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# LEGO BASED LOW COST TEACHING FOR ENHANCING MANUFACTURING EDUCATION

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**LEGO Based Low Cost Teaching For Enhancing Manufacturing Education**

**Synopsis**:

The United States to maintain its role in technology and innovation, Manufacturing industries provide an important foundation in ensuring the world leadership. According to a skills gap report conducted by the Manufacturing Institute and Delloitte consulting, critical concerns were addressed on the potential of the manufacturers to fill the positions required for manufacturing settings that require post secondary education with a deficit of Science, Technology, Engineering and Mathematics (STEM).

# LEGO based Low Cost Teaching For Enhancing Manufacturing Education

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**Abstract**

The United States to maintain its role in technology and innovation, Manufacturing industries provide an important foundation in ensuring the world leadership. According to a skills gap report conducted by the Manufacturing Institute and Delloitte consulting, critical concerns were addressed on the potential of the manufacturers to fill the positions required for manufacturing settings that require post secondary education with a deficit of Science, Technology, Engineering and Mathematics (STEM) skills. This portrays that the future of manufacturing industries is strongly dependent on STEM education. In this paper, a LEGO based teaching and project approach used to enhance student's technical skills in manufacturing, at The University of Texas, El Paso is introduced. The authors of this paper are aimed at integrating concept-based learning via hands on student projects into the manufacturing engineering curriculum at University of Texas El Paso to cultivate leaders in the fields of manufacturing especially among Hispanic and minority students.

## 1. Introduction

Manufacturing industries always positively enabled and helped in driving economy and in improving standards of our country. Manufacturing sector plays an important role in providing necessary infrastructure and tools such as improved machinery, materials and similar others for development across various sectors [1].
Several developing countries are leaping into the continuum of manufacturing as it helps in rising standards, for example, India currently continues to build its manufacturing industries with an aim to raise its manufacturing economy from the current 16 percent to a projected 25 percent by 2022 [1][1 ref 1]. According to a report from McKinsey and Company on Global growth and Innovation in manufacturing future, as of 2010 United States maintains its leadership position among the largely developing manufacturing economies [1]. The Manufacturing Institute and Deloitte in their third Skills gap study on manufacturing stress upon the fact that over the coming decade there will nearly be a three and a half million manufacturing jobs to be filled with an expected skills gap of around almost 2 million jobs to go unfilled [2]. In identifying the deficiencies, lack of problem solving, basic technical training, math skills, technical skills and computer skills were the main gaps observed [2].

This portrays the importance of creating a pool of emerging workforce embedded with manufacturing skills such as engineering, skill trades and production to prove critical in meeting the current competitiveness. To address this, the authors take a concept based teaching approach using LEGO based renewable energy kits in disseminating the concepts of manufacturing. Green Energy Manufacturing is one of the curriculum courses established in the Industrial Manufacturing and Systems Engineering Department at The University of Texas at El Paso. The core objective of the class is to introduce the students to fundamental concepts of Green Manufacturing. The authors to introduce concept based learning in this class, initial effort was required on identifying the core objectives of the class and on what the students are expected to learn. The next step was in identifying specific manufacturing related concepts that could be realized using simple student projects utilizing LEGO Renewable Energy Wind turbine kits. Included were the notions and ideas about: *Design Structured Matrix (DSM), Design for Assembly (DFA) vs. Design for Disassembly (DFD), Failure Mode Effect Analysis (FMEA),* and *Learning DFD Concepts through LEGO® based Project.* The following sections in this paper explain on how students used LEGO based renewable kits in realizing class-learning objectives.

## 2. Concept based Teaching for Manufacturing

Student teams were given a Lego Builders Kit with which they had to build a wind turbine and document each step of the process to improve every aspect possible of the assembly process. Using the concepts disseminated in the Green Energy Manufacturing class, students dissected the assembly process and decomposed the most basic assembly steps in an attempt to optimize the manufacturing process of the LEGO wind turbine. Concepts of Design for Manufacturing (DFM) were also used to consider all the possible scenarios during the assembly process early in the design stage. This translated to savings in team training; savings on rework operations (due to the complexity of the assembly process) and increase the volume production in less time.

### Creation of Design Structure Matrix

The design structure matrix is one of the many tools that can be found and used in engineering in order to make a system or process run as smoothly and optimal as possible. It helps analyze, and plan a project using the relationships between the subsystems of said system, project, or process.

<u>Scenario analysis</u>

A scenario analysis was done using design structure matrix based on the assembly method documented under the LEGO wind turbine kit. The relationship between LEGO kit components is referenced as shown in figure 1. The team used DSM in order to ensure the optimal assembly and disassembly processes of LEGO wind Turbine. This helped the teams to

- Revisit tasks arrangement.
- Keep interdependent tasks; separate tasks can cause considerable waste.
- Reduce information exchanges.
- Break down coupled tasks into smaller sets by changing task specifications.

| Element Name | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 pin block | 1 | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | | | | | | | | | |
| 4 pin doble flat | 2 | 1 | 2 | 1 | | | | 1 | | | | | | | | | | | | | |
| 4 pin single flat | 3 | | | 3 | | | | | | | | | | | | | | | | | |
| black pin | 4 | 1 | | | 4 | | | 1 | | | | | | 1 | | | | | | 1 | 1 |
| Generator | 5 | 1 | | | | 5 | | 1 | 1 | | | 1 | | | | | | | | | |
| 5 length acces | 6 | | | | | | 6 | | 1 | | | | | | | | | | | | |
| access support | 7 | | | | | | 1 | 7 | | | | | | | | | | | | | |
| 2 pin block | 8 | | | | 1 | | | | 8 | | | | | | | | | | | | |
| 8 pin block | 9 | | | | | 1 | | | 1 | 9 | | | | | | | | | | | |
| counter weith | 10 | 1 | 1 | 1 | | | 1 | | | | 10 | | | | | | | | | 1 | 1 |
| 8 length access | 11 | | | | | 1 | | 1 | | 1 | 1 | 11 | | | | | | | | 1 | |
| roler wheel base | 12 | 1 | | | | | | | | | 1 | | 12 | | | | | | | | |
| roler blue pin | 13 | | 1 | | | | | 1 | | | 1 | | 1 | 13 | | | | | | | |
| L block | 14 | | | | | 1 | | | | 1 | | | | | 14 | | | 1 | | | |
| gold pin | 15 | | | 1 | | | | 1 | | | 1 | | 1 | | | 15 | | | | | |
| Blades | 16 | 1 | | | | | 1 | | | 1 | | 1 | | 1 | | | 16 | | | | |
| roler lock | 17 | | | 1 | | 1 | | | | | | | | 1 | | | | 17 | | | |
| 15 white block | 18 | | | | | | | | 1 | 1 | | | | | 1 | 1 | 1 | | 18 | | |
| 4 access coupling | 19 | | | | 1 | | 1 | | | | 1 | | | | | | 1 | | 1 | 19 | 1 |
| 6 access coupling | 20 | | 1 | 1 | 1 | | | 1 | 1 | 1 | | 1 | | | 1 | | | | 1 | 1 | 20 |

Figure 1: LEGO kit DSM

**Assembly Process of LEGO Wind Turbine**

With the purpose of observing the assembly process of the Lego Wind Turbine, several experiments were conducted based on the modularity concept. The teams were limited to conduct only test trials before conducting the experiments to avoid a leaning effect. The optimal solutions given by the different cases were analyzed and discussed in the following sections.

## 2.1 Assembly Trial -1

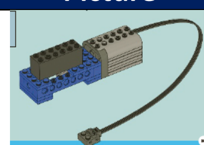
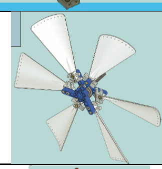
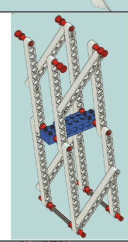
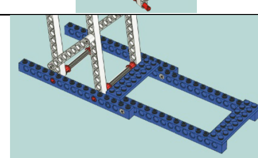
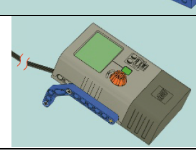
### 2.1.1 Material Handling

While assessing material handling, opening of the material packaging was time consuming for the operator.

*Figure 2: First encounter with the Lego materials*

This time constitutes to about 25+ minutes, much of the time spent was on finding individual components. Figure 1 shows the material acquisition process.
Once the process of obtaining the individual pieces was completed, the operator proceeded to arrange the individual pieces for the manufacture of the wind turbine in the provided white slot case (provided with the kit.) in no certain pattern. The operator's determined that just 117 pieces were needed out of the 300+ pieces provided in the kit. Sorting would have aid the operator to reduce unnecessary time spent finding for pieces while assembling. Table 1 shows the quantity of pieces required for the assembly to be completed.

*Table 1: Subcomponent item quantity*

| Subcomponent | Picture | Pieces |
|---|---|---|
| Turbine |  | 19 |
| Blades |  | 34 |
| Support Tower |  | 45 |
| Base |  | 9 |
| CPU |  | 10 |

**2.1 .2 Assembly Process**
The following diagram shows the process used in the assembly of the Lego wind turbine. The order of assembly is seen in Figure 3.


*Figure 3: Assembly process, as directed in the Lego Instructional book*

The operator satisfactorily completed the wind turbine system within 36 minutes. Most of the lost time was contributed to rework, improper material acquisition and dealing with unclear directions from the instructional manual. The following table shows a broad time analysis of assembly for the system. As seen in table, the time taken to fully complete the wind turbine assembly is 35 minutes and 41 seconds.

*Table 2: Assembly times for the wind turbine Lego system*

| Assembly Trial 1 | | | | |
|---|---|---|---|---|
| Component | Pieces | Completion Time | Assembly Time | % of Assembly Time |
| **Turbine** | 19 | 0:02:32 | 0:02:32 | 7% |
| **Blades** | 34 | 0:14:36 | 0:12:04 | 34% |
| **Tower** | 45 | 0:28:40 | 0:14:04 | 39% |
| **Base** | 9 | 0:30:30 | 0:01:50 | 5% |
| **Computer** | 10 | 0:34:22 | 0:03:52 | 11% |
| **Assembly** | 5 | 0:35:41 | 0:01:19 | 4% |

39% of the overall assembly time was spent building the tower. The tower required the most amount of work by the operator and the reason is because the operator is required to count holes in the tower support to make an assembly. This is just one observation noticed in the assembly process that will significantly reduce assembly process in several Trial(s).

**2.2 Second Lego Assembly Trial**

**Application of Lean Tool for Time Optimization (Second Trial)**

To improve assembly time, the team introduced lean manufacturing tools in the process. One of them is 5s, which aids in reducing the time the operator takes to complete the tasks by sorting, straightening, standardization, shining and sustaining.

**2.2 Material Handling**

Figure 3 shows a view of the material organization using 5S system; items were organized and sorted for a single operator single line assembly process. Components were sorted by size and type for ease of identification by the operator and time reduction.

*Figure 4: Material Organization using lean methods: 5S*

### 2.2.3 Assembly Process

The following Table shows accumulative time and sub-component assembly time required for the assembly process in the second trial. Most of the assembly time was allocated in the tower assembly. The tower is the most complex item in the system therefore having the greatest time of assembly.

*Table3: Assembly times for the wind turbine Lego system for Trial 2*

| Assembly Trial 2 | | | | |
|---|---|---|---|---|
| Component | Pieces | Completion Time | Assembly Time | % of Assembly Time |
| **Turbine** | 19 | 0:02:00 | 0:02:00 | 6% |
| **Blades** | 34 | 0:05:43 | 0:03:43 | 10% |
| **Tower** | 45 | 0:12:47 | 0:07:04 | 20% |
| **Base** | 9 | 0:15:13 | 0:02:26 | 7% |
| **Computer** | 10 | 0:16:50 | 0:01:37 | 5% |
| **Assembly** | 5 | 0:17:46 | 0:00:56 | 3% |

Inspection of each subcomponent was completed once the operator completed the assembly. This inspection time did not contribute to the assembly time. Once a subcomponent was inspected, the operator proceeded with the next assembly job.

To increase the accuracy of the analysis, the team removed negative times. This represents time in which the operator moved pieces unnecessarily, reworked assembly processed and excessive time reading the instructional manual. Once the unnecessary times were neglected, the team proceeded to divide sub-components into modules. With this data, the following schedule in a single operator, single assembly line was developed.

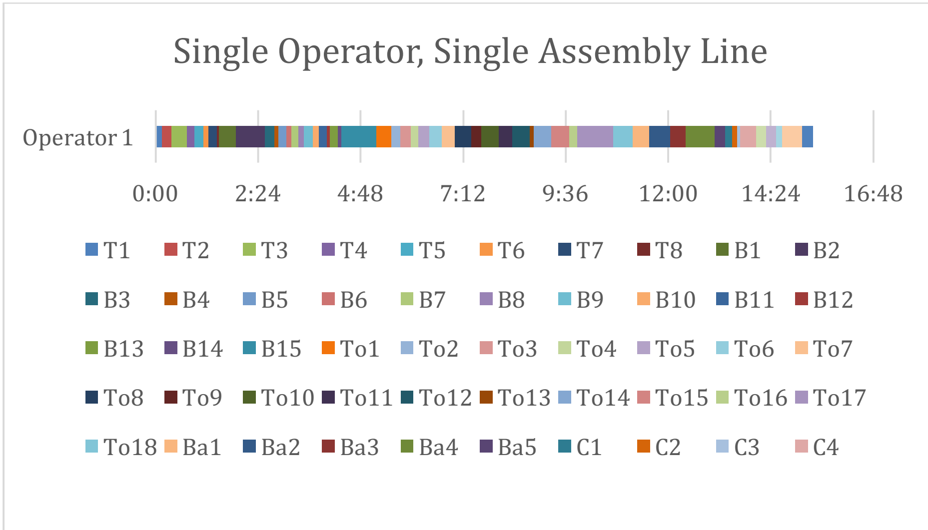



*Figure 1: Single operator, single assembly line timeline*

Analysis of costs and performance for the single operator and an inspector are shown in the following table. As a standard measure, the team assumed an hourly rate of $10.00 for an operator and $12.00 for an Inspector as indicated by Indeed.com for El Paso, Texas (Indeed.com, 2013). The cost to assemble a wind turbine by traditional methods currently is $2.96 and 3.4 wind turbines are produced in an hour.

*Table4: Traditional assembly costs*

| | Time of assembly (minutes) | Hourly Rate | Units per hour | Production cost per unit | Unit cost per unit with inspection |
|---|---|---|---|---|---|
| Operator 1 | 17.77 | $ 10.00 | 3.4 | $ 2.96 | $ 6.52 |
| Inspector | Up to 5 per hour | $ 12.00 | | | |

### 2.2 Optimization of Assembly Process

In order to set up goals in our optimization section, the team assumed that the process involved the following:

1. The manufacturing process involves an operator and an inspector
2. There will be analysis and optimization of material handling and assembly process
3. Optimization of the analysis will focus in reducing time of assembly, material selection, material organization and manufacturing costs.

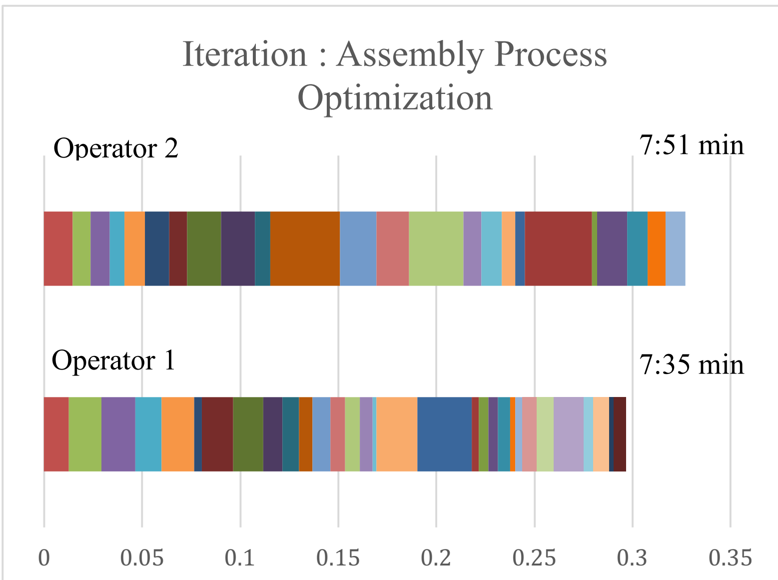
Limitations and constraints of work are:

1. Analysis of work performed by the engineers involved in the manufacturing sector
2. Manufacturer layout

Goals for the optimization process:

1. Increase productivity by 100%
2. Reduce production cost by 30%
3. Introduce random sampling to increase the limits of the inspection process

The team managed to develop an optimal assembly process between two operators that correlate to the goals that were set up by the team. The following diagram shows the accumulative time both operators will take in order to complete the entire assembly.




| Operator 1 | |
|---|---|
| Module | Time |
| To7 | 0:18 |
| To8 | 0:24 |
| To10 | 0:25 |
| To11 | 0:19 |
| To12 | 0:24 |
| To13 | 0:06 |
| Ba1 | 0:23 |
| Ba3 | 0:22 |
| B3 | 0:14 |
| B5 | 0:12 |
| B7 | 0:10 |
| B9 | 0:13 |
| B11 | 0:11 |
| B13 | 0:11 |
| T1 | 0:09 |
| 3 sec iddle | 0:03 |
| Ba2 | 0:30 |
| Ba4 | 0:40 |
| B4 | 0:05 |
| B6 | 0:07 |
| B8 | 0:07 |
| B10 | 0:09 |
| B12 | 0:04 |
| B14 | 0:05 |
| T4 | 0:11 |
| T5 | 0:12 |
| T3 | 0:22 |
| T6 | 0:07 |
| T7 | 0:12 |
| T8 | 0:03 |
| Sys1 | 0:09 |
| Sys2 | 0:28 |

| Operator 2 | |
|---|---|
| Module | Time |
| To1 | 0:21 |
| To2 | 0:13 |
| To3 | 0:14 |
| To4 | 0:11 |
| To5 | 0:15 |
| To6 | 0:18 |
| To9 | 0:13 |
| To14 | 0:25 |
| To15 | 0:25 |
| To16 | 0:11 |
| To17 | 0:51 |
| To18 | 0:27 |
| B1 | 0:24 |
| B2 | 0:40 |
| T2 | 0:13 |
| Ba5 | 0:15 |
| C1 | 0:10 |
| C2 | 0:07 |
| B15 | 0:49 |
| C3 | 0:04 |
| C4 | 0:22 |
| C5 | 0:15 |
| C6 | 0:13 |
| Sys3 | 0:15 |

*Figure 6: Assembly Process Optimization*

This optimization yields the following result table, in terms of cost and productivity.

*Table 5: Optimization Assembly costs and productivity*

| | Time of assembly (minutes) | Hourly Rate | Units per hour | Production cost per unit | Unit cost per unit with inspection |
|---|---|---|---|---|---|
| Operator 1 | 7.85 | $ 10.00 | 7.6 | $ 2.62 | $ 4.19 |
| Operator 2 | 7.85 | $ 10.00 | | | |
| Inspector | No Limit | $ 12.00 | | | |

With the introduction of random sampling, the inspector limit was removed and there was no need to hire an extra inspector to check for the increase of productivity. Productivity increased from 3.4 to 7.6 units; this is a 126% increase, surpassing the team's goal of 100%. Production costs were reduced from \$6.52 to \$4.19 resulting in a reduction of 36%, well under the team's goal of 30%.

**Disassembly Process of LEGO Wind Turbine**

Figure 7 shows the operator initiating the separation of the components for disassembly and identification of pieces for recycling (i.e. plastic Lego pieces, hard plastic and copper wire) and those that will head to disposal.

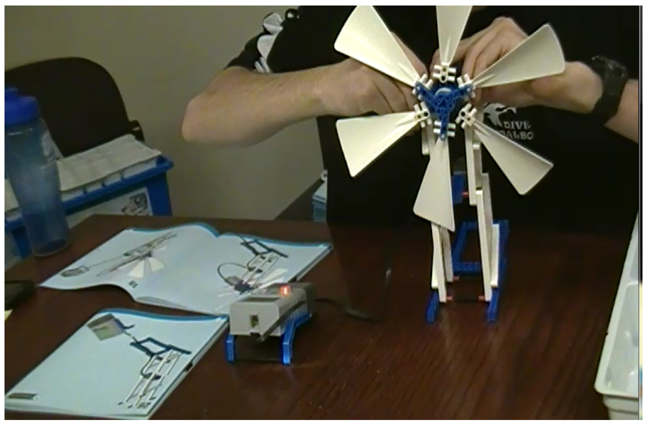


*Figure 7: Wind turbine assembly ready for disassembly*

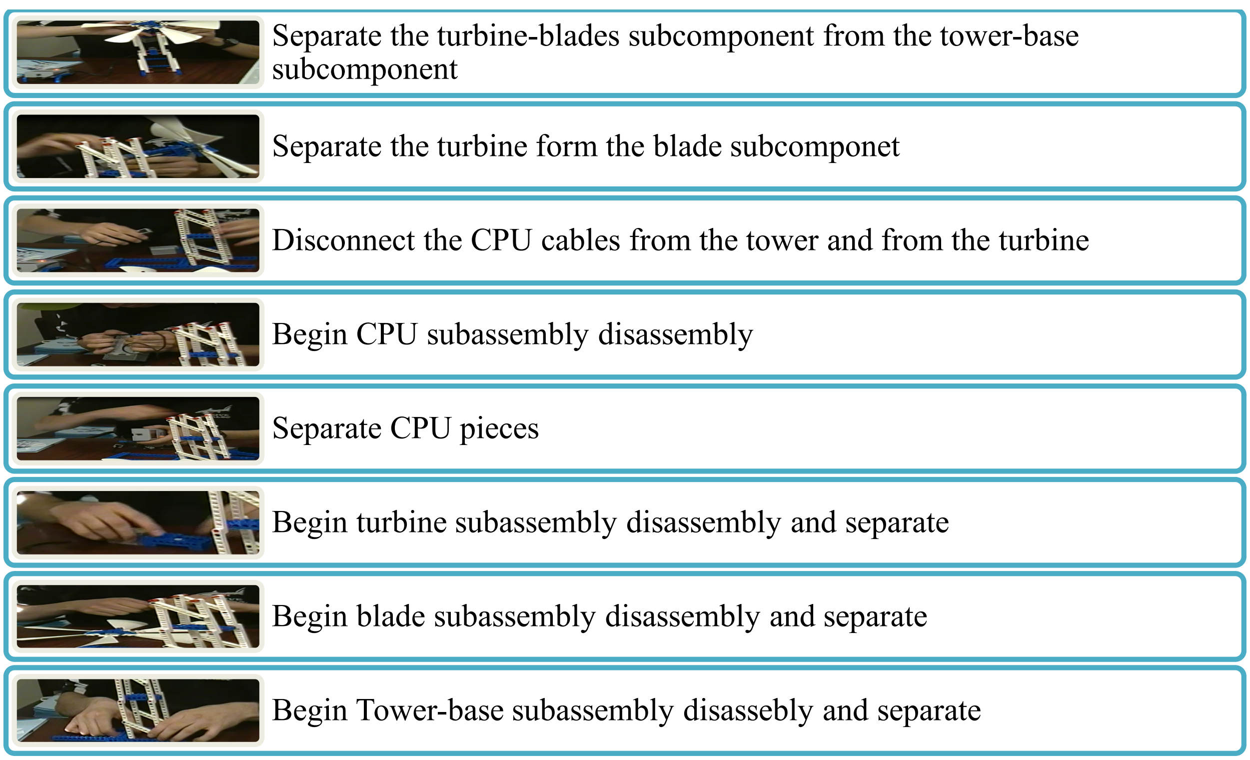



*Figure 8: Disassembly process*

Figure 8 shows the process of disassembly that the operator performed. The operator divides the components in four piles: (1) Lego pieces, (2) Cables, (3) hard plastics and (4) others.  Time for the disassembly process is shown in the following table 8. The entire process took almost 9 minutes.

*Table 8: Disassembly time analysis*

| | Start | Finished | Time |
|---|---|---|---|
| Turbine-tower | 0:36 | 0:59 | 0:23 |
| Turbine-tower | 0:59 | 1:05 | 0:06 |
| Cables | 1:05 | 1:25 | 0:20 |
| CPU | 1:25 | 1:59 | 0:34 |
| Turbine | 1:59 | 3:44 | 1:45 |
| Blades | 3:44 | 6:22 | 2:38 |
| Base | 6:22 | 7:15 | 0:53 |
| Tower | 7:15 | 9:19 | 2:04 |
| | **Total** | | **8:43** |

**Conclusion**

The completion of the projects provided the team valuable experience in manufacturing systems. During the assembly process of the LEGO wind turbine, the team was exposed to common difficulties in manufacturing settings such as the lack of component labeling, deficiency in training, vague instructions and inadequate organization of materials. The enforcement of the lean manufacturing tool of 5s: sorting, straightening, standardization, shining and sustaining, an improvement in time taken by the operator in the assembly process was noticeable reduced, as well as the cost. The lack of training and acquaintanceship of the components, definitively affects any manufacturing process. With the introduction of component specifications, and standard operating procedures, the operators in charge of each process would improve their performance. This paper provides a first attempt by the authors in using low cost platforms such as a simple LEGO based wind turbine for concept based classroom teaching in imparting manufacturing skills to the future workforce. The authors plan to build upon their experience working with student teams in finding an effective way of using low cost platforms such as portrayed in this paper for efficiently disseminating the concepts currently used in manufacturing industries.

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