AC 2010-2309: DESIGN FOR ASSEMBLY IN MANUFACTURING ENGINEERING TECHNOLOGY PROGRAM: EXPERIENCE AND SUCCESS

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Design for Assembly in Manufacturing Engineering Technology Program: Experience and Success

Abstract

This paper discusses various aspects and models of how Boothroyd Dewhurst's Design-For-Assembly (DFA) methodology can be integrated into Manufacturing Engineering Technology (MET) curricula. The DFA methodology involves a team that includes all the concurrent engineering disciplines and the stakeholders in the success of the product design phase. Manufacturing engineers usually play a vital role in the conceptual design phase. In order to educate the next generation of manufacturing engineers, we introduced and integrated the DFA methodology into our MET curricula. A detailed description of this model, including advantages and disadvantages, future directions and recommendations, are included.

Keywords: design for assembly, active learning, product design

Introduction

In recent years, there is a constantly growing need for manufacturing engineers possessing both design and manufacturing knowledge [2,3]. Shortages of design expertise and manufacturing experience often result in a low level of assemblability and manufacturability of product design [6,7]. Unfortunately, best manufacturing practices and design expertise are hard to disseminate to designers. To effectively disseminate and reuse this valuable knowledge, design and manufacturing departments need quantitative feedback mechanisms such as Design for Assembly methodology. Inevitably, our MET students need to learn how to generate quantitative feedback from manufacturing engineers to design engineers in the early design phase.

A designer usually spends 25-30% of design time searching previous product design and its related manufacturing information [6]. The assemblability of product designs could be drastically improved by using a good DFA method and tool. As the design team conceptualizes alternative solutions, it should give serious consideration to the ease of product assembly or subassembly. In order to teach our MET students to communicate with design engineers effectively and efficiently, Boothroyd Dewhurst's DFA methodology was introduced to accelerate ideas and exchange and generate alternative solutions. By using the DFA method, the students learned how to: (1) collect basic assembly information, (2) estimate part handling and insertion time, (3) calculate assembly efficiency, (4) identify assembly difficulties, and (5) generate alternative solutions. This paper proposes a structured problem-solving approach called DMAIC to develop a DFA learning model. The goals of this model are to:

1. Provide the students a clearly defined procedure for evaluating and improving product assembly efficiency,
2. Offer an active learning environment and motivate the students to practice their knowledge,

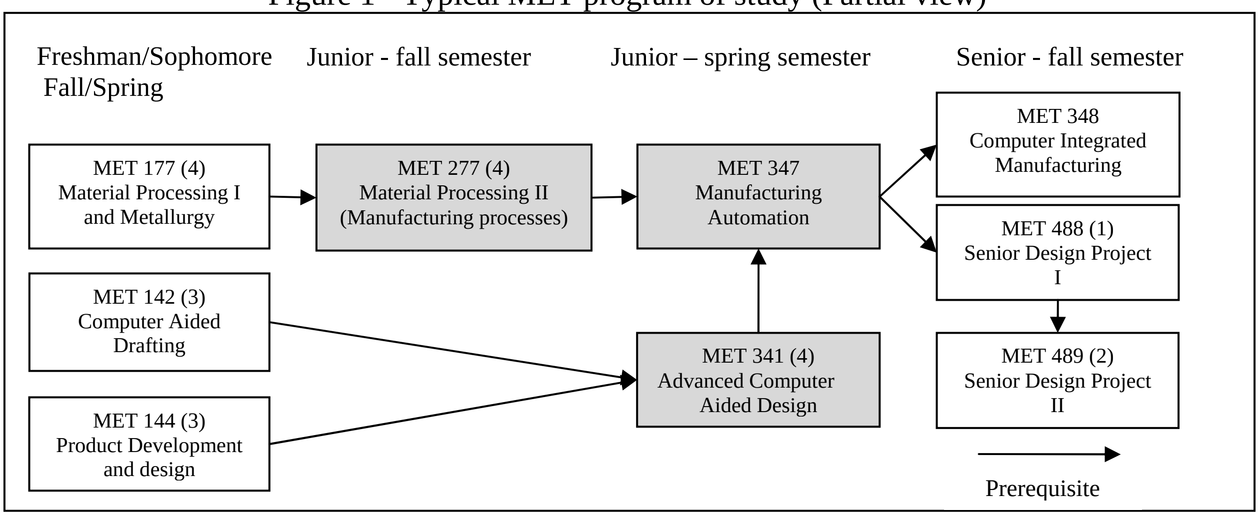
3. Guide the students to simplifying the product through a comprehensive consideration and instant feedback in both manufacturing and design viewpoints ,
4. Encourage the students to investigate new ideas and welcome new solutions, and
5. Help the students create alternative designs

By applying the DFA model, the students can systematically develop their own designs and identify many assembly difficulties. This paper also offers a clear example of improving product assembly efficiency.

Overview of Manufacturing Engineering Technology (MET) program at MSU

Many Manufacturing Engineering Technology (MET) curricula include both product design and manufacturing processes courses. These courses typically focus on different product realization processes and manufacturing process analysis, which often involve a lot of design and manufacturing issues and theoretical concepts. At Minnesota State University (MSU), Mankato many design and manufacturing projects attempt to provide the students opportunities to practice their design for assembly knowledge and build their own product assembly. In recent years, about 30 students in our program involve our DFA project every year. All of the students are given foundational DFA concepts, principles, and methodologies of the engineering disciplines during the first two years. They have to finish their study of Material Processing I, Computer Aided Drafting, and product development and design courses before they are accepted by the program (see figure 1).

Figure 1 - Typical MET program of study (Partial view)



In order to verify that the students meet the program outcomes, the DFA project has been utilized to help them practice their DFA knowledge and continuously improve our student learning environment. The supporting evidence in table-1 shows the relationship between ABET criterion 2 outcomes a-k and DFA learning outcomes. As we continue to use and improve this project, we expect that the DFA learning outcomes will meet ABET criterion 2 perfectly. Additionally, we will utilize more surveys to assess the effectiveness of the project.

Table 1 - DFA learning outcomes, program outcomes and ABET criterion 2 mapping

DFA Learning Outcomes	ABET Criterion 2 Outcomes a-k	*MET Program Outcomes	DFA Learning Outcomes	ABET Criterion 2 Outcomes a-k	*MET Program Outcomes
Analytical Ability	a,c,f	1,2,4	Oral Communication	e,g	6
Teamwork	e,f	6,7	Written Communication	e,g	6
Project Management	b,e	6,7	Visual Communication	e,g	6
Math Skills	b	3	Creative Problem Solving	d	1,2
System Thinking	d,e	4	Ethics and Professionalism	a,i	8
Self-Learning	h	5	Technology Skills	a,f	1,2
Respect for diversity	j	8	Continuous improvement	k	4

Note: ABET Criterion 2 Program Outcomes – Students will have:
a. an appropriate mastery of the knowledge, techniques, skills and modern tools of their disciplines;
b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology;
c. an ability to conduct, analyze and interpret experiments and apply experimental results to improve processes;
d. an ability to apply creativity in the design of systems, components or appropriate to program objectives;
e. an ability to function effectively on teams;
f. an ability to identify, analyze, and solve technical problems;
g. an ability to communicate effectively;
h. a recognition of the need for, and an ability to engage in lifelong learning;
i. an ability to understand professional, ethical and social responsibility;
j. a respect for diversity and knowledge of contemporary professional, societal and global issues; and
k. a commitment to quality, timeliness, and continuous improvement.
***MET program outcomes:** http://cset.mnsu.edu/met/about/outcomes.html

Proposed learning model for DFA methodology

Research has shown that problem-based learning is an exceptionally effective learning activity.

Table 2 – Design for Assembly principles and Guidelines

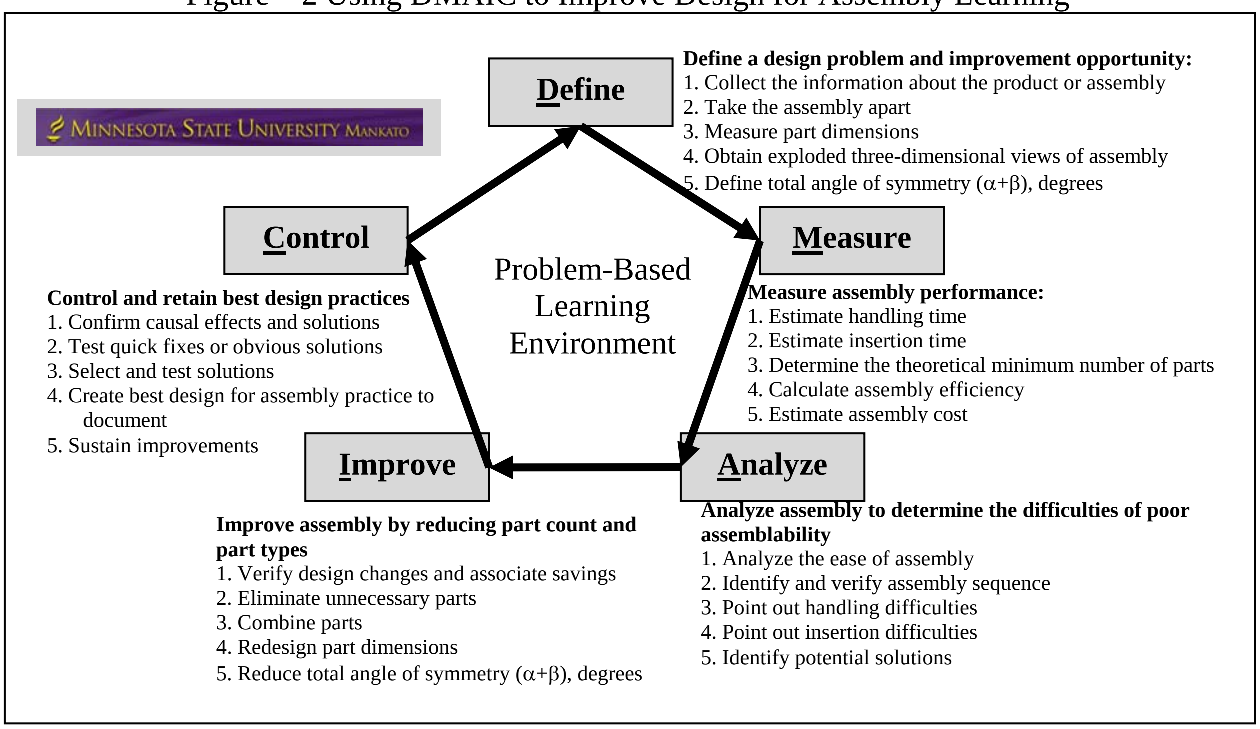
DFA Principles	IE Improvement Approach, ECRS	DFA assessment Guidelines	BDI assessment items
Simplify and reduce the number of parts	Eliminate, Combine	1.Reduce part count and part types 2.Eliminate separate fasteners 3.Standardize features and use standard parts 4.Check all parts for function and modify the design to eliminate redundant parts	Theoretical minimum parts: -Relative movement -Different materials -Separate for all other assembled parts
Design for ease of assembly	Combine, Rearrange, Simplify	1.Ensure adequate access and unrestricted vision 2.Design part assembly downward motion 3.Minimize part variation 4.Design for assembly motions that -can be done with one hand -do not require skill or judgment 5. Eliminate adjustments (no cable, conduits, …)	-Total angle of symmetry (α+β) -Easy to grasp and manipulate -Self-aligned and self-located -Adequate access and unrestricted vision -Part size and thickness -One hand & no additional tools -No Adjustment
Design parts for easy handling	Simplify, Symmetrize,	1.Minimize the need for reorientations during assembly 2.Design parts for easy handling (Ex: self-aligning & self-locating) 3.Ensure the ease of handling of parts from bulk 4.Maximize part symmetry if possible	-Grasping tools &/or aid required -Total angle of symmetry (α+β) -Part size and thickness -One hand & no additional tools -Easy to grasp and manipulate
Design parts for easy insertion	Combine, Rearrange, Simplify	1.Use insertion motions that are simple (top-down) 2.Avoid simultaneous operation 3.Design for efficient joining and fastening 4.Make parts obviously asymmetrical	-Secured immediately or not -Adequate access and unrestricted vision -Holding down required -Easy to align &/or position -Resistance to insertion -Separate operation
Mistake-proof product design and assembly	Combine, Rearrange, Simplify	1.Design parts that cannot be assemble incorrectly 2.Provide obstructions that will not permit incorrect assembly 3.Shape part unambiguously so that they cannot be assembled incorrectly.	-Make parts symmetrical -Mating features asymmetrical -Self-aligned and self-located -No flexible parts/no adjustment

BDI: Boothroyd Dewhurst, Inc.

Many university professors today accept this learning environment to transform past passive learning into active learning in their classrooms [8]. In order to find better ways of involving the students in their learning process, we introduced the BDI-DFA Design Project into our MET 277 Material processing II course. With the successful DFA design project (see table 2), the students learn more materials, retain the information longer, and enjoy the class activities more. The DFA design project allows the students to learn many DFA concepts, principles, and guidelines in the classroom with the help of the instructor and other classmates, rather than on their own.

The DFA design project consists of problem-based learning activities to encourage students to do more than simply listen to a lecture. They are able to evaluate and redesign their own product to prove their ideas and what they have learned from MET 277 course. After learning, processing, and applying information from DFA guidelines, methodology, and worksheet, the students are ready to share their ideas with team members. By dividing students into different roles and working cooperatively, the whole class (3-4 students/per team) will be able to work together to design their own products. DMAIC is a structured problem-solving methodology (see figure 2) widely used in Lean Six Sigma activities. The letters are an acronym for the five phases of Six Sigma improvement: (1) Define, (2) Measure, (3) Analyze, (4) Improve, and (5) Control. This DFA design project is divided into five phases. Each phase consisting of a number of strategies is briefly described in the following example:

Figure – 2 Using DMAIC to Improve Design for Assembly Learning



Design for Assembly project and class activities

The DFA project can be divided into four different activities:

Activity 1: Search potential assembly product (1-2 hours)

Task 1: conduct a search on the internet and explore information about DFA

Task 2: describe your assembly design in 50 words and /or a free hand drawing)

Activity 2: assembly efficiency estimation period, (2 hour)
Task 3: sketch your assembly design (output – assembly drawing on graph paper)
Task 4: prepare a Bill of Materials (BOM) for your product and materials procurement

Activity 3: product improvement and redesign period, (3 hours)
Task 5: prepare your DFA worksheet and ideas in the classroom

Activity 4: presentation period (1 hour).
Task 6: present your data and findings

Examples of DFA project Successes

A team of 3-4 students take on the traditional roles in a DFA process in their redesign of the product, such as design engineer, manufacturing engineer, production engineer, and so on. As an example, a model of implementing Boothroyd Dewhurst DFA will be illustrated further by using the following five phases of DMAIC methodology:

Phase 1: Define – define a design problem and improvement opportunity:

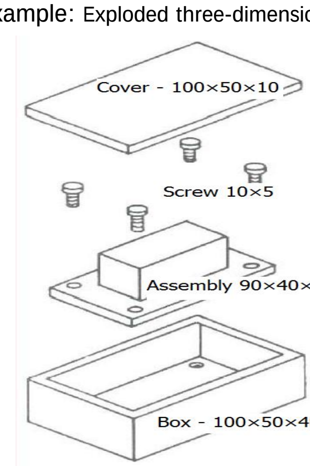
The phase one procedure is as follows:

(1) Obtain the best information about the product or assembly
(2) Take the assembly apart
(3) Measure part dimensions
(4) Obtain exploded three-dimensional views of assembly
(5) Define total angle of symmetry ($\alpha+\beta$), degrees

Students collect necessary product assembly data as follows (see figure 3):

Figure 3 - Basic product information about design for assembly

Example: Exploded three-dimension views



Source: BDI Product Design for Assembly handbook, 1989

Basic product information: Unit: mm

1.Exploded three-dimensional views:

2.Bill Of Materials (BOM):

3.Quantity: 1

4.Part dimensions: cover - 100×50×10; subassembly- 90×40×35;

5.Assembly sequence: top-down assembly

6.Route sheet:

7.Material costs:

8.Manfuacturing costs:

9. others:

Phase 2: Measure – measure assembly performance

In the example below (see figure 4), each column is completed by measuring the following assembly performance:

(1) Estimate handling time
(2) Estimate insertion time
(3) Determine the theoretical minimum number of parts
(4) Calculate assembly efficiency
(5) Estimate assembly cost

The students estimate the following times and costs (see table 3-5):

Table 3 - Two-digit manual handling code (Original design): One hand

Assembly part	$(\alpha+\beta)$	First digit	Handling difficulties	Second digit	Handling time
Box (100×50×40) on Work surface	540	2	Easy Grasp: ☑ yes, ☐ No Thickness: >2 size: >15	0	1.8
Place assembly (90×40×35)	540	2	Easy Grasp: ☑ yes, ☐ No Thickness: : >2 size: : >15	0	1.8
Screw (10×5) down assembly	360	1	Easy Grasp: ☑ yes, ☐ No Thickness: : >2 size: 6< 10 <15	1	1.8
Cover (100×50×10)	360	1	Easy Grasp: ☑ yes, ☐ No Thickness: : >2 size: >15	0	1.5

Table 4 - Two-digit manual insertion code (Original design): Part added but not secured

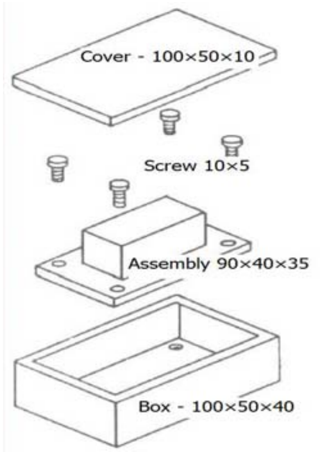
Assembly part and/or operation	Access and vision	First digit	Insertion difficulties	Second digit	Handling time
Box (100×50×40) on Work surface	Obstructed access: ☐ yes, ☑ No Restricted vision: ☐ yes, ☑ No	0	Holding down required: ☐ yes, ☑ No Easy to align: ☑ yes, ☐ No No resistance: ☑ yes, ☐ No	0	1.5
Place assembly (90×40×35)	Obstructed access: ☐ yes, ☑ No Restricted vision: ☐ yes, ☑ No	0	Holding down required: ☐ yes, ☑ No Easy to align: ☑ yes, ☐ No No resistance: ☐ yes, ☑ No	0	1.5
Cover (100×50×10)	Obstructed access: ☐ yes, ☑ No Restricted vision: ☐ yes, ☑ No	0	Holding down required: ☐ yes, ☑ No Easy to align: ☑ yes, ☐ No No resistance: ☐ yes, ☑ No	0	1.5

Table 5 - Two-digit manual insertion code (Original design): Part secured immediately

Assembly part and/or operation	Access and vision	First digit		Second digit	Insertion time
Screw (10×5) down assembly	Obstructed access: ☑ yes, ☐ No Restricted vision: ☑ yes, ☐ No	5	Screw tightening immediately after insertion Easy to align: ☐ yes, ☑ No No resistance: ☑ yes, ☐ No	9	12

Figure 4 - Design for Manual Assembly Worksheet – **(Original Design)**

Example: Exploded 3-dimension views



Source: BDI Product Design for Assembly handbook, 1989

Design for Manual Assembly Worksheet – **(Original Design)**

Name of Assembly: Dimension in mm	Total angle of symmetry (α+β), deg	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2) × [(4) + (6)]	Operation cost, cents 0.4 × (7)	Figures for estimation of theoretical minimum parts
Box (100×50×40) on Work surface	540	1	20	1.8	00	1.5	3.3	1.32	1
Place assembly (90×40×35)	540	1	20	1.8	00	1.5	3.3	1.32	1
Screw (10×5) down assembly	360	4	11	1.8	59	12	55.2	22.08	0
Cover (100×50×10)	360	1	10	1.5	00	1.5	3.0	1.2	1
							64.8	25.92	3
Design Efficiency $\frac{3*NM}{TM}$							TM	CM	NM

Design Efficiency: (Original Design) Design Efficiency $\frac{3*NM}{TM}$ = _(3×3)/64.8 = 13.89%______

Phase 3: Analyze – analyze assembly to determine the difficulties of poor assemblability
In the analysis of the original design, the students need to recognize and indentify the following assembly difficulties (see table 6-7):

(1) Analyze the ease of assembly
(2) Identify and verify assembly sequence
(3) Point out handling difficulties
(4) Point out insertion difficulties
(5) Identify Potential solutions

As a result of applying Boothroyd Dewhurst DFA analysis, a number of items can be identified for elimination or combination (see table 6 and 7) and the appropriate assembly time savings can be calculated for further assembly efficiency improvement.

Table 6 – Recognize and Identify insertion difficulties:

Assembly part	Problem(s)	Solution(s) – Redesign recommendation(s)
Screw (10×5) down assembly	Obstructed access and restricted vision	Eliminate 4 screws and use snap fit feature

Table 7 – Recognize and Identify handling difficulties:

Assembly part	(α+β)	Easy Grasp	Thickness & size	Improvement Potential	Assembly time improvement
Box (100×50×40) on Work surface	540	Yes	Thickness>2mm Size > 15 mm	EX: Redesign box (80×80×40); β symmetry (α+β)=450° ...	1.8 - 1.5 = 0.3
Place assembly (90×40×35)	540	Yes	>2 mm >15 mm	(α+β)=270°	1.8 – 1.13 = 0.67
Cover (100×50×10)	360	Yes	>2 mm >15 mm	(α+β)= 180° + 90° = 270°	1.5 - 1.13 = 0.67

Phase 4: Improve – improve assembly by reducing part count and part types

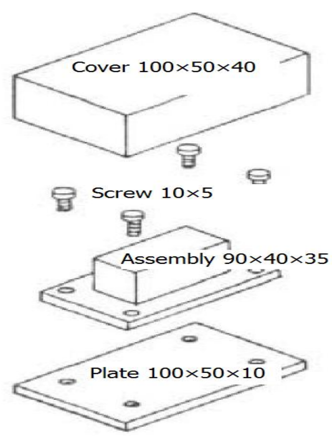
In order to improve assembly efficiency, the students need to apply DFA rules or guidelines to examine the following possibilities (see figure 5):

(1) Verify design changes and associate savings
(2) Eliminate unnecessary parts
(3) Combine parts
(4) Redesign part dimensions
(5) Reduce total angle of symmetry (α+β), degrees

A summary of the redesign items can be shown in figure 8. The following figure shows a conceptual redesign of the assembly box in which all the proposed design changes have been made. The revised DFA worksheet also presents the assembly efficiency is increased to 22.06%.

Figure 5 - Design for Manual Assembly Worksheet (Redesign)

Design concept to provide easier access during assembly



Source: BDI Product Design for Assembly handbook, 1989

Design for Manual Assembly Worksheet – Easy Access Assembly (**Redesign**)

Name of Assembly: Dimension in mm	Total angle of symmetry (α+β), deg	Number of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion time per part	Operation time, seconds (2) × [(4) + (6)]	Operation cost, cents 0.4 × (7)	Figures for estimation of theoretical minimum parts
Plate (100×50×10) on Work surface	360	1	10	1.5	00	1.5	3.0	1.2	1
Place assembly (90×40×35)	540	1	20	1.8	00	1.5	3.3	1.32	1
Screw (10×5) down assembly	360	4	11	1.8	38	6	31.2	12.48	0
Cover (100×50×40)	540	1	20	1.8	00	1.5	3.3	1.32	1
							40.8	16.32	3
Design Efficiency $\frac{3*NM}{TM}$							TM	CM	NM

Design Efficiency: (redesign) Design Efficiency $\frac{3*NM}{TM}$ = (3×3)/40.8=22.06%

Phase 5: Control – Control and retain best design practices

In this phase, the students learn how to control and retain best design practices.

(1) Confirm causal effects and solutions
(2) Test quick fixes or obvious solutions
(3) Select and test solutions
(4) Create best design for assembly practice to document
(5) Sustain improvements

Obviously, more significant improvement could be achieved by reuse and applying the above DFA design guidelines and best manufacturing practices to another designs. This example serves to illustrate how the effects of design changes can be quantified in order to guide the students to less costly and more easily manufactured products.

Results and Observations

After the DFA curriculum was developed through the cooperative effects of two MET courses, a limited amount of student assessment and feedback was collected in Materials Processing II and Manufacturing Automation classes at the end of semester 2009. The population size was 30 students (22 undergraduate students and 8 graduate students) and the total number of responses was 28. Some of the results from this student assessment present as follows:

1. Most (93%) of the students had strong confidence in their ability to apply DFA knowledge and correctly solve a similar problem in the future.
2. Almost 90% of the students were able to examine and analyze existing designs, identify assembly difficulties, and create alternative designs
3. 20 students ranked DFA project experience in the top two activities they liked overall
4. 22 students agreed that are more likely to remember the content delivered in these courses because of this new curriculum (Ex: systematic procedures, DMAIC model and team project experience)
5. When compared to a traditionally-taught course, 23 students preferred this approach over the traditional one.

The result of the DFA evaluation also indicated improvement in DFA skills and techniques among students. These findings suggest that students learn DFA better from coursework that incorporates content knowledge and practical, real case examples.

Conclusion

This study investigated a new model of teaching MET students DFA knowledge and skills that they need for a successful future. We also examined our curricula to ensure our students are familiar with the trends in manufacturing technology. This problem-based project challenged our MET students to practice Boothroyd-Dewhurst DFA method and skills. It also helped our students to better understand DFA principles and guidelines. In addition, it allows our students to strengthen their technology skills, exercise their creativity, and practice their research skills. This DFA design project is a motivational, fun, and enlightening project that provides students a hands-on opportunity while combining and practicing manufacturing, design, and project management skills. Finally, they demonstrated their DFA knowledge and insight by redesigning their own product assembly and then estimating assembly times and costs. They understood how this might be helpful to them in their manufacturing learning.

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