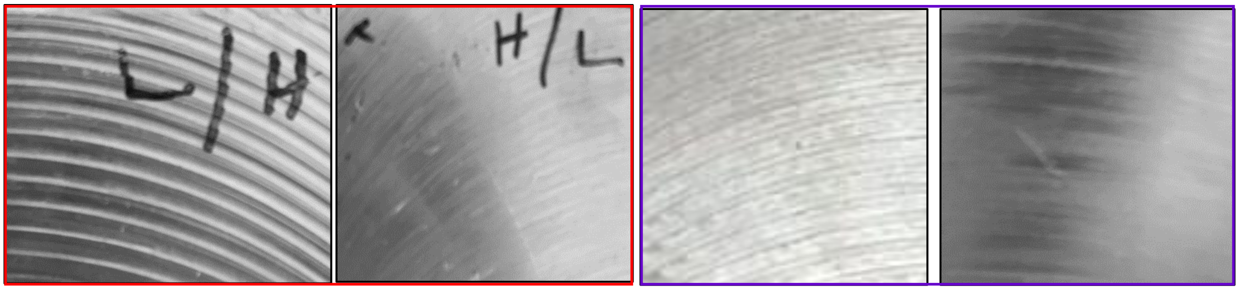


Figure 2: Copper machined with (a) sharp tool, (b) worn tool (Left: low rpm & high feed rate, Right: high rpm & low feed rate)

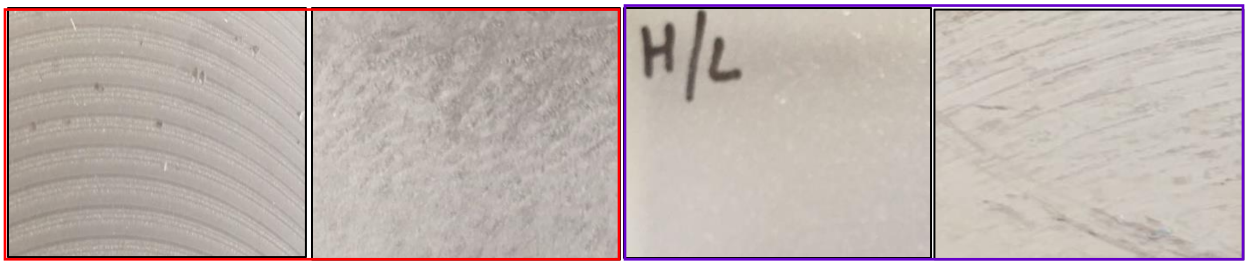


Figure 3: Acrylic machined with (a) sharp tool, (b) worn tool (Left: low rpm & high feed rate, Right: high rpm & low feed rate)

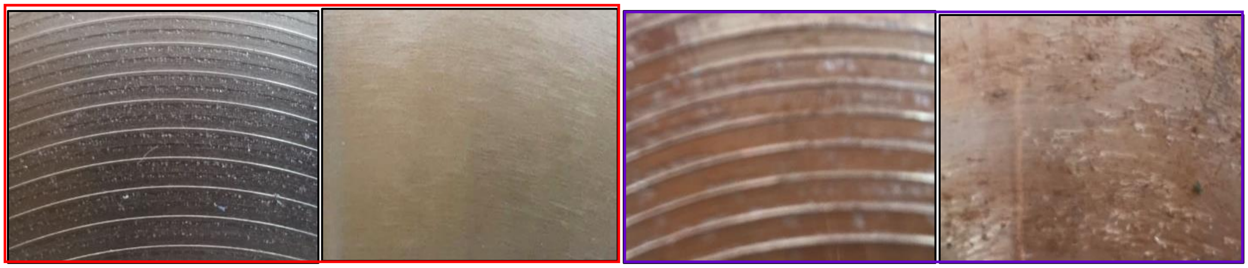


Figure 4: Copper machined with (a) sharp tool, (b) worn tool (Left: low rpm & high feed rate, Right: high rpm & low feed rate)

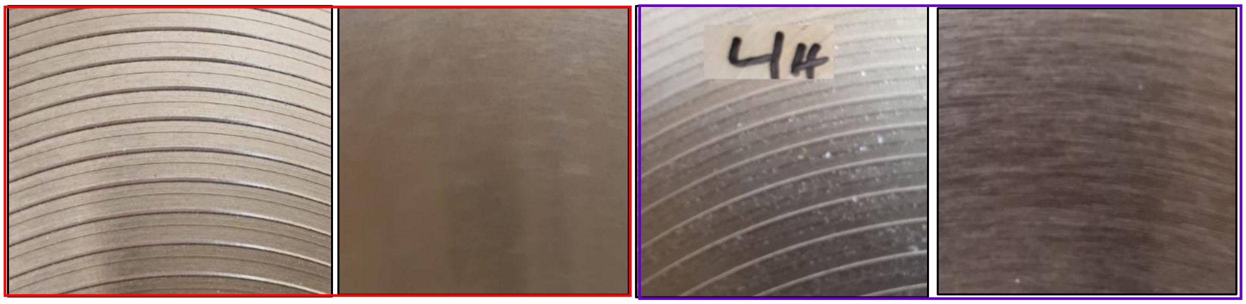


Figure 5: Aluminum machined with (a) sharp tool, (b) worn tool (Left: low rpm & high feed rate, Right: high rpm & low feed rate)

Workpiece material	Spindle speed H-850 rpm L-80 rpm	Feed rate H-233mm/min L - 45mm/min	Surface roughness (R_a- μm) **Worn tool**	Surface roughness (R_a- μm) **Sharp tool, w/o cutting fluid**	Surface roughness (R_a- μm) **Sharp tool, with cutting fluid**
BRASS	H	L	2.560	1.557	0.497
	L	H	5.879	3.712	2.602
ACRYLIC	H	L	5.863	3.184	0.938
	L	H	6.662	5.412	2.317
ALUMINIUM	H	L	1.284	0.791	0.299
	L	H	4.388	3.162	2.606
COPPER	H	L	2.954	0.478	0.155
	L	H	7.314	3.568	1.657

Table 2: Comparison of surface roughness with varying cutting parameters, worn and sharp tool w/o & with cutting fluid

Upon completion of the above exercise, the importance of selecting the right cutting parameters and its effect on the finish quality of the machined component was evident.

As a part of the assessments, the students were there asked to obtain the optimized cutting parameters for the given set of workpiece material and cutting tool for both turning and milling. Cutting tool suppliers' catalogue and machining handbooks were introduced. Speed and feed recommendations found in the websites of cutting tool suppliers' such as Kennametal, SGS tools were discussed.

The students were made aware of the fact that the machine controls the spindle speed (N) and the feed per revolution (f) and the need for the cutting parameters from Table 3 to be converted to spindle speed (rpm) and feed / rev based on the initial workpiece diameter / cutting tool diameters D_o in lathe and mill respectively and the number of teeth (N) in the cutting tool with the following equations.

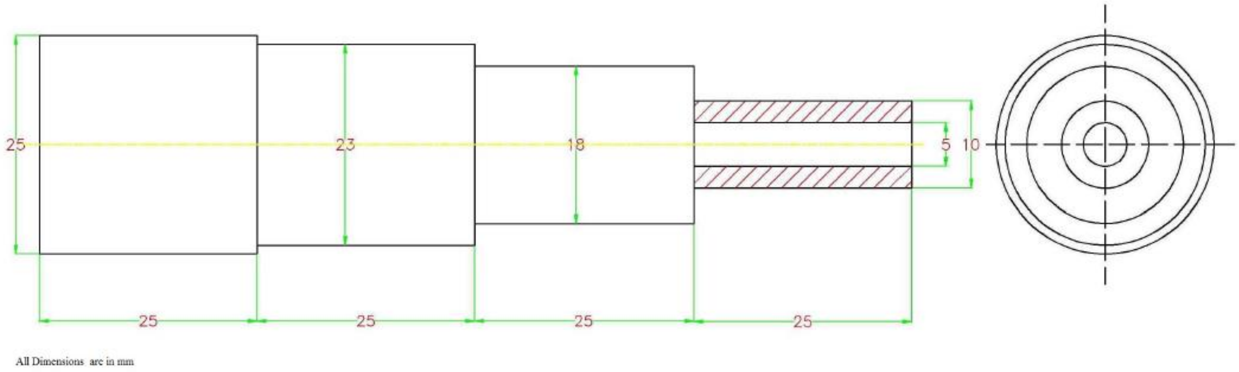
$$V = \pi D_o N$$

$$F = f\ Z\ N$$

Lathe			To find	
Operation	**Workpiece material**	**Cutting Tool material**	**Cutting Speed (V) m/min**	**Feed (F) mm / min**
Turning				
Internal drilling				
Mill				
Operation	**Workpiece material**	**Cutting Tool material**		
Face milling				
Slot (end mill)				
Drilling				

Table 3: Cutting Parameters for conventional lathe and milling operations

Simple part drawings as shown in Figure 6 and Figure 7 were given to the students. Each part drawing was prepared to include a maximum of four different operations based on students' feed-back of being overwhelmed with complex cutting operations such as external thread cutting in lathe.



All Dimensions are in mm

Figure 6: Part drawing – Turning

Students learnt and practiced on setting the workpiece in the a three-jaw chuck in lathes and table-vice in milling machines, selecting appropriate tools for each operation, setting tools in the tool holder, setting datum, marking the workpiece using surface plate & vernier height gauge, checking the size with calipers, setting spindle speed and feed rate in the machine with guidance.

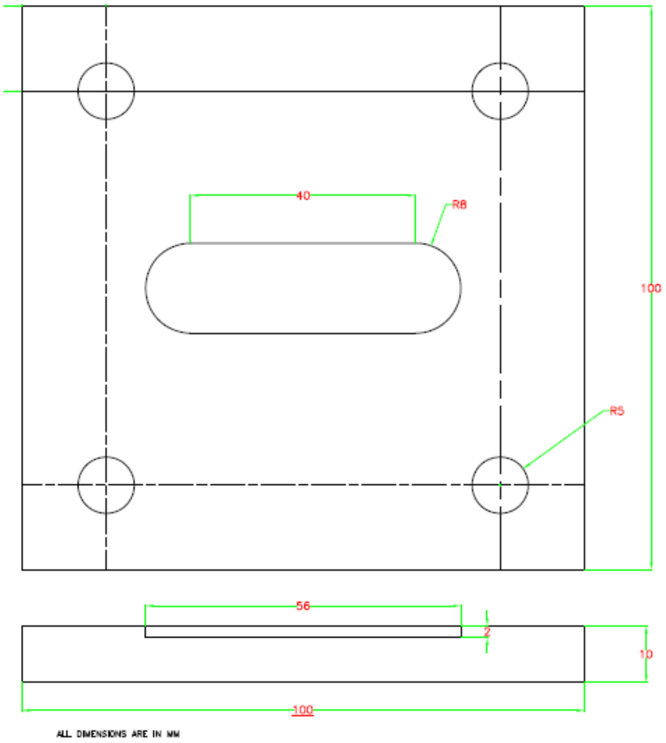


Figure 7: Part-drawing – Milling

In the following sessions, the students worked independently either with minimum or no assistance on both lathe and mill to machine the parts as per the provided part drawings. Students learnt to perform facing, step-turning, internal drilling using tail stock and parting, in a lathe; and face milling, slot end milling and drilling in a mill. Samples of parts machined by students are shown in Figure 8 and Figure 9.

Figure 8: Sample part - Turning

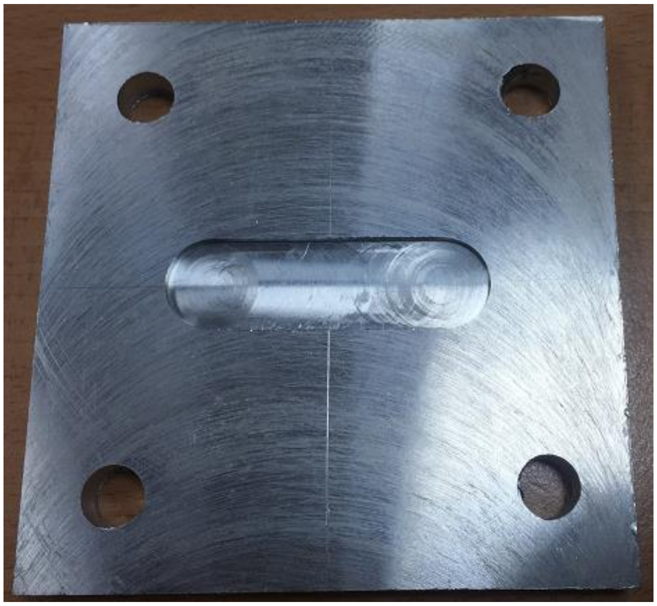


Figure 9: Sample part - Milling

Upon completion of the cutting operations, students measured the surface roughness of the machined surfaces using profilometer. Correlation between tool wear and surface finish was made evident.

3.2 CNC Machining

As the students returned to their classrooms after conventional machining practical sessions, advanced manufacturing technology with Computer Numerical Control (CNC) machines was introduced. It was emphasised that the basics of metal cutting and selection of cutting parameters remain the same with CNC machining and the requirement of addition skills on part-programing was explained. Components of a CNC machine, types of control, CAD / CAM software used in industries, difference between absolute and incremental programing, simulation of tool path and ATP (Automatically Programed Tool) were elaborated. Basic G and M – codes were introduced and practised individually in the class for various geometries using a CNC simulator software which enabled visualization of the cutting operation.

Later in the workshop, during the demo session, students learnt the machine limits, workpiece and tool setting, tool magazine, importing / exporting and executing the part-program, rectifying command errors, and other controls of the machine. The workshop is equipped with table-top CNC lathes and CNC mills that are generally used for educational purpose. The cutting tool material and the workpiece material combination remained the same as that of conventional machining.

For the groups' practical session, students generated part-programs for the same part drawings that was used for conventional machining (Figure 6 & Figure 7), imported the programs and machined the parts using CNC lathe and CNC mill. Complex 3D geometries that could be machined with the CNC machines were shown in the demonstration class but not added to the students' part-drawings in order to keep the learning process of the beginners simple.

Comparison between conventional and CNC machines in terms of advantages, disadvantages, quality, lead time, skill set requirement, cost, etc. were identified by the students themselves in their workshop report which otherwise need to be explained through lectures.

3.3 Additive Manufacturing – 3D Printing

3-D printing employs an additive manufacturing process whereby products are built on a layer-by-layer basis, through a series of cross-sectional slices. While 3-D printers work in a manner similar to traditional laser or inkjet printers, rather than using multi-colored inks, the 3-D printer uses powder that is slowly built into an image on a layer-by-layer basis. (11)

Students gained practical knowledge on 3D printer settings, and CAD drawing requirements. The part-drawings (Figure 6 & Figure 7) used for the metal cutting process were saved in the required STL format and the final product (Figure 10) was printed using the 3D printer; out of Acrylonitrile Butadiene Styrene (ABS) plastic material.

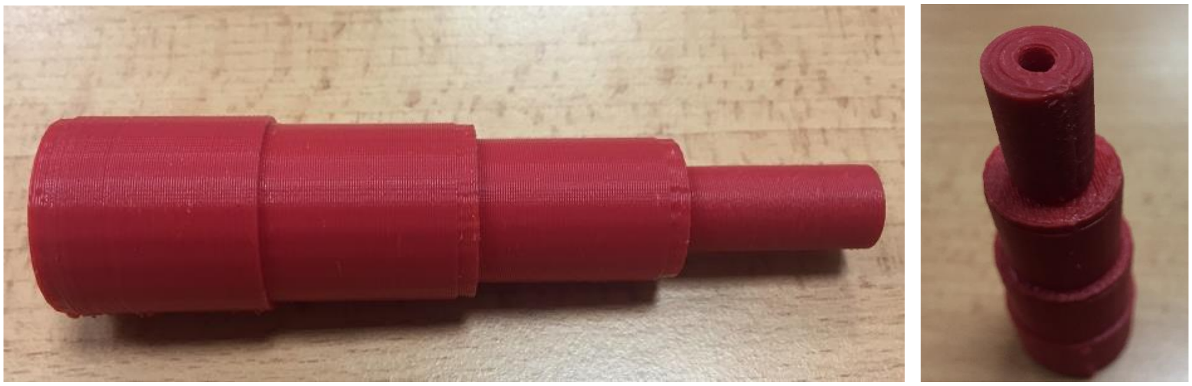


Figure 10: Sample part - 3D printing

Students reported on how the 3D printing process eliminates the requirement of expensive machine tools with reduced set-up time and almost no wastage of material as compared to metal cutting process. "Also, in today's world everything could be made by 3D printers, even houses and apartments are being built with 3D printers and it is a threat that there will not be any manufacturing jobs in the near future" stated a student's report. The fear of students that all the machining skills acquired becoming obsolete with the 3D printing technology was addressed with the limitations of 3D printing technology identified by themselves. The limitations of 3D printing, reported were (a) higher costs for large production including longer lead time, (b) reduced choices for materials, and surface roughness, (c) lower precision relative to other technologies and (d) limited strength and size of the parts produced by 3D printers.

4. Analyses and Discussion

Following are the CLOs of the Manufacturing Technology course:

CLO 1- Understand theories of metal casting, polymer molding.
CLO 2- Understand theories of metal cutting and apply the use of turning (lathe) machining.
CLO 3- Understand and apply the use of milling machines, CNC programming and machining.
CLO 4- Compare the techniques used for the measurement and inspection of manufactured parts.
CLO 5- Understand Design for Manufacturing and Assembly (DFM/A) and technologies related to Advanced Manufacturing Technology.

There were 70 students enrolled in this course. The weightage of each CLO in the final exam with the number of SR and CR questions are given below:

CLO	No. of SR questions	No. of CR questions	Weightage (%)	Average score (2017-Fall)	Average score (2016-Fall)
1	5	1	15	55.44	48.35
2	4	2	15	77.65	60.53
3	9	5	35	87.72	67.04
4	5	2	15	63.06	54.18
5	4	4	20	75.29	63.49

Table 4: Average score attained with and without the hands-on workshop sessions.

The class average had a significant improvement upon delivering the course with the methodology explained above. The knowledge retainment as measured in the final exam and quizzes, showed better results when compared with that conducted without the practical sessions.

Thus, the "Learning-by-Doing" approach adapted in delivering Manufacturing Technology course helped students to gain both theoretical knowledge and practical skills. It was interesting to analyze the knowledge retention of students as measured through various assessment tools based on the type of knowledge acquired such as theoretical knowledge, theoretical knowledge applied to practical applications and practical knowledge and compared with the outcome when the course was taught without any practical sessions. It was evident that the "Learning-by-Doing" approach showed significant improvement in student outcome attainments at all levels. Another interesting aspect observed was that, in the final assessment, questions related to the topics learnt by this approach had more appropriate responses than those taught only though lectures such as injection molding and casting techniques (CLO1).

The learning experience of the students were captured though the report that summarized all their workshop activities and the evaluation survey completed at the end of the term with students' feedback. Students were positive about their learning experience and it was also observed that the students were thrilled with their newly acquired practical skills and took pride in their work as reflected in their report. The feedback received from a particular student after a week's internship training in a manufacturing plant, stated how proud he was with the prior acquired knowledge and skills that he gained through the course that has impressed his trainer which in turn has motivated him to further enhance his knowledge in manufacturing; summed it all.

5. Conclusions

The goal of manufacturing courses in engineering education is to enable the students to select and assess different manufacturing alternatives for a given product using Design for Manufacturing and Assembly (DFM/A) methodologies. Learning-by-Doing approach might seem to be more demanding and time consuming, switching back and forth between lectures and workshop sessions. But, from the author's experience, with proper planning, this approach had actually made the learning as well as the teaching process more efficient and easier. It was observed that the students were very enthusiastic and fully engaged during both the workshop and classroom sessions compared to the lecture only approach.

Technical educators today are required to help learners acquire both soft and hard skills to meet the industry needs and expectations. More than 50% of the students enrolled in Mechanical Engineering program were sponsored by local industries and the students are expected to be readily employable upon graduation. Providing in-depth knowledge on the characteristics of machining, cutting parameters, tool life, surface quality and cutting fluid, with CNC programming, 3D printing thorough this "Learning-by-Doing" approach helped the students to gain hands-on skills, retain theoretical knowledge and apply what they learnt in the classrooms at work. It is evident from the assessment analysis that the knowledge retention had a significant improvement using this approach. In addition to it, this approach has let the students learn the basics of design of experiments for further scientific research. Students who learnt through this approach seemed more confident and used the workshop facilities independently for the fabrication part of their design project as well. 95% of the students enrolled for the Manufacturing Technology course using the learning by doing approach have enrolled for the advanced elective – Computer Integrated Manufacturing course, where project based learning technique is to be adapted.