MAKER: Converting the Sketch of an Artefact into a Composite Bezier Curve and Producing it in the Boxford Milling Machine

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Converting the Sketch of an Artefact into a Composite Bezier Curve and Producing it in the Boxford Milling Machine

Abstract:
Students in an Introduction to CAM course would have theory classes augmented by hands-on experiments in the lab. At United Arab Emirates University (UAEU) the students were taught parametric curves and NC programming in the theory classes. A project to inspire the students and excite their creativity while cementing the theory they have learned was needed. A $2 \frac{1}{2}D$ milling project, a memorabilia clock, was chosen as the candidate. The cross section was drawn on a graph paper and was broken into an assemblage of straight line and curve segments. The nodal points, tangency condition and optional intermediate points described the assemblage. It was transferred to CorelDraw software and the shape was modelled and the control points were obtained. The model of the cross section was transferred to the Boxford Milling Machine as an assemblage of straight lines and Bezier curve segments defined by their control points. The product was manufactured. The students had an exciting experience and learned an important practical side of Bezier Curves. The methodology developed is generic and can be used to make similar products.

1 Introduction

The course, Introduction to Computer Aided Manufacturing has several learning outcomes including (i) students will be able to apply the knowledge of mathematics and engineering science to model engineering shapes using parametric curves and (ii) students will be able to draw and transfer data using computerised drawing tools and programming tools. The laboratory has (i) four CNC bench lathes (ii) four CNC bench milling machines (BOXFORD - 190VMCxi Vertical Machining Centre) (iii) a Cincinnatti Arrow 2 series vertical machining center and (iv) a DMG horizontal machining center. The students have theory classes augmented by hands-on experiments in the lab. In the theory classes the students were taught parametric curves and NC programming. A project to inspire the students and excite their creativity while cementing what they have learned was needed. Boxford milling machines were fitted with the CAM package, BOXFORD CAD/CAM Design Tools V10, which can accept third order Bezier curves defined by their four control points. However the size of the work pieces they could handle was limited. This led to the choice of memorabilia items as the area for the project. A memorabilia table clock was chosen as the candidate. Section 2 describes the project as given to the students, the theory involved and the method employed in the design, and manufacturing. There were eighteen student groups of three who participated in the exercise. A typical sample of the work is described in section 3. Manufacturing the product became a challenge because of the shortcomings of the machines. Section 4 describes Assessing and evaluating the work. Section 5 describes the learning experience and Section 6 draws conclusions.

2 The Project

The project was to design a memorabilia clock for UAEU consisting of three parts (i) a clock insert bought outside (ii) a body to house the clock insert and the name tower or logo and (iii) the name tower itself. The main design task is that of the body. In order for the students to feel the importance and grasp the holistic picture they were asked to work as partners of a fictitious company making a bid. The brief given to students is as follows:
Following the traditions of big universities, UAEU wants to produce some memorabilia. A table clock has been considered with several other ideas and has been selected as the most appropriate one. It consists of a suitably designed stand onto which a clock insert is fixed. The manufacturing process considered for the stand is a 2.5D profile milling followed by the drilling of a hole and gluing a tower of the University Logo. The university wants to make 1000 pieces of this. It wants to contract this job out. You are a group of mechanical engineering graduates just graduated from UAEU and are in the process of forming a product design and manufacturing company. You want to have this contract to launch your company. But the competition is very high. Eighteen companies including yours have recorded interest in bidding for the contract. Make a bid on the specified format given and make a presentation to the interviewing board to convince them to choose your bid.

The students were told that the product should have the emotional appeal reflecting the characteristic character of the region and product differentiation, a rating of product’s uniqueness and consistency with the product’s corporate identity.

2.1 Theory

Bezier curves are named after their inventor, Dr. Pierre Bezier. He was an engineer with the Renault car company and set out in the early 1960’s to develop a curve formulation, which would lend itself to shape design [1]. The motivations and the passage of the invention is given in a letter written by Dr Bezier to Christophe Rabut which has been published by Rabut [2]. Text books [3 4] describe the theory in detail. A summary of the relevant parts is given here.

A third order Bezier curve is the point-bounded collection of points, which are the weighted sum of four special points called the Control Points. If the control points are marked by the capital letters like $P_i(X_i, Y_i)$ and a point on the curve is marked by the small letters like $p(x, y)$ then a general point on a third order curve can be written as

$$p = B_0P_0 + B_1P_1 + B_2P_2 + B_3P_3$$

where $p$ is an arbitrary point on the curve

$P_0, P_1, P_2$ and $P_3$ are control points

$B_0, B_1, B_2$ and $B_3$ are the blending functions

The blending functions are the Bernstein functions defined as the terms in the following expansion for a third order curve.

$$(1 - u)^3 + 3(1 - u)^2u + 3(1 - u)u^2 + u^3$$

Where $u$ is the independent parameter, which takes the value 0 at the starting point and 1 at the finishing point of a Bezier curve segment.

Expanding these terms and putting them in matrix form gives

$$[B_0, B_1, B_2, B_3] = [u^3, u^2, u, 1]$$

Substituting this in the defining equation gives
If the curve passes through four points this can be written as
\[
\begin{bmatrix} x & y \end{bmatrix} = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X_0 \\ X_1 \\ X_2 \\ X_3 \end{bmatrix} \begin{bmatrix} Y_0 \\ Y_1 \\ Y_2 \\ Y_3 \end{bmatrix}
\]

Thus if four points on the curve are known, the control points can be calculated. Alternately if the four control points are known points on the curve can be calculated.

2.1.1 Tangency Condition

Two curves, described by two sets of parametric equations, merge smoothly when they have the same slope at the meeting point. This is called the tangency condition. Consider the curves \( p_0p_1p_2p_3 \) and \( p_3p_4p_5p_6 \) as shown in Figure 2.

![Figure 2: Two Bezier Curves Merging Smoothly](image)

Then the tangency condition for smooth merging is the slope of curve \( p_0p_1p_2p_3 \) at the point \( p_3 \) should be equal to the slope of \( p_3p_4p_5p_6 \) at \( p_3 \).

Let the equation of a Bezier curve be
\[
p(u) = (1 - u)^3 P_0 + 3(1 - u)^2 u P_1 + 3(1 - u)u^2 P_2 + u^3 P_3
\]

Then
\[
\frac{dp(u)}{du} = 3(1 - u)^2 P_0 + 3[(1 - u)^2 + u (1 - u)(-1)]P_1 \\
+3[2u - 3u^2]P_2 + 3u^2 P_3
\]

When \( u = 0 \) this becomes \( 3(P_1 - P_0) \) and
When \( u = 1 \) this becomes \( 3(P_3 - P_2) \)
This means that the tangent vector at $p_3$ is along the line connecting $P_3$ and $P_2$ for the curve $p_0p_1p_2p_3$ and along the line connecting $P_3$ and $P_4$ for the curve of $p_3p_4p_5p_6$. This follows that the points $P_2$, $P_3$ and $P_4$ must lie on a straight line for smooth joining. Thus the tangency condition for smooth joint becomes, points $P_2$, $P_3$ and $P_4$ must be collinear.

### 2.2 The Methodology

The methodology starts with the visualization of the product and making a ‘Bounding box’. This will particularly be useful to proportion all the concepts to the same level. In the second step creativity and artistic thinking have been used to bring character, and sketch the cross section of the object to be milled. Make as many sketches as possible on graph (gridded) paper and then choose one. Once the cross section is chosen the next step is to break the sketch into a number of curve segments and label them. Read the coordinates of the nodal points from the graph paper and read any intermediate points in each segment through which the curve has to pass. Also note down the tangency condition where the curve segments meet. Now the curve is ready for transfer to CorelDraw software [5]. In CorelDraw open a file with a graph paper template as the fourth step. In the fifth step draw a polygon through the nodal points recorded earlier when segmenting the sketch. In the next step using the Bezier Tool from the software, convert the straight-line segments that have to be curves, into Bezier curve segments. Looking at the tangent vectors at each node ensure the required tangency condition is met. Make sure that the curve passes through the required intermediate points.

![Figure 3: Steps in the Transfer of the Sketch to CorelDraw](image)

This process of making the complete composite Bezier curve is the sixth step. Once the curve in CorelDraw is made to meet all the requirements and thus transferring the sketch to the computer, one can proceed to the final step. The final step in CorelDraw is to go through clicking at all the nodes, one by one, and reading and recording the intermediate control points. This procedure is illustrated in Figure 3 where Figure 3 (a) shows the sketch broken as curve segments, Figure 3 (b) showing the polygon formed by the nodal points, Figure 3 (c)
showing the partially converted sketch and Figure 3 (d) completed sketch with some of the common tangents.

A similar procedure is repeated in the BOXFORD CAD/CAM Design Tools V10 software in the Boxford Milling Machine. A polygon is drawn and the curve segments are constructed by keying in the intermediate control points. Once the curve definition is completed the software is prompted to generate the NC code. The generated code can be simulated to prove the code and edit if necessary. The last step is to secure the work piece, set the datum planes and manufacture the body. The clock is then inserted and the logo is mounted. The methodology is schematically illustrated in the flowchart shown in Figure 4.

Figure 4: The Methodology

3 Typical Sample of the Student Work

Members from one of the eighteen groups are part of the authoring group and they mainly wrote this section. This work has been done during the 2011/2012 academic year. Concept generation and selection was an important step that had to be followed for producing the product. Each member of the teams drew different concept sketches. All eighteen groups had novel designs that reflected their aspirations and feelings for this project. The concept selection was one of the most important decisions that had to be taken in the project. All eighteen groups had chosen concepts that represented the conscience of the region. Some of the interesting concepts chosen by the students are as follows:

i. The first concept was the striking features of the ‘Lion’, which also reflected the graduate power.

ii. Another concept was the ‘Camel’, which can survive for several days without water and which provided means of transport across the desert permitting the UAE’s Bedu nomads to move from place to place in search of food and water. Without the camel, the hard, nomadic life of the UAE’s Bedu would not have been possible.
iii.  Religion is a very important component of UAE society and another very important concept was the ‘Worshipping Man’. Worship is an all-inclusive term for all the god lovers and it is everything one says or does for the pleasure of Allah.

All concepts looked innovative and would have looked even better when coloured with paints. Concepts have been chosen based on four important requirements which are (i) attractive appearance with an underlying meaning (ii) ease of manufacturing, (iii) stability of the product and (iv) uniqueness of the product.

Some of the concepts had several special geometric details specially the curves and their targeted smoothness. One of the challenges in this project was choosing a CAD software with sufficiently high technology to convert this sketch into digital representation. The theoretical lessons on parametric curves helped to visualize different types of Bezier curves. Some of these considerations are (i) curves and points which were contained within the control polygon (ii) curves crossing the control polygon and (iii) different tangent shapes at the nodes and their mathematical conditions.

The conceptual sketches were partitioned with due consideration for different characteristic features of the profile. There were many intricate shapes that had to be taken care of. Use of CorelDraw permitted the consideration of more points in the partitions than those allowed by mathematics. Some segments were small and some segments were big. Some segments were straight lines. The ‘to and fro’ movement between the sketch and CorelDraw achieved a full understanding of Bezier curves. A simple profile having all different types of Bezier Curves is chosen here for description.

3.1 Partitioning the Sketch

Partitioning the sketch is an important part of the project. Good partitioning gives the flexibility and freedom to manipulate the segment to include the characteristic features of the segment. In the sketch shown in Figure 5 section AB is a straight line while segment BC is a curve blending into AB with a smooth joint at B, requiring a tangency condition. Segment CD is a straight line which meets BC at C with a sharp corner. Segment DE is a straight line which will form the platform for the name tower. EF is a near straight segment. EF blends smoothly with DE at E and FG at F and both require the tangency condition. HG is a straight segment with sharp corners. Thus the partitioning needs visualizing the entire curve segments. These details are given in Table 1.
Table 1: Curve Segment and Properties

<table>
<thead>
<tr>
<th>Curve Segment</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>Vertical straight line</td>
</tr>
<tr>
<td>BC</td>
<td>Bezier curve with smooth joint at B</td>
</tr>
<tr>
<td>CD</td>
<td>Vertical Straight line with 90° joint at C</td>
</tr>
<tr>
<td>DE</td>
<td>Horizontal Straight line with 90° joint at D</td>
</tr>
<tr>
<td>EF</td>
<td>Near Straight with tangency condition at E &amp; F</td>
</tr>
<tr>
<td>FG</td>
<td>Smooth joint at G and 90° joint at H</td>
</tr>
<tr>
<td>GH</td>
<td>Horizontal line with 90° joints at G &amp; H</td>
</tr>
<tr>
<td>HI</td>
<td>Simple curve</td>
</tr>
<tr>
<td>IJ</td>
<td>Straight line with smooth joints at both I &amp; J</td>
</tr>
<tr>
<td>JK</td>
<td>Bezier curve with smooth joints at both J &amp; K</td>
</tr>
<tr>
<td>KL</td>
<td>Bezier Curve with vertical tangent vectors</td>
</tr>
<tr>
<td>LA</td>
<td>Horizontal line with 900 joints at L &amp; A</td>
</tr>
</tbody>
</table>

The coordinates of the nodal points A, B, C, D, E, F, G, H, I, J, K and L are taken from the graph paper. Optional interim points were also recorded for the curves. They will be useful if mathematical methods are to be used instead of CorelDraw.

Table 2: Nodal Points

<table>
<thead>
<tr>
<th>Nodal Point</th>
<th>Coordinates</th>
<th>Optional Interim points</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(0, 0)</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>(0, 5)</td>
<td>(15, 10) in BC</td>
</tr>
<tr>
<td>C</td>
<td>(0, 25)</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>(0, 30)</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>(35, 30)</td>
<td>(60, 30) in EF</td>
</tr>
<tr>
<td>F</td>
<td>(90, 17.5)</td>
<td>(105, 5) in FG</td>
</tr>
<tr>
<td>G</td>
<td>(105, 0)</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>(95, 0)</td>
<td>(95, 3) in HI</td>
</tr>
<tr>
<td>I</td>
<td>(85, 10)</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>(30, 25)</td>
<td>(24, 23) in JK</td>
</tr>
<tr>
<td>K</td>
<td>(20, 15)</td>
<td>(15, 10) in KL</td>
</tr>
<tr>
<td>L</td>
<td>(10, 0)</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Marking the Nodes in CorelDraw and Drawing the Polygon

Open CorelDraw with graph paper template and mark off the nodal points. Connect them as a continuous line polygon of straight line segments as shown in Figure 6.
3.3 Convert the Required Straight Line Segments into Bezier Curves

The first Straight line segment that needs to be converted to a Bezier curve is BC. The main thing about this curve is that it forms the leg of the lion. The shape should reflect the strength and muscle power of a lion’s leg. This is a special curve because the control points $P_1$ and $P_2$ are on the opposite sides of the curve (refer Figure 7). The curve can be manipulated to pass through all the intermediate points by pulling and pushing the tangent vectors or the curve itself. The process was repeated for all the segments that have to be converted to Bezier curves and the main thing to observe was the tangency conditions.

3.4 Obtaining the Control Points and the Equations of the Curves

CorelDraw will show the control points associated with the curves connected to a node when that node is clicked under the Bezier tool. The control point can be moved by clicking and holding while moving. Thus it is very easy to meet the tangency condition. Figure 7 shows the Control Points for the curve segments forming the profile.
The procedure is continued until all the required segments are converted into Bezier segments. The equations, though were not required to manufacture, were derived in the following way:

In general a third order Bezier curve can be written in the matrix form as

\[
\begin{bmatrix}
  1 & 3 & -3 & 1 \\
  3 & -6 & 3 & 0 \\
 -3 & 3 & 0 & 0 \\
  1 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
  X_0 \\
  X_1 \\
  X_2 \\
  X_3
\end{bmatrix}
= \begin{bmatrix}
  x \\
  y
\end{bmatrix}
\]

Then all what is required is to substitute the control points to get the equations.

### Table 3: Control Points

<table>
<thead>
<tr>
<th>Curve Segment</th>
<th>Control Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>Straight line (0, 0) (0, 5)</td>
</tr>
<tr>
<td>BC</td>
<td>(0, 5) (0, 12.5) (20, 25) (0, 30)</td>
</tr>
<tr>
<td>CD</td>
<td>Straight line (0, 30) (0, 35)</td>
</tr>
<tr>
<td>DE</td>
<td>Straight line (0, 35) (35, 35)</td>
</tr>
<tr>
<td>EF</td>
<td>(35, 35) (40, 35) (75, 22.5) (90, 17.5)</td>
</tr>
<tr>
<td>FG</td>
<td>(90, 17.5) (102.5, 12.5) (105, 12.5) (100, 0)</td>
</tr>
<tr>
<td>GH</td>
<td>Straight line (105, 0) (95, 0)</td>
</tr>
<tr>
<td>HI</td>
<td>(95, 0) (95, 5) (92.5, 7.5) (85, 10)</td>
</tr>
<tr>
<td>IJ</td>
<td>Straight line (85, 10) (30, 25)</td>
</tr>
<tr>
<td>JK</td>
<td>(30, 25) (20, 27.5) (20, 22.5) (20, 15)</td>
</tr>
<tr>
<td>KL</td>
<td>(20, 15) (20, 10) (10, 12.5) (10, 0)</td>
</tr>
<tr>
<td>LA</td>
<td>Straight line (10, 0) (0, 0)</td>
</tr>
</tbody>
</table>

With this data it is now possible to find the equations for all the curves. Table 4 shows a sample calculation and the equations for all curves. However these equations are not needed to complete the manufacture of the product.
### Table 4: Equations of the Curves

<table>
<thead>
<tr>
<th>Curve</th>
<th>Equation with Derivation</th>
</tr>
</thead>
</table>
| BC    | \[
|       | \begin{bmatrix}
|       | x & y \\
|       | \end{bmatrix} = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix}
|       | \begin{bmatrix}
|       | -1 & 3 & -3 & 1 \\
|       | 3 & -6 & 0 & 0 \\
|       | -3 & 3 & 0 & 0 \\
|       | 1 & 0 & 0 & 0 \\
|       | \end{bmatrix} \begin{bmatrix}
|       | 0 & 5 & 0 & 12.5 \\
|       | 20 & 25 & 0 & 30 \\
|       | \end{bmatrix}
|       | \begin{bmatrix}
|       | -60 & -12.5 \\
|       | 60 & 15 \\
|       | 0 & 22.5 \\
|       | 0 & 5 \\
|       | \end{bmatrix}
|       | \]
|       | The Bezier equation of the curve BC:
|       | \begin{align*}
|       | x(u) &= -60u^3 + 60u^2 \\
|       | y(u) &= -12.5u^3 + 15u^2 + 22.5u + 5
|       | \end{align*}
| EF    | The Bezier equation of the curve EF:
|       | \begin{align*}
|       | x(u) &= -40u^3 + 75u^2 + 15u + 25 \\
|       | y(u) &= 15u^3 - 30u^2 + 35
|       | \end{align*}
| FG    | The Bezier equation of the curve FG:
|       | \begin{align*}
|       | x(u) &= 7.5u^3 - 30u^2 + 37.5u + 90 \\
|       | y(u) &= -17.5u^3 + 15u^2 - 15u + 17.5
|       | \end{align*}
| HI    | The Bezier equation of the curve HI:
|       | \begin{align*}
|       | x(u) &= -5.5u^3 - 4.5u^2 + 95 \\
|       | y(u) &= 2.5u^3 - 7.5u^2 + 15u
|       | \end{align*}
| JK    | The Bezier equation of the curve JK:
|       | \begin{align*}
|       | x(u) &= -10u^3 + 30u^2 - 30u + 30 \\
|       | y(u) &= 35u^3 - 45u^2 + 7.5u + 25
|       | \end{align*}
| KL    | The Bezier equation of the curve KL:
|       | \begin{align*}
|       | x(u) &= 20u^3 - 30u^2 + 20 \\
|       | y(u) &= -22.5u^3 + 22.5u^2 - 15u + 15
|       | \end{align*}

### 3.5 Modelling in the BOXFORD CAD/CAM Design Tools V10 and Generating the NC Code

The software supplied with Boxford machine is ‘Boxford CAD/CAM Design Tools V10’ which is an integrated suite of CAD and CAM tools. The CAD part of the software offers a 2D interface to model the object. Using CAM part, CNC program consisting of international industrial standard G and M code can be generated, simulated and manufactured. There are two different approaches in order to work on this package.

- Automatically processing a drawing created with the integrated CAD package or imported from any major package using the CAM processor
- Manual data inputting using a sophisticated program editor, interactive help and in-built error checking.

It was an obvious choice to go with the first option. Under the mill design tools interface, the left hand toolbox contains a variety of basic drawing tools as shown in Figure 8 (a), which are grouped by the type of entity they define. Generally, ‘Line’ and ‘Bezier’ tools are used to sketch the profile. Here, the size of the work-piece that would be used later also has to be
defined. The CAD part is completed with a 3D model as shown in Figure 8 (b). Using the integrated nature of the package, the CAD file is directly converted into CNC program consisting of G and M code.

![Image of Mill Design Tool Interface and model built in Boxford Machine]

**Figure 8: Mill Design Tool Interface**

### 3.6 Simulation of the Manufacture

When the CAD profile is completed and ready to be processed into a G&M code CNC program, the ‘To Mill’ command, which is located under the file menu, has to be selected. Some fundamental decisions like work-piece material, its specification, and the type of the cutting tool(s) going to be used for machining have to be made at this point. Further the depth of cut and type of the profile that has to be cut (whether it’s an areas, closed profile or open profile etc.) has to be given to the program.
Figure 9: Some Windows showing the Simulation and Manufacture Stages

Once these decisions are made, simulation window opens. Here the CNC program can be reviewed and edited if required. The simulation windows also give the estimated time for cutting. This time is an estimate since the feed rate of the axes can be manipulated during cutting.

The important thing during simulation is to re-view the final shape of the work-piece at the end of the simulation. If the result is not as per expectation, the CNC program has to be reviewed. Because of the integrated nature of the CAD/CAM program, it is quite possible to get slightly different result contrary to expectation. The program can be edited directly or the drawing can be modified to get the desired result.

3.7 Manufacture

Once the simulation is complete and the result produces a satisfactory shape of the product, the actual manufacturing begins. The process starts with the input of the following two important data into the system:

- Tool offset (calculating the length of the cutting tool and diameter)
- Datum setting
The Boxford software offers tool library that holds the data for the existing tools as shown in Figure 9 (a). Any tool from the library can be selected and tool offset have been entered already. Alternatively, a new tool can be added to the library. In that case tool offset need to be entered into the system.

Since a rectangular plastic block has been selected as the work-piece the machining origin needs to be defined. This machining origin or datum is the reference point for machining (also termed as home position). Based on the geometry of the work-piece, front-left corner of the block is usually taken as datum. Certain steps need to be performed at this stage. The work-piece needs to be touched using cutting tool first from the left side and then, from the front-side and finally, from the top surface of the work-piece. Now, the program is ready for actual cutting of the material.

After setting the datum, the CAM design tool offers ‘manufacture’ option. Once this option is selected, a new window opens and the data, which have entered already, is displayed on the screen as shown in Figure 9(b). This is like confirmation message. The software also gives the option for clamping the work-piece with a vice or any other technique. On choosing the vice, the software inquires about the height of the work-piece after clamping in the vice as shown in Figure 9(c). Upon selecting the continuous cycle start button manufacturing starts. On completion a message saying the manufacture is complete through a screen shown in Figure 9(e).

3.8 Drilling the Hole, Inserting the Clock and Fixing the Name Tower

Drilling the hole for the clock insert and machining the name block and gluing it to the block were all important tasks that had to be performed to make the product. However they are tasks that are familiar. Figure 10 shows the tasks and the finished product.

4 Assessing and Evaluating the Work

Generally mathematics in theory will not appeal to everyone. Tutorial classes and office hours are always packed with students having a variety of questions. But this exercise was an exception. The students had to finish the conceptual design to start the CorelDraw. There was only one CorelDraw license and they had to take turns. The students patiently waited for their turns. Once they were on it they tried various experiments moving the nodal points, moving the control points and shortening and extending the tangent vectors were some of the experiments (playing) they did. Every student played with the software. This permitted them to shape the curve to bring the character. By the time they went for manufacturing every student was thorough with theory of Bezier curves and how changing something actually changes the curve. The assessment was divided into four parts the conceptual design, transferring to CorelDraw and obtaining the Control Points, deriving the mathematical equation of the curve and the manufacture of the product. Every group and every student did exceptionally well in the assessments. Figure 11 shows the items produced by all the nine female groups. The male students made a similar set too. The cohort that came during the succeeding academic years modelled and produced different products. For example the cohort in 2012/2013 modelled and manufactured camels while the cohort in 2013/2014 made falcon badges. The results were similar all the time. The students got full understanding and ability to use Bezier curves in designs. They could analyse a sketch to break it into suitable curve segments, evaluate a division for its flexibility and they could synthesize new shapes that exploit the features of composite Bezier curves.
Figure 10: Manufacturing Windows and Finished Product

a) Machine Set for Drilling Hole
b) Manufactured Hole
c) Machining the Name Plate
Finished Product

Figure 11: Memorabilia Clocks Produced by the Female Students
5 Learning Experience

Drawing a curve segment in the way the students want was the thrilling experience for them. Thus the most interesting part in this project was using CorelDraw to draw Bezier curves and composite curves to model a shape they want. They never had the experience of transferring a hand-sketch to a computer and this ability gave great excitement. The real power of Bezier tool in CorelDraw comes from drawing smooth curves.

Writing about a Term Project three years after its completion itself is a testimony for the strength of the learning experience. The mathematics and its physical realization; Playing with control points; Tangency condition and its variation; Feeling of Excitement; Team spirit and confidence experienced; and the achievement itself. These are the memories that were cherished by the two authors who were students at that time to take part in the project.

6 Conclusions

A methodology that breaks a complex shape into simple curves and straight line segments and describes the shape as an assemblage of the segments has been developed. The nodal points, tangency condition and optional intermediate points described the assemblage. This description was used to transfer the sketch to the computer. CorelDraw software was used to model the cross section in the computer. This enabled easy manipulation of the control points and the resulting tangent vectors. The software ‘Boxford CAD/CAM Design Tools V10’ came with the machine was made full use to produce a component having a composite Bezier curve as its cross section. An effective method to teach Bezier Curves in a practical way has been demonstrated.

References: