AC 2012-5319: USING DESIGN FOR ASSEMBLY METHODOLOGY TO IMPROVE PRODUCT DEVELOPMENT AND DESIGN LEARNING AT MSU

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Using Design for Assembly Methodology to Improve Product Development and Design Learning at MSU

Abstract

This paper discusses various aspects and models of how Boothroyd Dewhurst's Design-For-Assembly (DFA) methodology can be integrated into product development and design curriculum. 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 Manufacturing Engineering Technology (MET) curricula at Minnesota State University-Mankato (MSU). A detailed description of this model, including advantages and disadvantages, future directions and recommendations, are included in this paper.

Keywords: design for assembly, active learning, product development and design

Introduction

Design for assembly (DFA) is a systematic analysis process primarily intended to simplify product structure and reduce the assembly costs of a product, since the total number of parts in a product is a key indicator of product assembly quality [5]. Boothroyd Dewhurst's DFA methodology allows the designers to rate the assemblability of their product designs quantitatively [2]. This method also ensures that the DFA rules are being correctly applied and the influence factors are being correctly evaluated and improved. Design improvement is achieved by iteratively reviewing and interpreting the evaluation results. In addition, DFA also provides a method of identifying and/or integrating components that may possibly be eliminated entirely, or combined with other components [2]. Finally, the DFA index is a useful indicator of assembly efficiency of the part design; the larger the value is the more efficient the design.

In recent years, there is a constantly growing need for manufacturing engineers possessing both design and manufacturing knowledge [1,2,3]. Shortages of design expertise and manufacturing experience often result in an unacceptable level of assemblability and manufacturability of product design [6,7]. Unfortunately, best manufacturing practices and design expertise are hard to disseminate to designers. In order to effectively disseminate and reuse this valuable knowledge, design and manufacturing departments need quantitative feedback mechanisms to improve communication between these two departments. Design for assembly (DFA) provides a quantitative method for evaluating the cost and assemblability of the design during the design stage. Inevitably, 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 [8]. 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 simplify product designs for low cost and high quality assembly. 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 and continuously improve DFA learning process. The goals of this model are to:

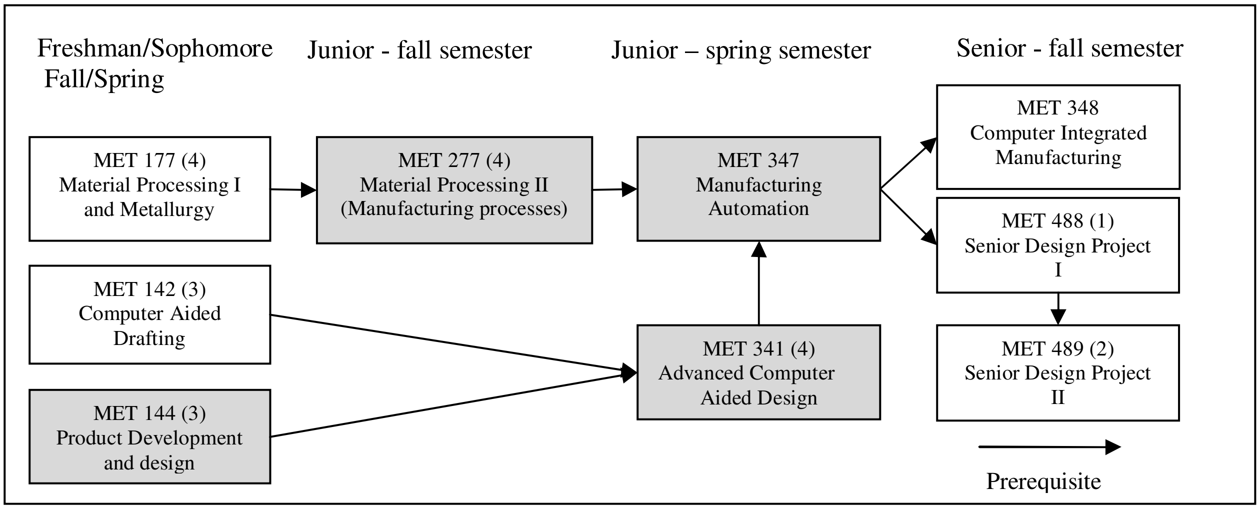
1. Provide the students a clearly defined methodology for evaluating and improving product assembly efficiency,
2. Offer an active learning environment and motivate the students to practice their design and manufacturing knowledge,
3. Guide the students to simplifying the product structure through a comprehensive consideration and instant feedback in both manufacturing and design viewpoints,
4. Encourage the students to investigate best practices in assembly design and welcome new design concepts and solutions,
5. Help the students create alternative designs

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

Overview of Manufacturing Engineering Technology program at MSU

Many Manufacturing Engineering Technology 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-Mankato many design and manufacturing projects attempt to provide the students opportunities to practice their design for assembly knowledge and promote creativity and innovation. In recent years, almost 40 students in our program are involved our DFA projects every year. All of the students are given foundational manufacturing and design concepts, principles, and methodologies of the engineering disciplines during their first two years. MET students have to finish their study of Material Processing I (MET 177), Computer Aided Drafting (MET 142), and product development and design (MET 144) courses before they are accepted by the program (see Figure 1).

Figure 1 - Typical MET program of study - DFA related courses (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 the student learning environment. The supporting evidence in table-1 shows the relationship between ABET criterion 2 outcomes a-k and the DFA learning outcomes. As we continue to use and improve this model, we expect that the DFA learning outcomes will eventually meet ABET criterion 2 perfectly. Additionally, we will utilize more surveys to assess the effectiveness of the model.

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 model for DFA learning

Research has shown that project-based learning is an extremely effective learning activity. Many university professors today accept this learning environment to help students make the transition from passive learning to active learning learners in their classrooms [8]. In order to find better ways of involving the students in this 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.

Table 2 – Design for Assembly principles and Guidelines

DFA Principles	**ECRS** principles	DFA Guidelines	*BDI assessment items
Simplify and reduce the number of parts	**E**liminate, **C**ombine	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	**C**ombine, **R**earrange, **S**implify	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	**S**implify, **S**ymmetrize,	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	**C**ombine, **R**earrange, **S**implify	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	**C**ombine, **R**earrange, **S**implify	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: **B**oothroyd **D**ewhurst, **I**nc.

The DFA design project consists of project-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 (3-4 students/per team). By dividing students into different roles and working cooperatively, the whole class will be able to work together to design their own products.

Bloom's cognitive domain vs. DFA learning Objects

In 1956, Benjamin Bloom created taxonomy of cognitive development levels [10]: (1) B1-Knowledge, (2) B2 - Comprehension, (3) B3 - Application, (4) B4 - Analysis, (5) B5 - Synthesis, and (6) B6 - Evaluation. These six levels of cognitive development help us describe and classify observable learning outcomes, knowledge, skills, behaviors and abilities. By creating DFA learning objects using measurable verbs (see Table 3), we indicate explicitly what the students must do and complete in order to demonstrate student learning outcomes and thinking skills.

Table 3 - Bloom's Taxonomy of Cognitive Development vs. DFA Learning Objects

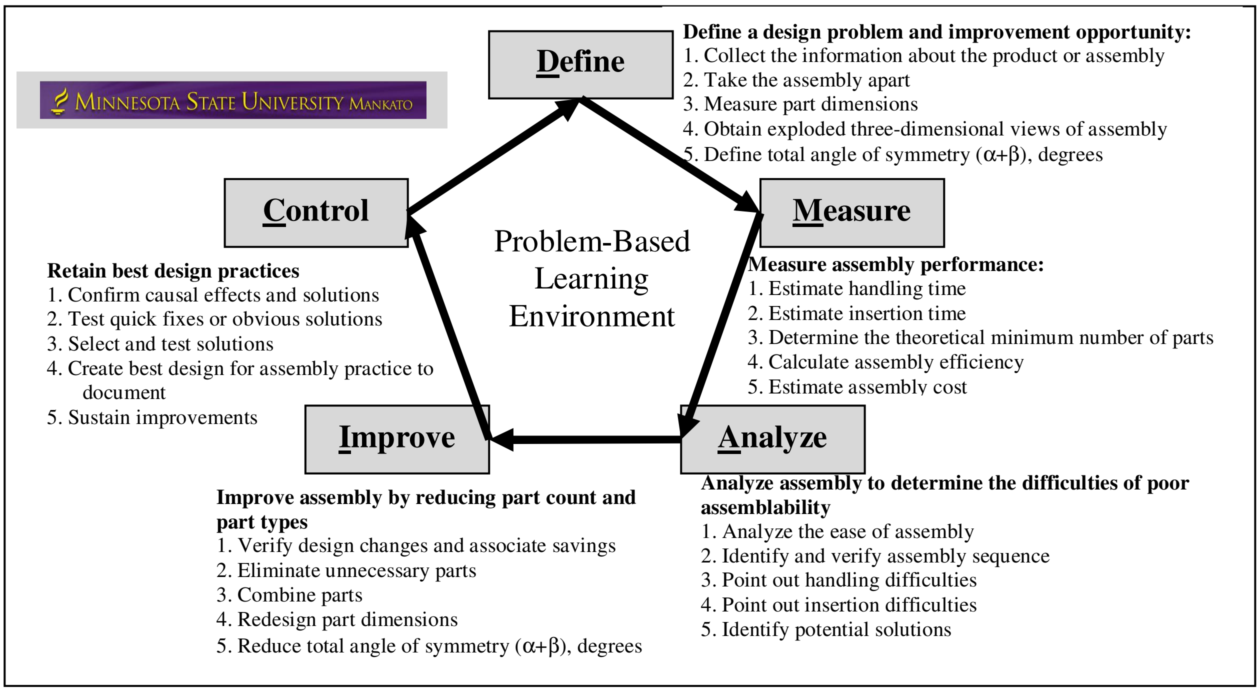
Levels of Learning	Bloom's Taxonomy Verbs	DFA Learning Objects	Thinking skills
B1: Knowledge - to recall or remember facts without necessarily understanding them	Define, list, name (label), count, order, assign, record, recognize ...	Object 1: Take the assembly apart (Ex: Exploded three-dimensional views) Object 2: **List** parts in the order of assembly (Ex: An existing) Object 3: **Assign/record** each part name and number (Ex: Engineering drawings) Object 4: **Count** assembly parts and interfaces (Ex: Exploded three-dimensional views) Object 5: **Define** product function and functional requirements	Lower Order Thinking Skills
B2: Comprehension - to understand and interpret learned information	Identify, indicate, classify, discuss, locate, explain, review ...	Object 1: **Identify** and verify assembly sequence (Ex: Ex: Exploded three-dimensional views) Object 2: **Identify** parts that can be standardized Object 3: **Indicate** quality (mistake proofing) opportunities Object 4: **Locate** part handling difficulties and identify opportunities Object 5: **Locate** part insertion difficulties and identify opportunities	
B3: Application - to put ideas and concepts to work in solving problems	Determine, apply, construct, operate, select, practice, sketch, use, solve ...	Object 1: **Determine** theoretical minimum number of parts (Ex: DFA worksheet) Object 2: **Select** manufacturing processes and materials Object 3: **Select** assembly methods	
B4: Analysis - to break information into its components to see interrelationships and ideas	Analyze, calculate, categorize, test, examine, inspect, question, differentiate contrast ...	Object 1: **Calculate** total angle of symmetry (α+β) Object 2: **Estimate** (two-digital handling code) handling time Object 3: **Estimate** (two-digit insertion) insertion time Object 4: **Calculate** total operation time and cost Object 5: **Calculate** assembly efficiency (DFA index)	Higher Order Thinking Skills
B5: Synthesis - to use creativity to compose and design something original	Create, design, develop, collect, formulate, propose, setup, compose ...	Object 1: **Design/redesign** parts with self-locating features Object 2: **Design/redesign** parts with self-fastening features Object 3: **Design/redesign** for component symmetry for insertion Object 4: **Design/redesign** for a base part to locate other parts	
B6: Evaluation - to judge the value of information based on established criteria	Evaluate, appraise, assess, judge, justify, value, select, ...	Object 1: **Evaluate** design changes and associated savings Object 2: **Select** the best design for assembly practice to document Object 3: **Sustain** improvements	

The above table of DFA learning objects contained six different levels of cognitive domain. In DFA learning process, critical thinking involves logical thinking and reasoning including skills such as classification, sequencing, planning, and comparison. Creative thinking involves creating and generating something new or original. It also involves the skills of brainstorming, modification, attribute listing, and originality. The purpose of DFA creative thinking is to stimulate curiosity among students and promote product structure simplification. Bloom's Taxonomy provides a useful structure in which to categorize DFA learning objects when assessing student learning outcomes. Asking students to think at higher levels is an excellent way to stimulate student's thought processes. In DFA learning process, the purpose of writing Bloom's questions is to apply Bloom's theory of developing higher levels of thought processes to

DFA classroom. Asking high level questions of your shared inquiry groups is one way of making personal connections to literature, creating a bridge to your imagination, and developing your self-understanding.

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 (see Figure 2):

Figure – 2 Using DMAIC to Improve DFA Learning Process



Design for Assembly project and class activities

The DFA project can be divided into four different class activities:

Activity 1: Search potential assembly product (Ex. 25 ± 5 parts) (1-2 hours)
- Task 1: conduct a search on the internet and explore information about DFA
- Task 2: describe assembly design in 50 words and /or a free hand drawing

Activity 2: assembly efficiency estimation period (3 hour)
- Task 3: sketch assembly design (output – assembly drawing on graph paper)
- Task 4: prepare a Bill of Materials (BOM) for the product and make-or-buy decision list

Activity 3: product improvement and redesign period (4 hours)
- Task 5: prepare DFA manual assembly worksheets in the classroom (original and redesign worksheets)

Activity 4: project presentation and peer evaluation period (2hour)
- Task 6: present data and findings

Example of DFA Class Learning Process

A team of 3-4 students take on the traditional roles in the DFA process in their redesign of the product, such as design, manufacturing, production, quality 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 – collect the product information and identify improvement opportunities:

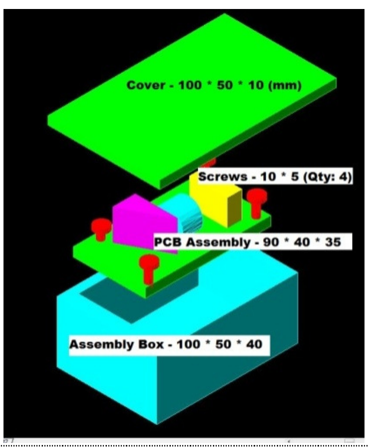
The phase one procedure is as follows:

(1) Obtain the best information about the product assembly
(2) Take the assembly apart
(3) Measure part dimensions (Ex. size, thickness, length/diameter (L/D ratio) ...)
(4) Obtain exploded three-dimensional views of assembly
(5) Define total angle of symmetry ($\alpha+\beta$), 0 - 720 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



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: Aluminum 6061 - T5
8.Manfuacturing costs
9. others

Phase 2: Measure – estimate assembly time and cost, and calculate assembly efficiency

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

(1) Estimate handling time and cost (Ex. Two-digit handling code and handling time)
(2) Estimate insertion time and cost (Ex. Two-digit insertion code and insertion time)
(3) Determine the theoretical minimum number of parts
(4) Calculate assembly efficiency (Ex. DFA Index = 3* NM / TM)
(5) Estimate assembly cost

In the class learning process, the students estimate the following times and costs (see Table 4-6):

Table 4 - Two-digit manual handling code (Original design): One hand

Assembly part	(α+β)	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 PCB 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 5 - Two-digit manual insertion code (Original design): Part added but not secured

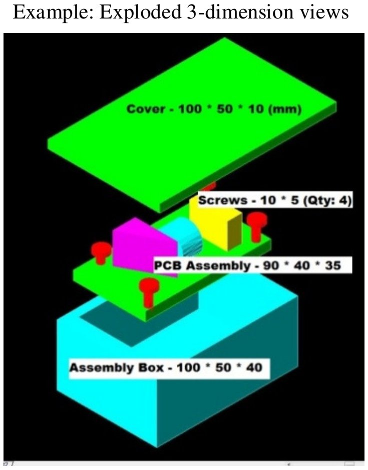
Assembly part and/or operation	Access and vision	First digit	Insertion difficulties	Second digit	Handling time
Box (100×50×40) on Work surface	Obstructed access: ☐ yes, ☑ No Restricted vision: ☐ yes, ☑ No	0	Holding down required: ☐ yes, ☑ No Easy to align: ☑ yes, ☐ No No resistance: ☑ yes, ☐ No	0	1.5
Place PCB 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 6 - 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



Design Efficiency: (Original Design)

Design Efficiency = 3*NM/TM
= (3×3)/64.8 = 13.89%

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	Operation cost, cents	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 PCB 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 = $\frac{3*NM}{TM}$ = 0.1389							TM	CM	NM

*Design for Manual Assembly Worksheet originated from BDI Product Design for Assembly handbook, 1989 [4]

Phase 3: Analyze-analyze the assembly to determine the difficulties of product assemblability

In the analysis of the original design, the students need to recognize and indentify the following assembly difficulties (see Table 7-8):

(1) Locate handling difficulties (Ex. Nest or tangle, stick together, slippery, fragile, sharp …)
(2) Locate insertion difficulties (Ex. Restricted view, obstructed access, not easy to align …)
(3) Identify and verify assembly sequence
(4) Analyze the ease of assembly
(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 7 and 8) and the potential assembly time savings can be calculated for further assembly efficiency improvement.

Table 7 – Recognize and Identify insertion difficulties

Assembly part	**Problem(s)**	**Solution(s) – Redesign recommendation(s)**
Screw (10×5) down assembly	Difficult to insert, part must be release before it is located, figers cannot access desired location	Eliminate 4 screws and use snap fit feature
Assembly box (100×50×40)	Obstructed access and restricted vision	Provide access for operators to assemble parts

Table 8 – 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 product assembly efficiency by reducing part count and part types

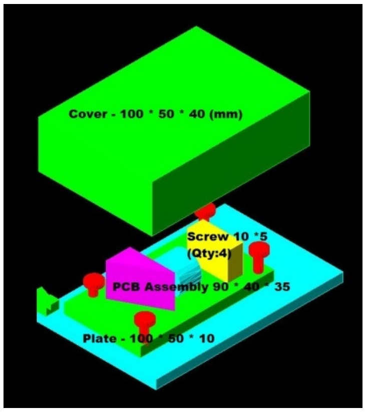
In order to improve assembly efficiency, the students learn how to apply DFA rules or guidelines to examine the following possibilities (see Figure 5):

(1) Eliminate unnecessary parts (Ex. Apply the theoretical minimum part count criteria)
(2) Combine parts (Ex. Apply the theoretical minimum part count criteria)
(3) Redesign part dimensions (Ex. Brainstorm to generate redesign ideas)
(4) Reduce total angle of symmetry (α+β), 0 – 720 degrees
(5) Verify design changes and associate savings

A summary of the redesign items can be shown in Figure 5. The following figure shows a conceptual redesign of the assembly box in which all the proposed design changes have been made. The redesign DFA worksheet 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



Design Efficiency: (redesign)

Design Efficiency=3*NMTM
= (3×3)/40.8=22.06%

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

Name of Assembly: Dimension in mm	Total angle of symmetry ($\alpha+\beta$), 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	Operation cost, cents	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=$\frac{3*NM}{TM}$=0.2206							TM	CM	NM

*Design for Manual Assembly Worksheet originated from BDI Product Design for Assembly handbook, 1989 [4]

Phase 5: Control – retain best design practices and continuously improve the DFA process

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

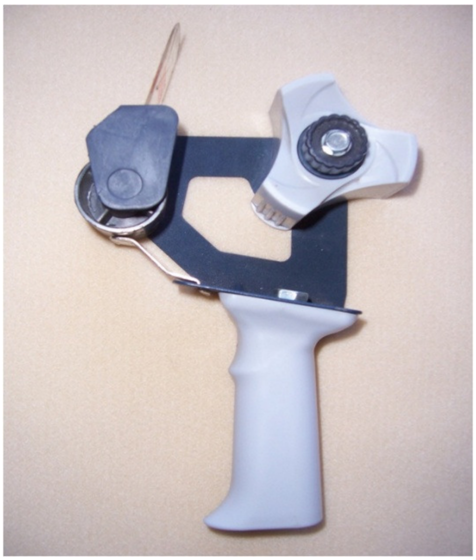
(1) Confirm causal effects and solutions
(2) Test quick fixes or obvious solutions
(3) Select and test alternative solutions
(4) Create best design for assembly practice and document the results
(5) Sustain improvements

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.

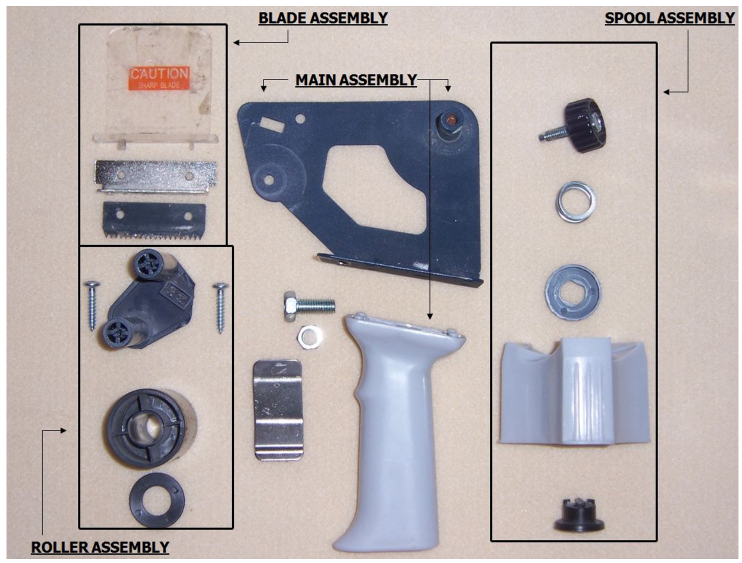
DFA Student Project

In the past two years, a number of DFA student projects have been selected to help MET students understand the importance of DFA when the intention is to improve product design course learning. In general, student design teams are given a small assembly product (25 ± 5 parts) that has not been designed using the DFA principles and then asked to develop a redesign solution that simplify the product structure and also meet the DFA design rules and guidelines. Obviously, the DFA student projects add the ability for students to not only complete a design cycle, but also to examine product improvement opportunities. Along with giving MET students the opportunity for a complete DFA design experience, these student projects also give them the opportunity to practice their communication skills and to enhance their design learning experience. Below is one of the DFA student projects that demonstrate what they have learn from this project (see Figure 6).

Figure 6 - Exploded Assembly Diagram - Tape Dispenser



Product price: $27.94; Size: 3" core

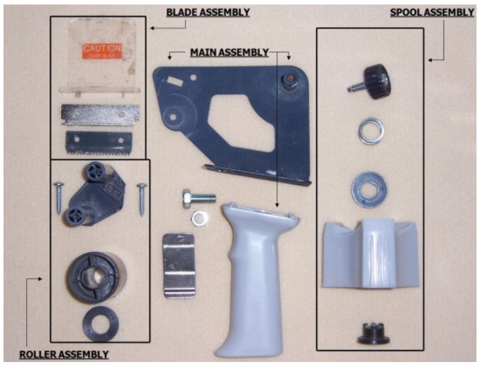


Total parts = 19; 4 fasteners; 1 spring; materials: metal + plastics

The average students spent 3-4 hours on the redesign of this tape dispenser, and applied what they have learned from DFA lecture in the classroom. The DFA implementation in the product development and design course provided many benefits. The students were able to incorporate product design experience and manufacturing experience early in the design cycle. Teamwork was promoted and communication increased between product design, and manufacturing. A better understanding of the design's impact on manufacturing cost was gained. In addition, students now have a much better sense of product development and design process.

After students created their DFA solution for the original tape dispenser (see Figure 7) in MET 277 course, each team developed a redesigned case and modeled it in Pro/ENGINEER. These new designs were then built on the Pro/ENGINEER assembly and students were able to test how well their new designs worked. Most teams needed at least two different redesign solutions to demonstrate how much they have learned from this project. Figure 8 shows an example of one of the students redesign worksheet. This particular redesign increased design efficiency by 60%.

Figure 7 - Design for Manual Assembly Worksheet* (Original Design)



Name of Assembly: Tape Dispenser (All dimension in mm)	Total angle of symmetry ($\alpha+\beta$), 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	Operation cost, cents	Figures for estimation of theoretical minimum parts
1. Metal frame (100 × 80 × 60)	720	1	30	1.95	06	5.5	7.45	2.98	0
2. Frame bolt (15 × 30)	360	1	00	1.13	28	10.5	11.63	4.65	0
Assembly part rotate 180 degrees	720	1	00	0.0	98	2.0	3.0	1.20	0
3. Frame nut (12 × 8)	360	1	00	1.13	59	12.0	13.13	5.25	0
Screw tightening	720	1	69	9.0	92	5.0	14.0	5.60	0
4. Rubber washer (25 × 5)	180	1	03	1.69	00	1.5	3.19	1.28	0
5. Plastics roller (60 × 45)	180	1	00	1.13	00	1.5	2.63	1.05	1
Assembly part rotate 90 degrees	720	1	00	0.0	98	2.0	2.0	0.80	0
6. Blade mount (60 × 10)	720	1	30	1.95	06	5.5	7.45	2.98	0
7. Blade (60 × 20 × 2)	720	1	33	2.51	06	5.5	8.01	3.20	0
8. Guard (55 × 15 × 2)	720	1	30	1.95	06	5.5	7.45	2.98	1
9. Roller/blade binding	720	1	30	1.95	59	12.0	13.95	5.58	0
Assembly part rotate 90 degrees	720	1	00	0.0	98	2.0	2.0	0.80	0
10. Screws (8 × 30)	360	2	00	1.13	38	6.0	14.26	5.70	0
11. Spool space (20 × 30)	360	1	10	1.50	00	1.5	3.0	1.20	0
12. Spool (60 × 45)	360	1	10	1.50	00	1.5	3.0	1.20	1
13. Spring housing (45 × 25)	360	1	10	1.50	00	1.5	3.0	1.20	0
14. Spring (35 × 30)	180	1	00	1.13	81	4.5	5.63	2.25	0
Adjustment of parts	720	1	00	0.0	98	9.0	9.0	3.60	0
15. Spool bolt (15 × 30)	360	1	00	1.13	03	3.5	4.63	1.85	1
16. Spool bolt knob (15 × 30)	360	1	00	1.13	34	6.0	7.13	2.85	0
17. Tape tensioner (35 × 25)	720	1	30	1.95	00	1.5	3.45	1.38	0
18. Spacer (15 × 10)	360	1	00	1.13	03	3.5	4.63	1.85	
							153.6	61.5	4
Design Efficiency= $\frac{3*NM}{TM}$ =(3*4) / 153.6 = 0.0781							TM	CM	NM

*Design for Manual Assembly Worksheet originated from BDI Product Design for Assembly handbook, 1989 [1]

Using DFA methodology to teach students in MET 277 course is a significant improvement to the class. Without the addition of DFA course project to the curriculum, students would not have been able to understand how to apply DFA concepts to product design phase and they would not have had access to real-world design experience. The DFA course project has the potential to positively affect student learning outcomes in the area of product development and design. It allows students to simplify product structure and close the loop on design process that have traditionally been taught through lecture and homework. The additional learning and resulting student confidence is both noteworthy and exciting, and can be also easily accomplished through the choice of an appropriate DFA project.

Figure 8 - Design for Manual Assembly Worksheet* (Redesign)

Name of Assembly: Tape Dispenser (All dimension in mm)	Total angle of symmetry ($\alpha+\beta$), 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	Operation cost, cents	Figures for estimation of theoretical minimum parts
1. Main assembly: handle+mainsub(200 × 150 × 60)	180	1	00	1.13	00	1.5	2.63	1.05	1
2. Guard (55 × 15 × 2)	720	1	30	1.95	06	5.5	7.45	2.98	1
3. Spool (60 × 45)	360	1	10	1.50	00	1.5	3.0	1.20	1
4. Spool bolt (15 × 30)	360	1	00	1.13	03	3.5	4.63	1.85	1
							17.71	7.08	4
Design Efficiency= $\frac{3*NM}{TM}$ =(3*4) / 17.71 = 0.6776							TM	CM	NM

*Design for Manual Assembly Worksheet originated from BDI Product Design for Assembly handbook, 1989 [4]

Results and Observations

There are a number of approaches to assessing student learning outcomes. Each assessment method has different adavantages and disavantages and yields only partial insight into student learnng and teaching effectiveness. However, a combination of direct and indirect ourcome measures can provide valuable information that can be used to address learners' problems and enhance insturctional organization and delivery. In order to measure DFA learning outcomes, we used the following methods to assess the outcomes and colloect necessary data:

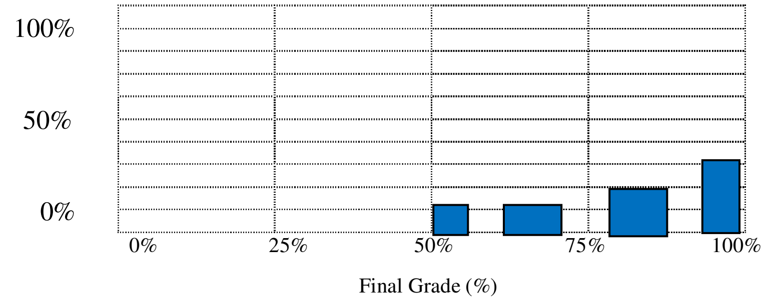
(1) Course-based tests and examinations - What knowledge and abilities have students acquired from our lectures and project activities (see Figure 9),
(2) In-class observation - Many student skills are demonstrated by performing product disassembly and assembly in the classroom (see Figure 6 and Table 9),
(3) Student survey - according to our university policy, we have to collect and conduct sutent surveys (at least two courses/per semester) at the end of each semester,
(4) Project presentation - Students present their results and findings to the class (peer evaluations 50% + instructor grading 50%),
(5) Project report - Normally prepared outside of class, students report include written assignment, designs, analysis worksheets, portfolios, or redesign drawings.

When employed carefully and thoughtfully, the DFA learning outcomes may highly contribute to judgments of teaching. Apparently, we will continuously use the above student outcome information to support and improve instructor teaching styles and/or student learning, not contribute to instructors' fear, stress and alienation.

Figure 9 - Exam I Design For Assembly (part I) | MET 277 Manufacturing Processes - fall 2011

Class Statistics:	10 multiple choice questions
Class average:	82.22%

Score distribution:



Question Statistics

Questions	Statistics	Avg. Grade/ attempts	Levels of DFA Learning
Question1: DFA definition		100% (18 attempts)	B1, B2
Question2: Characteristics that affect assembly time		100% (18 attempts)	B2, B3, B4
Question3: Total angle of symmetry (α+β)		83.33% (18 attempts)	B4, B2
Question4: Benefits from part reduction		88.89% (18 attempts)	B6, B1, B6
Question 5: Locate part handling difficulties		100% (18 attempts)	B2, B4
Question 6: Locate part insertion difficulties		88.89% (18 attempts)	B2, B4
Question 7: Minimum part criteria		50% (18 attempts)	B3
Question 8: Estimate(two-digital handling code) handling time		83.33% (18 attempts)	B4, B5
Question 9: Estimate(two-digital insertion code) insertion time		61.11% (18 attempts)	B4, B5
Question 10: Assembly Efficiency (DFA Index) calculation		66.67% (18 attempts)	B4

Table 9 - DFA results vs. Observable Student Learning Outcomes

DFA Results	Original Design	Redesign	Difference	Observable student learning outcomes (Bloom's Taxonomy of Cognitive Development)
Part count reduction	19 parts	4 parts	- 78.9%	*B3-O1, B3-O3, B5-O4,
Assembly Efficiency	7.81%	67.76%	+ 59.95%	B4-O5, B3-O1, B4-O2, B4-O3, B4-O5,
Assembly time (seconds)	153.6	17.71	- 88.5%	B4-O4, B4-O2, B4-O3,
Assembly cost ($ cents)	61.5	7.08	-88.5%	B4-O4, B4-O2, B4-O3,
Total cost ($ dollars)	4.56	3.24	-28.9%	B4-O4, B4-O2, B4-O3,
Annual saving (Ex:100,000)	456,000	324,000	-132,000	B6-O1, B5-O1, B5-O2, B5-O3, B5-O4,
Fastener count	4	0	-100%	B1-O1, B1-O2, B1-O5,
Weight change (kg)	0.76	0.52	-31.6%	B3-O1, B5-O4, B6-O2,
Assembly tools	4	2	-50%	B1-O1, B1-O2, B1-O4, B1-O5,
Assembly operations	5	2	-60%	B2-O4, B2-O5, B2-O2, B2-O3,

*__B3-01__: B3-application; Object 1 – Determine theoretical minimum number of parts, Etc.

After the DFA curriculum was developed through the cooperative effects of two MET courses, a number of student assessment and feedback was collected in Materials Processing II and Manufacturing Automation classes at the end of semester 2009 and 2010. 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 these 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 DFA project challenged our MET students to practice Boothroyd-Dewhurst DFA methodology and skills. It also helped our students to better understand DFA principles and guidelines. In addition, it allows our students to strengthen their design and manfacturing technology skills, exercise their creativity, and practice their research capabilities. 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 design and manufacturing learning.

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References

1. Andreasen, M.M. and Hein, L., (1987), "Integrated Product Development" IFS Publications Ltd, Springer-Verlag, pp. 11-19.

2. Boothroyd, Geoffrey, Dewhurst, P. and Knight, W. (2002). Product Design for Manufacture and Assembly. NewYork: Marcel Dekker.

3. Boothroyd, Geoffrey, Dewhurst, P. and Knight, W. (1991). Product Design for Assembly Manual. Rhode Island: Boothroyd Dewhurst, Inc.

4. Boothroyd, Geoffrey, Dewhurst, P (1989). Product Design for Assembly Handbook. Rhode Island: Boothroyd Dewhurst, Inc.

5. Priest J.W. and Sánchez, J. M. (2001). Product Development and Design for Manufacturing: A Collaborative Approach to Producibility and Reliability, Marcel Dekker, Inc., New York, pp.1-5.

6. Redford, A. and Chal, J., (1994), "Design for Assembly Principles and Practice", McGraw-Hill Book Company, England.

7. Sackett, P. J. and Holbrook, A.E.K., (1988), "DFA as a Primary Process Decreases Design Deficiencies", Assembly Automation, Vol. 8, 3, pp.137-140.

8. Syan, C.S. and Swift, K.G., (1994), "Design for Manufacture", *Concurrent Engineering,* Chapman & Hall, pp. 101-115.

9. University of California Davis, Teaching Resources Center. http://trc.ucdavis.edu/

10. Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, Toronto: Longmans, Green.