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Designing with Lessons from the Machine Design Course: A Capstone Experience

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Abstract:
Extensive procedures and complex calculations involved in the Machine Design courses make the students feel dull. To enthuse the students there is a need to have inspiring capstone projects that integrate machine elements, the impact of engineering designs and designers on society, and the systematic design process. Belonging to something noble fascinates people most of the times and it makes people to work hard to achieve that belonging. Relating to elite groups from a career would encourage young students to choose and belong to that career. A display item boasting the glory of mechanical engineering was chosen, to highlight the elite groups from mechanical engineering that made significant impacts on society and, to demonstrate the building blocks of mechanical engineering. A project displaying five historically prodigious achievers and achievements on a slowly rotating dodecahedron, driven by a power train made up of components learnt in machine design courses, was accomplished. The paper describes in detail how the project was implemented and what lessons have been learned.

1 Introduction

More general field of mechanical design involves the design of several Machine Elements, which are elementary components of a machine. To design mechanical devices and systems therefore, one must be competent in the design of individual machine elements that comprise the system. To this effect Machine Design courses cover general topics such as the principles of strength of materials, the design properties of materials, combined stresses, design for different types of loading, and the analysis and design of columns and beams as well as primary machine elements such as belt drives, chain drives, gears, shafts, keys, couplings, seals, and rolling contact elements. The contents of the course involve extensive procedures and complex calculations which make the students to feel dull. Further, this knowledge alone is not sufficient in the modern context where the students are expected to be able to integrate several components and devices into a coordinated, robust system, involving several decisions. They should be able to understand and evaluate the impact of such engineering designs in the society. In the capstone project students, as a norm, gain experience with the complete systematic design process spanning through the definition of the problem, drawing of engineering specifications, generation and evaluation of conceptual designs, choice of the final design, and analysis and proving of the final design. Thus there is a need to have inspiring capstone projects that integrate machine elements, the impact of engineering designs and designers on society and the systematic design process. This paper describes the carrying out of such a project and the lessons learned.

2 Brief Description of the Project

The broad aim was to develop a capstone project that would (a) provide the learning experience in using the knowledge and skills acquired by students from machine design courses during their residence in the university in an inspirational way and (b) enable them to become ambassadors for mechanical engineering by realizing and preaching the impact mechanical engineering had and has on a global and societal context. It was felt that belonging to something noble fascinates people most of the times and it makes people to work hard to achieve that belonging, like the full member status in a professional body.

With the above in mind a project entitled 'A Display Item Boasting the Glory of Mechanical Engineering' was designed and given to a group of three senior students as their graduation project at United Arab Emirates University, UAEU. The objectives of the project from the faculty members' point of view were as follows:

i. Incorporate many interdependent machine elements so that the students gain experience in selecting and integrating machine elements to form a mechanical system
ii. Enable the students to appreciate the impact of engineering solutions of the past
iii. Should make the students to feel good about their choice of mechanical engineering as their career.
iv. Should be achievable within two semesters.

The project was conceptually divided into two halves. The machine design part has to provide a mobile system that starts from an electric motor and ends up with a slow rotating vertical shaft to carry the display that would rotate with it. The display should be made up of a polygonal structure that should carry descriptions of mechanical engineering achievers and achievements that had great impacts.

3 Process Adopted by the Students

The students followed a systematic design model having requirements, product concept, solution concept, embodiment and detail design as its stages.

3.1 Requirements, Product Concept and Solution concept stages

The students started with a design brief which had (i) product description (ii) a rough concept (iii) benefits to be delivered (iv) target market (v) target position and price (vi) stakeholders (vii) Possible features and (viii) areas for innovation as its elements. Having understood the product they went to the stakeholders to record their requirements. Their verbatim were recorded and subsequently translated by the students to needs with weighting. They used these weighted needs to draw their specifications. Part of their specifications is given in Table 1.

Table 1: Part of Specifications

Specification	Quantity	Units
Number of Faces and landmarks	5	number
Area of Face	0.154	m^2
Overall Height	1.7	m
Number of Words	<35	Number
Percentage of Face	50%	Percent
Number of Layers	1	Number
Push Button Switch	-	AC motor ON-OFF
Weight of the Unit	60-70	Kg
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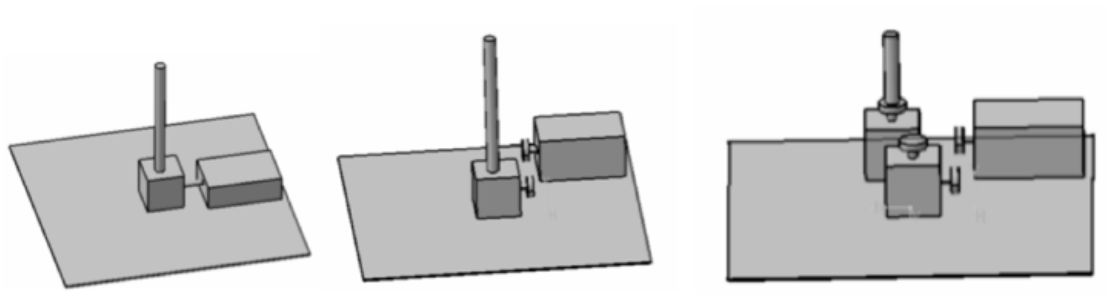

Figure 1: Conceptual designs for the Base

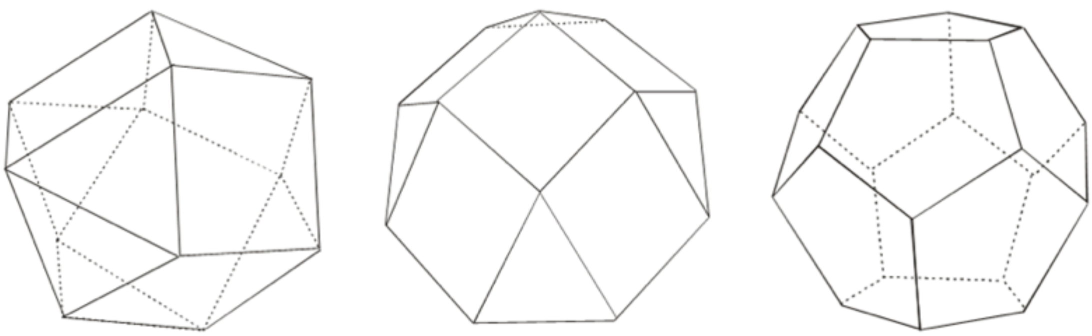

Figure 2: Conceptual Designs for the Display

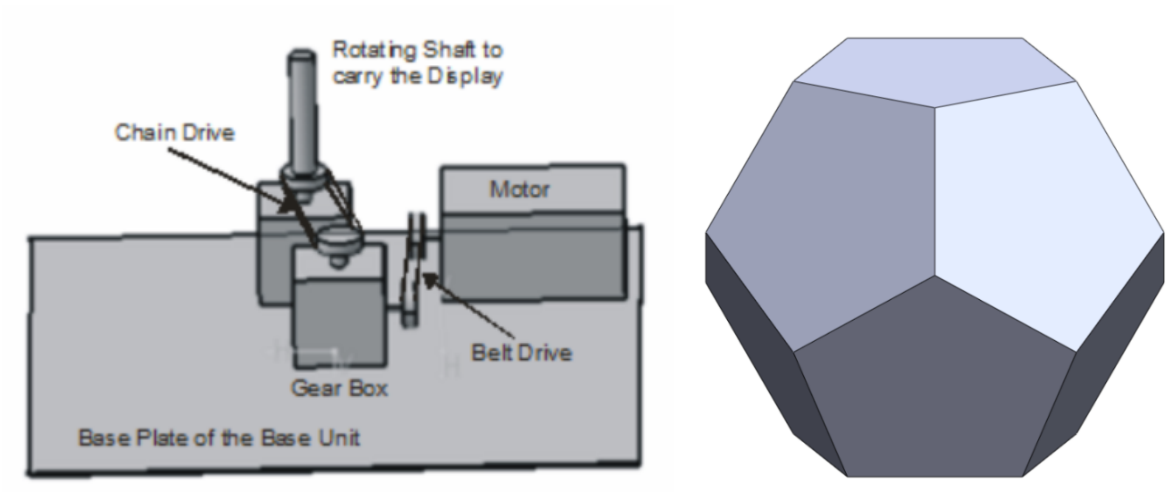

Figure 3: Chosen Concepts

They then developed a function tree for the product and used the high level functions identified, as the basis for a Morphological chart. They divided the project into two halves, the base and the display. They have developed concepts for the base separately and the rotating body separately. It was a small team consisting of three students. But they had a list of interim outputs for each stage of the design model, which helped them to keep the work under control. Figures 1, 2 and 3 show the conceptual designs of the hardware items.

3.1.1 Landmark Items for the Display

Though the mechanical system carries them, the display items to be described form the crucial and inspiring aspect that would decide, the success and failure of the artifact or, the fitness for the purpose. Products that made impact on the society in a big way, materials that have important roles in landmark products and people who made significant contributions, were considered. Several products such as mechanisms, CNC machine tools, trains, ships and aircrafts, several significant materials like diamond, carbides and composites and several people like Galileo, Newton, Hooke, Brunel, Einstein and Timoshenko were considered. It was felt that relating a career to these elite groups would encourage young students to choose that career. The choice should be familiar, exciting and give a feel good factor to be associated with it. Further they should be makeable on a piece of wood using a CNC machine. The final choice of items were as follows:

i. *Model T Car* – The car that was voted as the car of the 20th century, which changed the American (why the world's) way of life with respect to mobility.
ii. *Concord Aircraft* – The first supersonic aircraft which crossed the Atlantic in half the flight time of other aircrafts
iii. *Sir Isaac Newton* – The inventor of force which is so fundamental to every engineer
iv. *Albert Einstein* – The inventor of the Dot Notation which made life easy for all stress analysts
v. *Composite Materials* – The concept that gave the capability to design materials with the desired properties.

Figure 4: Chosen Concepts for the Display

3.2 Embodiment Design

The embodiment design started with establishing a parts tree showing what and what important components go into each sub-assembly to make the product. This acted as a checklist for the students reminding things that have to be done. Figure 5 shows their parts tree. The embodiment for the display unit and the embodiment design for the mechanical system were developed separately and the following sub-sections describe them.

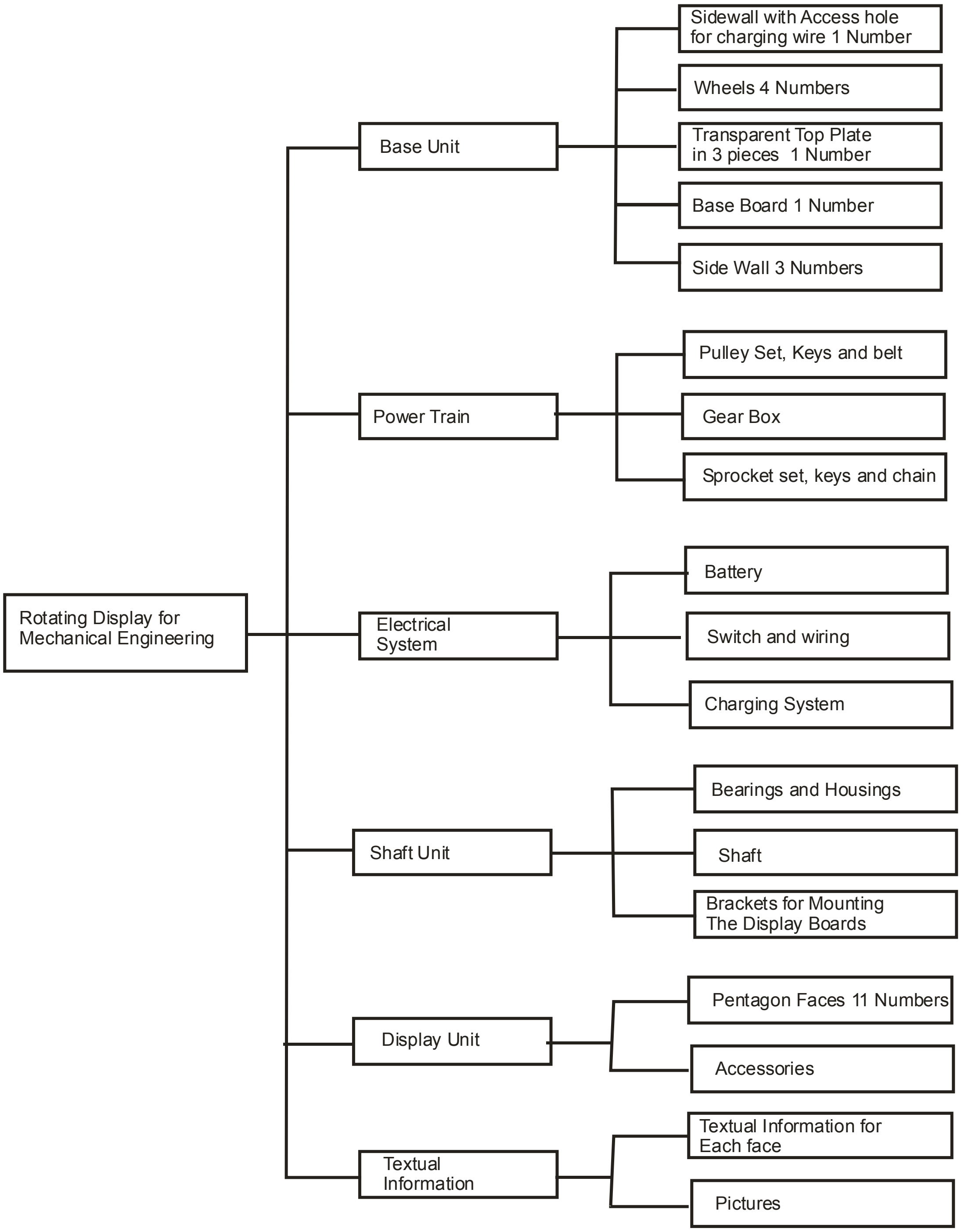

Figure 5: Parts Tree for the Rotating Display

3.2.1 Embodiment Design of the Mechanical System

The embodiment determining requirements for the mechanical system were identified as follows:

i. The entire display should be able to travel through standard doors
ii. The entire display should be able to travel in standard lifts so that they can go to different floors in commercial buildings and the university
iii. The unit should be able to function using standard single phase AC supply at 230volts and 50 Hz
iv. The output shaft should be at the center of the base so that the structure would be symmetric and aesthetically pleasing.
v. The base houses moving components and hence guards form an essential set of components.

In order to meet the above requirements the base dimensions were determined to be $1000\ mm \times 760\ mm$ and the layout was planned to be as the one shown in Figure 6.

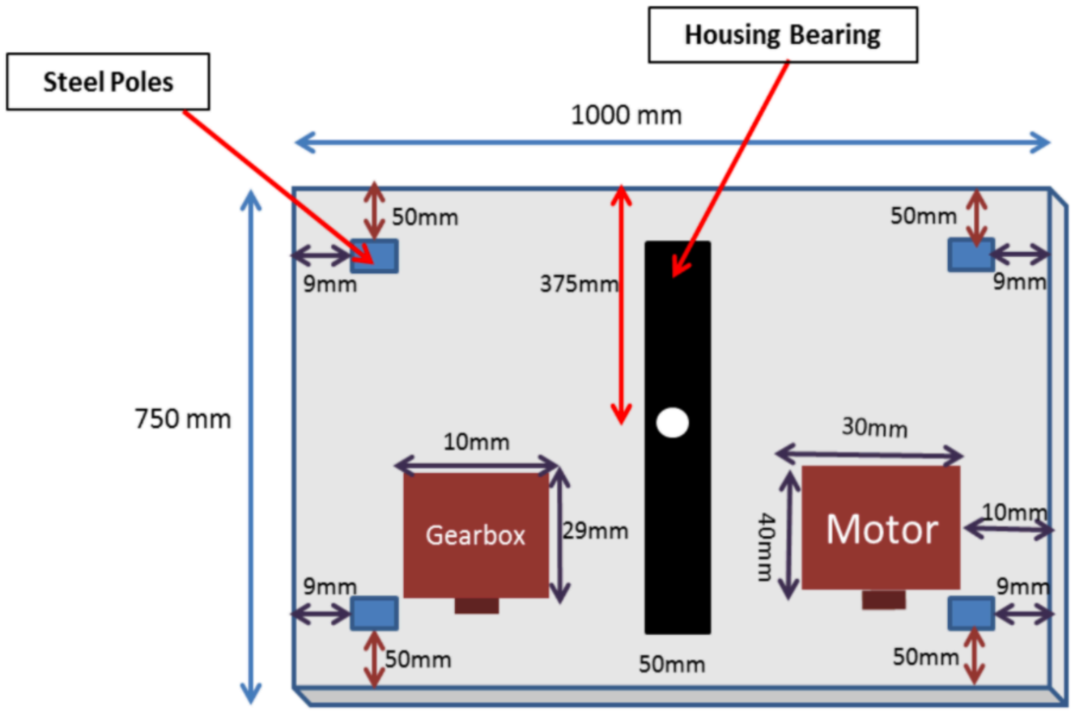

Figure 6: Plan View of the Layout

Material dimensions were fixed to coincide with those available in the market since the number of units to be produced is only one and the manufacturing cost would become very much higher for turning parts to user defined dimensions.

The power train design started with the purchase of a 1 kW AC motor whose power was nearer to that required to drive the display. The motor speed was 1400 rpm. The display was expected to run between 3 and 5 rpm. Thus the reduction required was in the region between 475 and 280. Such high reduction are possible only with worm and wheel gear boxes and due to its complexity it was decided to purchase a ready made worm wheel gearbox with a reduction of 1:100. Also it gave the output at right angle to the input, which was needed by the system. Now a further reduction in the range of 3 to 5 is needed. It is achievable in single or double stages. The students decided to go for a two-stage reduction. They made the right choice of having a low-tension high-speed belt system at the input side, and the high-tension low-speed chain system at the output side. The belt length and pulley sizes were chosen from available components in catalogues based on theoretical calculations. Similarly sprockets and chain were chosen from catalogue based on calculations. Interfaces with short shafts and keys and keyways completed the embodiment design of the base housing the drive system. The motor and the gearbox were installed on an adjustable frame that permits tensioning of the belt and chain during use. Figure 7 shows the completed base system.

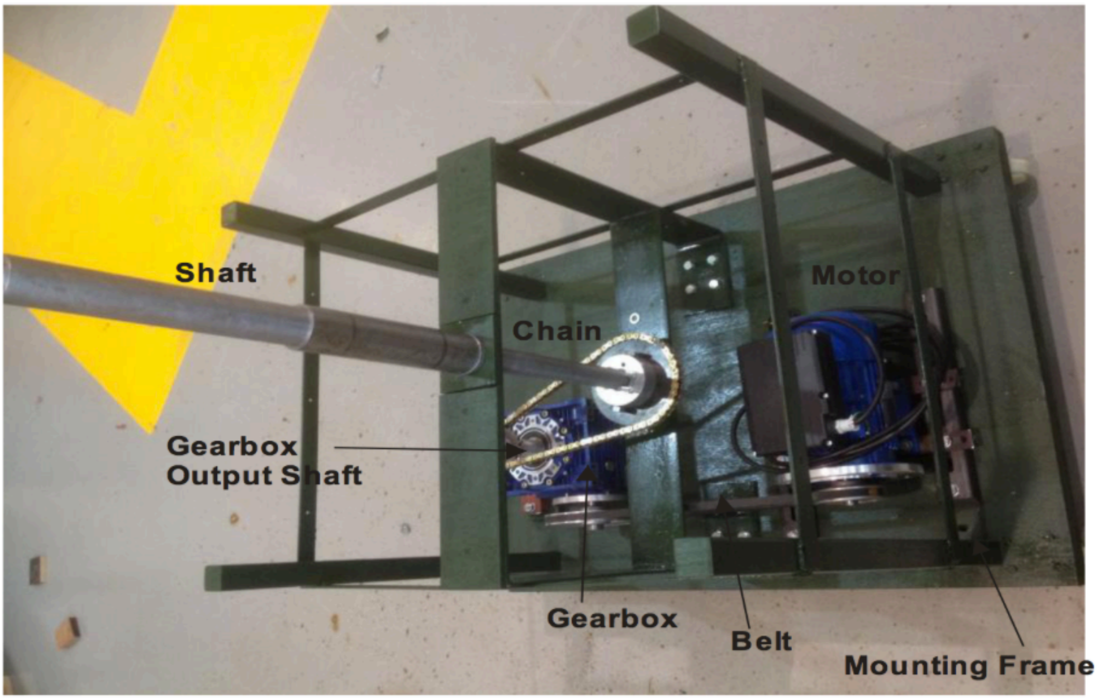

Figure 7: Completed Base System

3.2.2 Embodiment Design of the Display Unit

In the paper design the dodecahedron is a relatively easy figure. However it proved to be very challenging to the students. It required assembling 12 pentagons of appropriate size and joining them together. The first challenge was the connection of the wooden pentagonal faces with the adjacent ones. This required machining of the bounding faces of the joining pieces to form the required angle of the dodecahedron. Figure 8 shows the joining faces in a single panel.

Figure 8: Joining Faces in a Single Panel

Figure 9 shows the assembled pentagonal faces with the three wooden blocks holding the three adjacent face panels together.

The dimensions of the pentagon are controlled by the maximum assembled width of the dodecahedron and the maximum size of the wood that could be accommodated by the CNC machine, which was found to be 500 mm. The side of the pentagon at 300 mm meets these requirements.

Figure 9: Assembly of the Upper Half of the Dodecahedron

The top half of the dodecahedron was made of pentagons, which were 44 mm in thick while the bottom half pentagons were made of 18 mm thick wood. These were dictated by the sizes available in the market.

Manufacturing and fixing it to the shaft proved very challenging to the students. It required a lot of three-dimensional solid geometry. Even the three wooden blocks needed at each vertex were to be cut at the required angles. The next difficult challenge associated with the display unit was the transfer of the load to the shaft. An arrangement of a unit consisting of a spider, legs and ribs as shown in Figure 9 was developed to transfer the load. The spider was sitting on the shaft and spot welded to prevent rotation. A similar assembly for the bottom half is made and connected to the shaft before the top half was assembled. In order to gain access the top pentagon was removed during the assembling process. It was put in place as the last piece in the assembly. The handle that appears as an aesthetic part (refer Figure 10) was introduced to facilitate handling.

Figure 10: Completed Display Assembly

The load of the dodecahedron display and that of the shaft was transferred to the base and located in place by two bearings as shown in Figure 11.

Figure 11: The Load and Guide Bearings

3.2.3 The Detailed Design or the Engineering Calculations

A substantial number of calculations were needed to establish the system dimensions in both two and three dimensions. The individual component designs proved equally challenging. In addition there were calculations on the design of the individual machine elements, which include calculations relating to the pulleys, belt, keys and keyways, chains and sprockets, power transmission, power required to rotate a given load, combined stresses, bearing selection and reliability etc. In effect this was a complete application of almost everything the students learned in the Machine Design courses but in the excitement of the project the students did not feel it. Figure 12 shows the complete product.

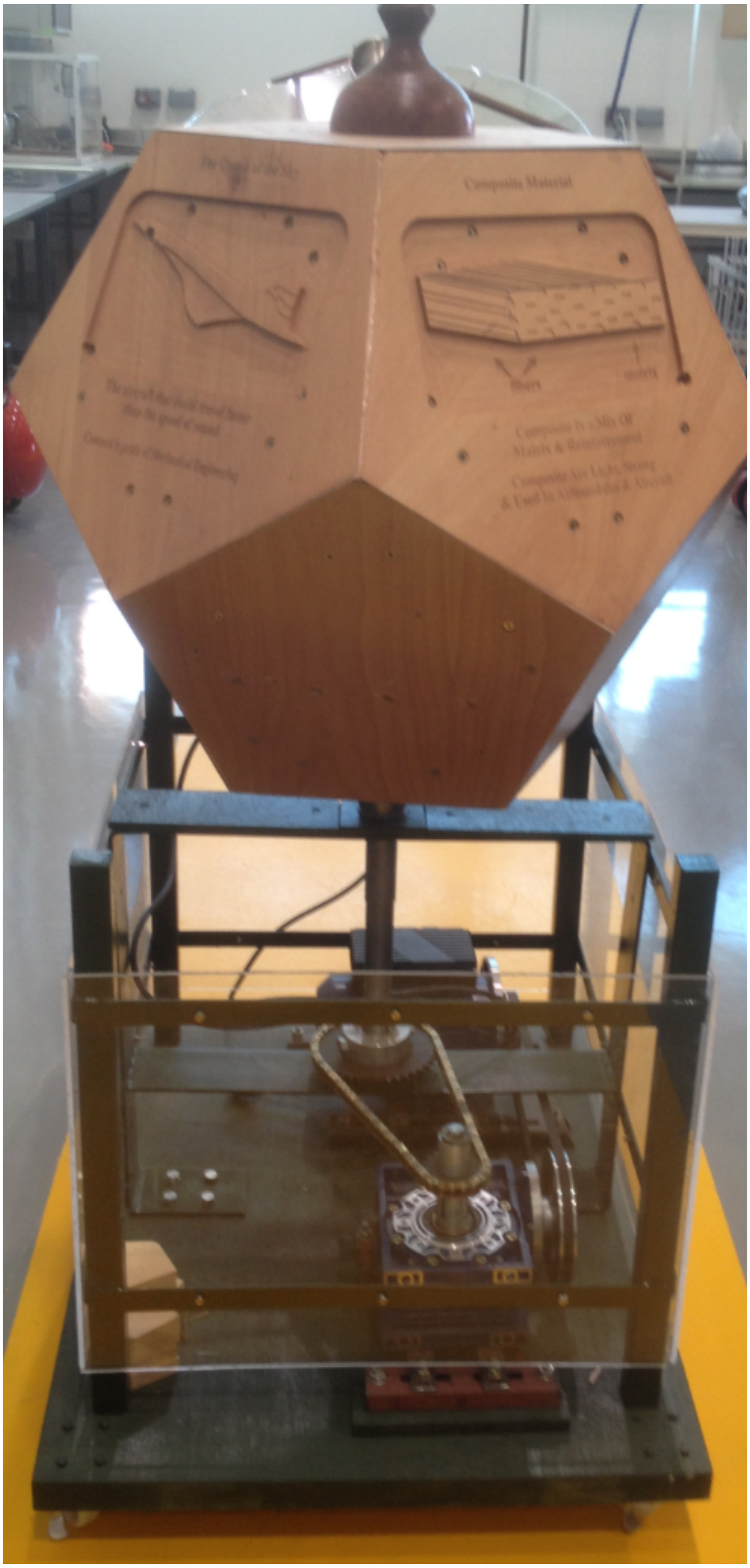

Figure 12: Complete Rotating Display

4 Analysis of the Learning Experience

The learning experience was analyzed in two perspectives (a) specific to the project and (b) in a broader generic approach as explained in the following sub-sections. The analysis presented here is carried out by the faculty members who were supervisors and advisers to the project, with an intention of continuous improvement.

4.1 Specific to the Project

With respect to the design process the initial reaction from the students was very dull. They did not see the connection between the stakeholder requirements and the product. But the relevance was clearly felt when they started looking for embodiment determining requirements to develop the embodiment design. Also they heavily depended on the targeted interim outputs at various stages of the design process. A design model with a preplanned list of outputs greatly facilitated the students to monitor and control their work.

At United Arab Emirates University the students meet a coordinator once in every fortnight and make a presentation on the progress. The students received a lot of inputs from a 'fresh pair' of eyes.

With respect to the objectives outlined in section 2 the students had experience to their hearts' content in incorporating many interdependent machine elements they learned in the machine design courses to form a mechanical system. Many a times and often the students said that they cleared many grey areas in their understanding by the applications in the project. Specific to the details, the students showed increasing commitment as they advanced into the project. The second semester work was more organized and was of better quality. This could be attributed to the better insight or accurate and deeper understanding they have gained as they progressed into the project. They have developed a significantly better understanding on the inter-related nature of the mechanical elements. They entered into more detailed discussion on the application of the machine elements rather than the calculations. For example the recommended minimum belt speed, if not followed the belt would be subjected to increased load and would get damaged quicker. There are several instances like this. The project has given them an awakening in the application side of the machine elements.

When choosing the five achievers and achievements for the display, the students suddenly realized the enormous number of contributions of mechanical engineering to civilization. They could appreciate the impact of engineering solutions of the past on society and this was clearly visible when they had opportunities to explain their project to the curious junior students who come to see their project. In one sentence their pride of their choice of mechanical engineering was visible in their eyes. On the amount of work and the magnitude of the work, the advisors felt that they have heavily under estimated the quantity of the work involved. The students really had to work very hard to complete the project. The main factor that contributed to the success of the project was the early understanding of the project and the tasks by the students. This greatly facilitated their time management.

4.2 Generic View of the Learning Experience

With the success of the project the authors wanted to look at the learning experience from a generic point of view and this section outlines some of the thoughts. From a generic point of view the learning experience can be analysed in the following way. Barron et al [5] have given a broad view of learning as a structured updating of system properties based on the processing of new information. Learning, as applied to engineering students, can be defined as the process of updating students' knowledge, skills and behavior. The presented capstone experience is a Project Based Learning method. Carmody and Berge[6] have argued that the most effective learning methods are those that engage six dimensions of human existence: physical, social, emotional, psychological, intellectual, and spiritual. These dimensions are adapted from the six dimensions of wellness model developed by Bill Hettler [7]. These dimensions are found to be useful in examining individual's experience. Carmody and Berge have used this dimensional model to compare four contemporary methods of online teaching and learning. Table 2 shows how the same six dimensional model can be used to analyse the presented learning experience.

Table 2: Project Analysis in Accordance with the Six Dimensional Model

Model by Carmody and Berge [6]	Model applied on the project
Social - Activities or processes relating to people, such as personal interactions, relationships, and communication; also the perception of being a valued contributor as well as a supporter of group activities.	The project is to show the contribution of the mechanical engineers in the society. The project will be used to demonstrate such contribution. This should stimulate each individual student to contribute in the work.
Emotional - This element addresses issues relating to personal feelings and those activities or processes involved in self-identity and self-regard and promoting individual security.	This project is very strong in the self-identification for the mechanical engineering students. The display type is the element that is used to encourage students' emotion to support working and fulfilling the requirement of the project.
Psychological - Activities that engage or utilize mental processes and behaviors; this element especially pertains to the expectation of outcomes and the realization of those outcomes in activities whereby understanding/meaning is derived.	Large part of the project requires fundamental understanding of the mechanical design and related subjects. Students have to perform all requirement component design calculation to complete the project.
Intellectual - Activities or processes requiring the use of the mind; especially relating to critical or higher order thinking.	The engineering design process includes many steps that requires critical thinking and high level engineering thinking to achieve the course outcome.
Spiritual - Activities or processes relating to the spirit, the non-tangible or non-material, and the search for subjective meaning or intrinsic value.	These type of projects create encouraging environment for student erudition and promote advancement.
Physical - Activities or process relating to the body; also physical security, skills, competencies, biological processes, behaviors, tangible assets and work environment.	In this project students have to be physically engaged. In fact almost all steps in this project are simply physical activity. It requires skills and competence in all project details. The instructor monitors the distribution of the individual and group physical tasks to insure that all members are involved.

5 Lessons Learned and Conclusions

As lessons the following can be said:

i. A clearly defined design model and a list of interim outputs helped the students to exercise self-monitoring and control by students on their project.
ii. The coordinator's role as viewing with a fresh pair of eyes greatly enhanced the student learning.
iii. Letting the students to choose the historical achievers and achievements woke the students up to realize the magnanimity of mechanical engineering. This contributes to the school of thinking, which states that Social History of Engineering should be taught as part of the curriculum.
iv. The project has again demonstrated that designing and building is one of the best methods to teach mechanical engineering. It has cleared many theoretical doubts from the students' minds and made them confident.

As conclusions the following can be said:

i. Machine design can be made interesting by projects that are application oriented. When the students are enthusiastic on the project the complex procedures and calculations would become easy for them.
ii. Students get attracted to Mechanical Engineering when they see applications that directly use what they learn in the classes. When the product was in the assembling stage it attracted several other student visitors to see the product.
iii. Directing the students to learn the impacts of landmark engineering products like the Model T car, fascinated many young students and made the mechanical engineering students to feel proud about their specialization.

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