Reforming CAD/CAM and CNC Machining Course by Using "Process-oriented" for Higher Education Institutes (HEI's)

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Abstract

Computer Aided Design (CAD)/ Computer Aided Manufacturing (CAM) and computer numerical controlled (CNC) machining technology is an important course for the mechanical and manufacturing design. Therefore, technical Higher Education Institutes are highly pressured to develop a new "process-oriented" course to keep up with the rapid changes. However, the integration of CAD/CAM and CNC programs into technical HEI's course is low in Uzbekistan, 40% and 10% respectively and rarely "process-oriented". Consequently, in a continuous effort to develop and incorporate innovative teaching styles in the Mechanical Engineering course reformed at Turin Polytechnic University in Tashkent (TPUT) a new "process-oriented" laboratory course titled CAD/CAM/CNC under Erasmus MechaUz project has been offered, wherein the bachelor students are revealed to CAD and CAM skills. The main goal of this course is to introduce the knowledge in the area of CAD/CAM technology and its application in CNC machines. The "process-oriented" reformation process performed in three phases: exploration, reforming and integration. Generally, the reformed course reflects teaching methods to make the teaching process obey the company`s requirements for students and to acquire numerical control skilled employees with high quality.

Keywords
Engineering Education, CAD, CAM, CNC, Integration.

1. Introduction
Starting from mid of the 20th century, the Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technologies have been rapidly developed and widely used in the worldwide, which has brought revolutionary changes to the field of design and manufacturing (Miao Y. , Liu L., Zhang X., 2016; Wang B., 2015). The development of software and advanced technologies has posed severe challenges to Uzbek manufacturing industry. In order to realize the leapfrog development of manufacturing industry and increase global competitiveness of Uzbek companies, the need for more diverse skills like information technologies like CAD/CAM and numerical control processing technology like CNC set in important for new employees. Thus, technical Higher Educational Institutes are highly pressured to develop a new "process-oriented" course to keep up with the rapid changes in CAD/CAM/CNC field.

As claimed by statistics, there are 16% of technical HEI`s in Uzbekistan. Moreover, the mechanical engineering students are not rigorously trained software and advanced technologies. Great teaching difficulties exist in "process-oriented" modes, which directly affect enthusiasm for learning. Survey analysis showed that there was low integration of CAD and CAM technologies in local technical HEI's in Uzbekistan, 40% and 10% respectively (Kambarov & Inoyatkhodjaev, 2021).

Furthermore, the teaching programs on mechanical courses are heavily oriented toward theory (Yixian, Qihua, Xuan, & Kongde, 2014). Thus due to excessive theory, students feel bored and lose concentration, which ignores subjective motivations, also they cannot possess important theoretical knowledge from the explanation of basic software and thus fails to satisfy the sustainable development of students (Kambarov & Inoyatkhodjaev, 2021).
In particular, it was observed that the students missed the actual working concept of machining and difficulty of the CNC machining such as selection of tools, tool path simulating, fixing job on the machine, relation between the

CAD and CAM model and actual machining, selection of post processor and finally its metrological measurements and analysis.

Hence, in a continuous effort to develop and incorporate innovative teaching styles in the Mechanical Engineering course at Turin Polytechnic University in Tashkent (TPUT) a new laboratory course titled CAD/CAM/CNC has been offered under MechaUz Erasmus project, wherein the bachelor students are exposed to Computer Aided Design (CAD) and computer aided manufacturing (CAM) skills. The improved laboratory sessions are designed to reveal the students to the concepts of CNC machining process planning such as, selection of machining process, selection of tools based upon the process and material, selection of cutting parameters, preparation of operational sheets, orientation of CAD model in CAM software linked with actual machining, selection of machining strategy and parameters, tool path editing, understanding of G and M Codes and their editing, selection of postprocessor, cutting behavior of the machine and its effect on dimensional metrology.

Based on the above-mentioned description of the educational aspects of CAD/CAM/CNC, the remainder of this article is organized as follows: Section 2 describes state of art of existing courses and contents, teaching methods and practical links are summarized. Section 3 describes the methodology how the existing course is transformed into "process-oriented" course using three phases of transformation exploration, reforming and integration. Then, in section 4, we will discuss reformed course in detail about its mode contents. Section 5 summarizes results and discussion of research whereas section 6 provides a conclusion.

2. Literature Review

Since the 1950s, Computer Numerical Control (CNC) machines have been widely used in manufacturing industry until now (Kellock, 1997; Okokpujie, Bolu, Ohunakin, Akinlabi, & Adelekan, 2019). The standardized G and M codes and CAD/CAM software have made its application and learning processes easier. The CNC machines allow machining of very complex shapes with high accuracy. In addition, CAD/CAM technology has become the core of manufacturing, which improves product and process design process, manufacturing and management of industry. These technologies are also key creating value on productivity and competitiveness of the manufacturing sector (Dollar, Kerdok, Diamond, Novotny, & Howe, 2005). Therefore, not only in the manufacturing but also in the Higher Education sector, CAD/CAM/CNC is becoming an integral part of mechanical engineering courses in most of the technical universities.

In the most all manufacturing and mechanical engineering courses of the technical HEI`s, CAD/CAM/CNC is now essential part of the education program. The literature proves that, different implementation of CAD/CAM/CNC integration teaching methodologies in worldwide. Systematic analysis verifies, the different CAD/CAM/CNC implementation programs have been offered in the past. A detailed literature document confirms that universities are mainly focused on the CAD model design in the practical course of software operation. For instance, Hu Q. , Dai H., Gao F., (2002) explored the importance of 3D modeling technology to engineering modeling and the spatial thinking abilities of students. Further Peng, (2009) dispensed the teaching reform course based on course setting, teaching mode, and material compilation. Sadchikova, (2017) discussed the of the introduction of computer-aided design NX by Siemens Software to the classes of a higher education institutes. Meanwhile, Yan, Yu, Hui, & Zhou, (2017) developed" Standard Parts Library of Rolling Bears based on SolidWorks" as an example to illustrate that mechanical engineering students make teamwork. Nevertheless, some HEI`s enriched integration CAM practice teaching modes. Pan, (2017) introduced the design competition into CAD/CAM course to construct the CAD/CAM course standard for competition and teaching. Zhang (2013) organized students to participate in professional competitions by assigning a "Big homework" (Zhang et al., 2013). Eventually, the first attempt on CAD/CAM and CNC machining program done by Chan, (2004), they offered program through projects at Mechanical Engineering Department of Ryerson University. This course is based on production of a Mini Car and Catapults through CNC machining. The project requires student teams to design from a common kit of stocks materials. Experiences gained in the CNC machining laboratory to taught students the importance and the intricacies of the machining.

Meanwhile Dutta, Geister and Tryggvason, (2004), developed Introduction to Design and Manufacturing course, which is core for undergraduate mechanical engineering students at the University of Michigan. In this course, the students are trained in CAD/CAM system and CNC lathes and milling machines. However, the most offered programs overemphasize the theoretical knowledge of mechanical CAD/CAM and CNC technology, which neglects "process-oriented" operation. Therefore, students are short of application abilities although the concept and principle are understood and the application ability is lacking.

On the other hand, Fernandes et al., (2020) reported a teaching methodology based on a project-based learning approach as a learning tool for integration of CAD/CAM/CAE in mechanical engineering curricula. This work addresses knowledge and skills of CAE applied to advanced problem-solving of design, product development and manufacturing engineering programs. Furthermore, three aspects of the CAD knowledge, including computer graphics theory, practice of CAD systems, and applications of CAD/CAM in engineering design and manufacturing, including additive manufacturing, were discussed based on the requirements for the engineering programs of the faculties by Titotto and Dobelis (2017). As evident from the literature review presented above, the most of the works reported in the literature are focused on the product manufacturing. Consequently, the highlight of the models selected for manufacturing in our new course, is to teach the students all the possible features and machining strategies. Hence keeping this mind, comprehensive models have been chosen whereby the students shall learn the various aspects of the 2.5D and 3D such as roughing, finishing, countering, facing, etc.

3. Research methodology

The course is reformed by taking product design, modeling, process simulation, and CNC programming. Students fully acquire the entire process of product design and production after the theoretical learning and practical skill training of the whole process (part pattern analysis, 2D drawing, solid modeling, process design, simulation processing, and automatic programming). In this course, according to the teaching content, this paper derivers the systematic framework to reform existing course into the "process-oriented" course. Figure 1 represents the consequence of "process oriented" course reformig methodology.

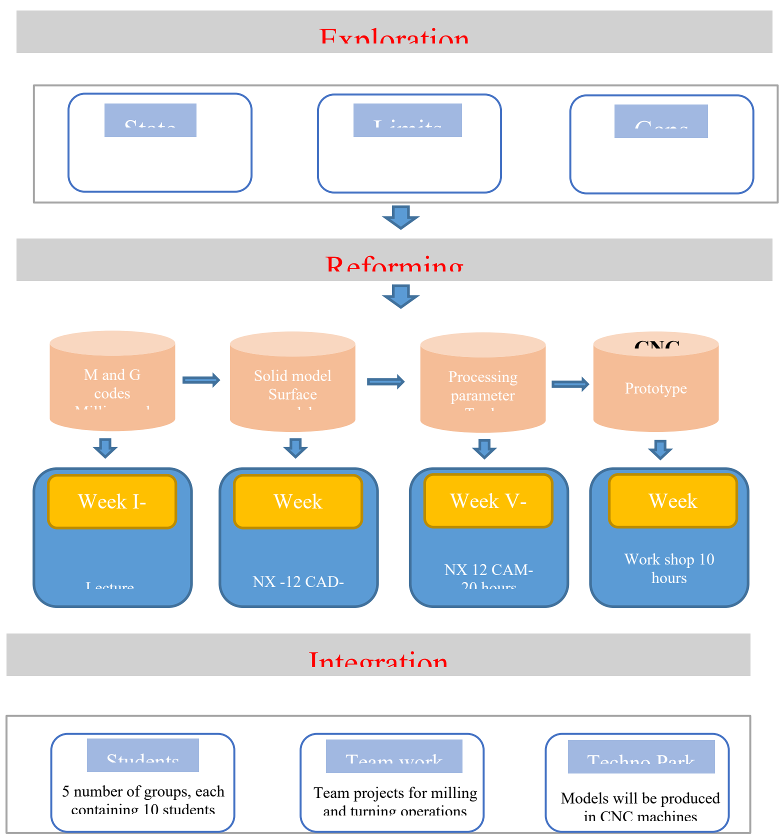


Figure. 1. CAD/CAM/CNC "process-oriented" course reforming methodology

This process is divided into three phases, first exploration phase which analyses the current state of the course, limitations and gaps. The second phase is reforming and it is divided into four modes: Theory, CAD, CAM and

CNC. This phase demonstrates a transformation towards "process-oriented" course and takes the offered program content. In theory building mode, students acquire fundamental knowledge of CNC machines programming using G and M codes, their classifications, tools and components.

CAD/CAM mode is intended for experiencing software skills of the students during laboratory sessions using NX Unigraphics. The students learn advanced modeling and simulation techniques during these laboratories' courses. The last mode is a workshop, where students will produce a prototype of the work piece developed previous modes using milling and turning machines. The last third phase of the methodology is important one because it is needed to properly implement and replace the new course into existing one. This last phase is called an integration.

4. Detail of reformed CAD/CAM/CNC "process-oriented" course

As it can be seen in Figure 2, the preceding course offered to students only simple 2D and 3D modeling in NX Unigraphics with manual writing of G and M Codes. It remarked that the students missed the actual working concept of machining and intricacy of the CNC machining.

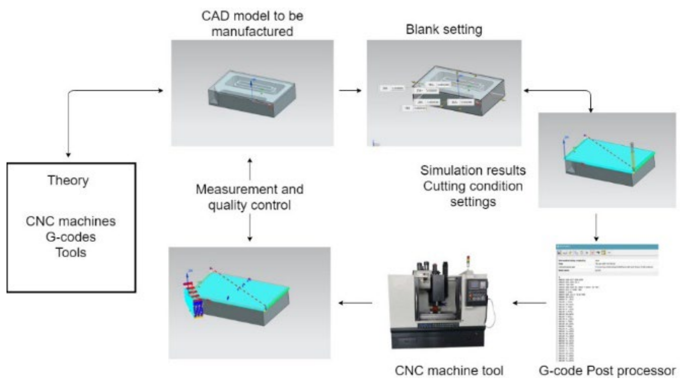


Figure 2. The flow diagram of CAD/CAM/CNC "process-oriented" courses

Thus, the focus of the new CAD/CAM/CNC course is to introduce the students some very important elements of CNC machining with a "process-oriented" project consisting of well-designed sequence of various fundamental features which are normal part of any complex machining situation, and emphasize the designing in CAD, programming in CAM and hands on experience of prototyping in CNC machines.

4.1 Theory. Introduction to CNC machines

Table 1 provides the description of the lecture contents as well as the objective of the class topics. Lecture session is included 10 lectures with a specific focus of CNC machines and its operations.

Table 1. Content of the lecture mode

Lecture Session	Manufacturing Processes Lesson Title	Objective of the Lesson
Lecture 1	Introduction to CNC machines	Students acquire the fundamentals of CNC machines, advantages and disadvantages, the main classification of the CNC machines and their main building blocks
Lecture 2	Turning Process and Machines	After this part of the course students learn the main type of CNC machine and it is turning or lathe operation. They study the main working principles of turning operation, turning machine components and tool selection criteria for this type of operation

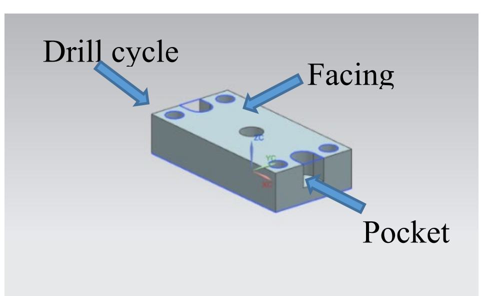
Lecture Session	Manufacturing Processes Lesson Title	Objective of the Lesson
Lecture 3	Milling Process and Machines	In this part of the course students will get the second main type of material removal operation that is milling operation. After completing this part, they are able to distinguish between milling and turning operation. They will get knowledge about type of milling operations like vertical and face milling, several type of tools available for milling operation, they will get deep knowledge about horizontal and vertical machines
Lecture 4	G and M codes. Coordinate systems in CNC machines	In this lecture, students will get information about the first introduction on how to write codes for CNC machines. They acquire preparatory and miscellaneous codes, starting and end of the program and as well as how to use absolute G90 and relative G91 codes for programming
Lecture 5	Rapid Positioning (G00) and Linear Interpolation (G01) codes in Milling Operations.	This lecture is first step towards writing G-codes for machined parts. Students will learn rapid positioning G00 code and linear interpolation G01 code. This is both is linear movement of the tool and also students learn how to calculate spindle speed and feed rate of the process by making several practical exercises
Lecture 6	Clockwise (G02) and Counterclockwise (G03) angular Interpolations codes in Milling Operations	After linear interpolation codes, in the lecture 6, students start to learn write for circular movement of the tool with some radius, namely G02 is for clockwise movement of the tool and G03 is for counterclockwise movement of the tool and they are called angular interpolation. In this part they will learn how to use arc radius “R” or alternatively incremental movement of the radius using “I” or “J” parameters along “X” and “Y”. As well as they perform some practical exercises on angular interpolation codes to get more experience
Lecture 7	Tool radius compensation right (G42) and left (G41) codes in Milling Operations	This part of the course, students study the codes to help them tool radius compensation in order to increase tool life and process efficiency. Those codes are G42 for right side and G41 for left side compensation. In addition, they will learn G40 code for tool radius compensation cancel code with some exercises
Lecture 8	Drill cycles G81, G82 and Drill cycle cancel G80 codes in Milling Operations	In this part of the lecture, they learn how to efficiently to drill many series and parallel holes using G81 and G82 drill cycle with practice and how to cancel drill cycle with G80
Lecture 9	Rapid and Linear Positioning codes in Turning Operations.	Students will learn how to use G00 and G01 linear interpolation codes for Turning operation, they will perform several practical exercises to distinguish difference between to use G00 and G01 using in turning and milling machines
Lecture 10	Clockwise (G02) and Counterclockwise (G03) angular Interpolations codes in Turning Operations	In the last lecture, the students will get knowledge about how to use circular interpolation codes for turning operation and will get how is the differ to program turning machines rather than milling machines

4.2 Development 3D CAD model

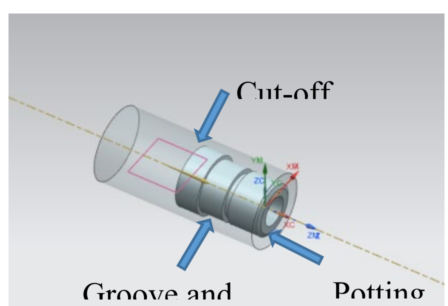
In order to develop 3D CAD model of parts, it is proposed to have laboratory class hours for students. Table 2 provides the content of CAD modelling laboratory classes with more details. It includes 10 lab hours that follows step by step approach to modelling in computer software. On the other hand, the most of the manufactured parts are a combination of various features such as pocketing, facing, contouring as shown in Figure 3 a and b part for milling and turning operations respectively.

Table 2. Content of the CAD mode

Laboratory Session	**Manufacturing Processes Laboratory Title**	**Objective of the Laboratory**
Lab 1	Sketch Techniques	-Sketching - Use constraints and dimensioning to control the shape and size of the sketch - Learn sketching commands - Learn commands and options that help you create sketches easily
Lab 2	Extrude and Revolve Features	- Constructing Extrude and Revolve features in the Modeling template - Creating Reference Frames Additional Options in the Extrude and Revolve commands
Lab 3	Placed Features	Holes, Threads, Slots, Blends, Chamfer, Draft, Shell
Lab 4	Patterned Geometry	Mirror features, Linear patterns, Circular patterns, Along curve patterns, Helical patterns
Lab 5	Additional Features and Multi body Parts	Ribs, Slots, Emboss features, Split bodies
Lab 6	Modifying Parts	Edit sketches, Edit Feature parameters, Synchronous modeling
Lab 7	Assembly	Starting an assembly, Inserting components, Adding constraints, Moving components, Replace components, Top-down Assembly design
Lab 8	Drawing	Create model views, Projected view, Auxiliary view, Section view, Detail view, Break-out section view, Center marks
Lab 9	Sheet Metal Design	- Tabs, Flanges, Bend Allowance, Bend Tables Counter Flanges
Lab 10	Surface Design	Basic surfaces, swept command, swept the along guide, Through curves, Through curve mesh



a)



b)

Figure 3. Industrial part with features for Milling Operation (a) and Turning operation (b)

4.3 CAM development

Table 3 presents the content of CAM development part of the course. This part also consists of 10 laboratory classes to strengthen the practical competence of the students.

Table 3. Content of the CAD mode

Laboratory Session	Manufacturing Processes Lesson Title	Objective of the Lesson
Lab 1	NX CAM introduction	Students acquire the fundamentals of CAM, steps of controlling program, analysis geometry, blank and preparation of the CAD model for manufacturing. Then, they will be introduced tool selection and tool types
Lab 2	Cavity Mill	In this part of the laboratory students will learn how to use cavity mill operation for rough milling. For instance: - Cavity mill for depths milling; - Plunge mill for circumferentially milling; - Corner rough for corner milling Rest milling for milling remained materials
Lab 3	Face Milling	In this part of the course students will learn milling of overstock from surface of the work piece
Lab 4	Z-level profile and Drilling cycle	Here students acquire how to operate with drill cycle and obtain pocket elements
Lab 5	Facing Operation in Turning process	Students learn how to perform face milling, stock and material selection for turning operation
Lab 6	Roughing and Finishing Operations in Turning process	Students gets familiar with tool selection and process parameters for rough and finishing operations
Lab 7	Chamfer and Groove Operations in Turning process	Students gets familiar with tool selection and process parameters for chamfer and grooving operations
Lab 8	Spot and Drilling Operations in Turning process	Students gets familiar with tool selection and process parameters for spot and drilling operations
Lab 9	Threading cycle in Turning process	Students gets familiar with tool selection and process parameters for threading operation
Lab 10	Cut-off process in Turning	Students gets familiar with tool selection and process parameters for cut-off operation

5. Results and Discussion

5.1 Exploration phase:

Very beginning, we investigated the current Mechanical Engineering course of the Manufacturing Processes course at Tashkent Turin Polytechnic University. A result shows us that, the existing course mainly oriented to theory of CNC machines and developing part program by hand. In consequence students feel bored and lose concentration during the lessons, which ignores subjective motivations, also they cannot possess important theoretical knowledge from the explanation of basic software and thus fails to satisfy the sustainable development of students. Furthermore, the observation showed that there was low integration of CAD and CAM technologies in local technical HEI's in Uzbekistan, 40% and 10% respectively.

In general, it was observed that the students missed the actual working concept of machining and difficulty of the CNC machining such as selection of tools, tool path simulating and etc.

5.2 Reforming phase:

Taking into account the results of the previous phase, the existing course is reformed according to the four modes: Theory, CAD, CAM and CNC.

Theory. Week I and II. Introduction of Computer Numerical Machines (CNC): This session mainly focused developing the basic knowledge on Computer Numerical Control programming of milling and turning machines, control systems, feedback systems, tool types, holder types, tool nomenclature, introduction to G and M Codes. In class-based lectures they will write programming codes for given parts. After this theoretical part, students will be able to choose process and tool technology for machining operation. Concept of G codes such as rapid positioning G00, linear interpolation G01, clockwise and counter clockwise movement of the tool G02 and G03 respectively, tool radius compensation G41 and G42, drill cycle G81 and, etc. In addition, this part of the course introduces M codes like M03 for spindle speed selection, M06 for tool selection, M90 for absolute coordinate systems and other codes required to start and stop of the program.

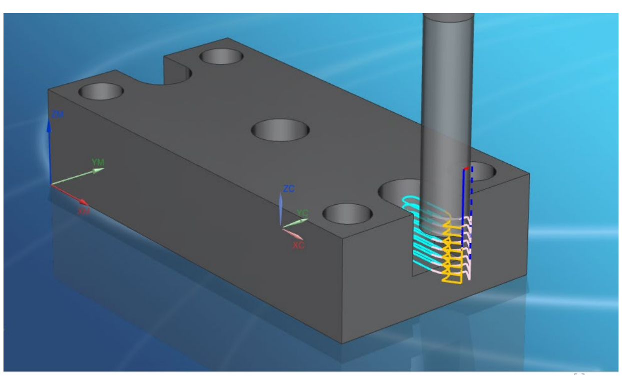
CAD: Week III and IV. Computer Aided Design laboratory: Geometric modeling technology is the precondition of achieving CAD/CAM and the integration. Students will learn to master the concepts and methods of 2D drawing and 3D modeling, and the method of feature modeling for the manufacturing process. The students use modeling software is NX Unigraphics to quickly sketch and edit 2D graphics. The appropriate modeling method is selected to conduct 3D solid, surface modeling, drafting and as well as assembly.

CAM: Week V and VI. Computer Aided Manufacturing laboratory: Students learn to use software, such as CNC programming software NX Unigraphics. The appropriate parameters are set to generate process simulation. Thus, students learn the post-processor to generate G-code for the given sample and will use this code for prototyping in next module.

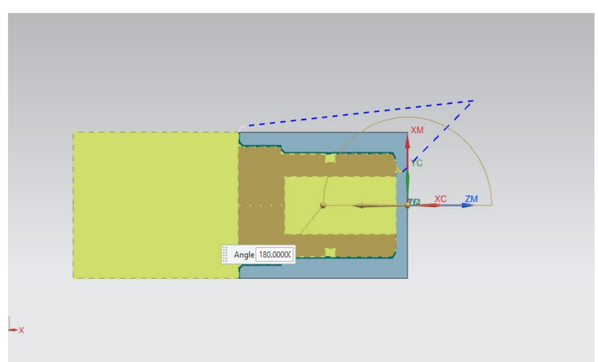
CNC: Week VI. Workshop with Computer Numerical Control machines: This module is intended for prototyping. Students using CNC machines like milling and turning will produce the elements done on CAD/CAM modules.
Based on module organization teaching, we obtained the CAD/CAM/CNC framework with more systematic teaching content with highly consistent knowledge and efficient teaching.

5.3 Integration phase:

To integrate the reformed course, we divided students into five groups containing ten students in each group. This division is very important, because experience showed that students in small groups were able to get more experience individually. Then, for each group will be given “process-oriented” projects for both milling and turning operation. Each group individually fill work sheet given, information like, tool, materials, working conditions of the process (cutting speed, feed rate, rotational speed, depth of cuts). They will produce the given product in Techno Park of the university and finally develop the report of the work. Figure 4 a and b part represents tool path simulation for Milling and Turning operations respectively. However, real workshop example of Manufacturing phase is shown in Figure 5.



a)



b)

Figure 4. Tool path simulation for Milling Operation (a) and Turning operation (b)

Figure 5. Workshop process

6. Conclusion

The "process-oriented" course has been proposed to inculcate the understanding of CNC machining and use of CAD/CAM to the students. A new reformed program has the characteristics of combining with theoretical teaching, practical teaching, and laboratory teaching with CAD/CAM and workshop with CNC machines. The following conclusions could be drawn.

1. The "theory-based" teaching method reformed into "process-oriented" to form the integrated mentality of the theory, practice, and laboratory and workshop. Through this, students motivated to improve their eagerness from passive learning to active learning. The actual industrial assignments were investigated.

2. The students actively analyzed 2.5 D and 3D part modeling and simulation methods with computer practice. For instance, in group discussion, students were thinking of part modeling, tool and process parameters selection. Different solutions were proposed by different groups to discuss a part. Through NX Unigraphics software, students experienced the whole process product life cycle, from design to code generation.

3. In the workshop, the students using milling and turning machines produce prototype of the designed products. Over this, the practical design and manufacturing problems were solved by students.

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