

*Journal of*

---

# **INDUSTRIAL TECHNOLOGY**

---

*Volume 20, Number 4 - September 2004 through December 2004*

---

## ***Testing a New Curriculum of Design for Manufacturability (DFM) in Technical Education***

*By Dr. Bernie P. Huang, Dr. Jacob Chen and Dr. Joseph C. Chen*

*Peer-Refereed Article*

**KEYWORD SEARCH**

**CIM  
Curriculum  
Manufacturing  
Materials & Processes  
Teaching Methods**

---

*The Official Electronic Publication of the National Association of Industrial Technology • [www.nait.org](http://www.nait.org)*

© 2004

---



Dr. Bernie P. Huang is an assistant professor in the School of Technology at Georgia Southern University. He received his Ph.D. degree in Industrial Technology at Iowa State University in 2002. His research and teaching interests are the CAD/CAM integration, design for manufacturability, lean cell manufacturing system, cost engineering, and application of fuzzy-neuron control and statistical tools in machining detection.



Dr. Jacob Chen is an assistant professor in the Department of Industrial Engineering and Management at Ching-Yun University, Taiwan. He received his Ph.D. degree in Industrial Technology program at Iowa State University in 2003. His research interests include QFD applications, Taguchi parameter design, automatic machining control, Management, and evaluation and curriculum development in engineering.



Dr. Joseph C. Chen is a Professor in the Department of Agriculture and Biosystems Engineering at Iowa State University. His teaching interests include: Lean manufacturing system design, automated manufacturing processes, facility design, Taguchi design in quality, etc. His research interests include: manufacturing system control, manufacturing system design, design for manufacturing education, smart CNC machining, simulation as a design tool, simulation techniques, and cellular manufacturing system design.

# Testing a New Curriculum of Design for Manufacturability (DFM) in Technical Education

By Dr. Bernie P. Huang, Dr. Jacob Chen and Dr. Joseph C. Chen

## Introduction

In the internationally competitive marketplace, the availability of products has increased, leading to more selection for consumers and more competition for manufacturers. To stay competitive, manufacturers have had to increase product quality while decreasing product cost. To achieve these antithetical goals, manufacturing engineers and technicians have attempted to continuously improve product quality while streamlining manufacturing processes for lower cost, utilizing methods such as statistical process control, time-motion study, and link-cell manufacturing system design. The goal of these methods is to eliminate process defects and inefficiencies before they can impair product quality and increase production costs.

However, most of these methods focused on the manufacturing processes, not on the product itself. Most engineers and technicians were trained to improve the manufacturing processes and seldom consider the product. Design for manufacturability (DFM) opens another solution for engineers and technicians to improve the quality and quantity of a product. The purpose of this study is to develop and test practical curriculum modules with the knowledge and applications of DFM concepts in technical education and evaluate them for further modification.

In any manufacturing process, design is the first step. Even though the typical design phase amounts to only five percent of the total production budget, it is the cornerstone of the production process. Boothroyd (2002) stated that the design phase:

- Influences seventy percent of the final production costs
- Fulfills half of the customer demand
- Influences product quality
- Influences process productivity
- Has potential to significantly reduce final costs of manufacturing and assembly

Therefore, a sound product design can help a company lower production costs and, more importantly, it can ultimately make a product competitive in the global marketplace.

A problem that many companies face is coordinating the product design with the manufacturing system, which is a complex arrangement of physical elements, such as machines, tools, people, and material handling devices. The design department may not be a part of the manufacturing system, but the interactions between the two significantly affect product cost, product quality, and process productivity. Therefore, there is great value in coordinating the product design with the manufacturing system.

One method of coordinating the product design with the manufacturing system is concurrent engineering design. Concurrent engineering is a nonlinear approach that brings people and processes together during input, processes, and output for a product (Bertoline & Wiebe, 2003). Through concurrent engineering, designers, engineers and non-technical people communicate their professional opinions to each other to achieve a superior product. In order to communicate well with designers in concurrent engineering, manufacturing engineers have increas-

ingly turned to Design for Manufacturability (DFM) techniques in recent years. O'Driscoll (2002) defined DFM as the practice of designing products with manufacturing in mind. Boothroyd (2002) stated that DFM is concerned with understanding how product design interacts with the other components of the manufacturing system and with defining product design alternatives that facilitate optimization of the manufacturing system.

Since DFM is increasingly used by manufacturers in many different industries worldwide, there is a need for new graduates from two-year technical schools and four-year universities to be versed in this concept when they enter the workplace. Traditionally, however, industrial technology curricula in institutions of higher education have focused on teaching concepts and techniques of manufacturing systems with little discussion of linking these processes to the design phase. Most students gain knowledge of design solely through skills courses such as technical or CAD drawing. These courses teach students to understand, create, and read technical drawings. While these are important skills for students to have, they do not inform students of the concept of concurrent engineering achieved through DFM.

The American Society of Mechanical Engineers (ASME), with funding from the National Science Foundation, published the results of a study that examined the necessary curriculum changes to more effectively integrate the elements of the product realization process into the education of engineering or technology students (Prziembel, 1995). The ASME study showed that in order to prepare students adequately for jobs in industry, DFM must be introduced into two- and four-year industrial technology curricula.

According to the needs illustrated by the ASME study, a DFM curriculum designed for students concentrating on manufacturing-related programs in both two- and four-year colleges was developed. Discussions of the proposed

teaching method for the curriculum, the pilot-test using the proposed method, and the test results, which provide data used to continuously improve the curriculum are included in the following sections. This study impacts both technical education and the curriculum development methodology. The pilot test procedure could also influence future technical education endeavors.

### ***Proposed teaching method for DFM in introductory manufacturing design courses***

This DFM curriculum development is divided into four modules, each module consisting of two or three units. The content of each module is briefly described as follows:

#### **Module 1 - Design for Manufacturing ability principles**

The objective of this module is to give a brief overview of DFM and illustrate its goals. There are two units in this module, one to discuss the general concepts of DFM with several successful case studies and the other to discuss the application of team approaches in DFM for the need of concurrent engineering. These units pave the way for students to learn core knowledge about DFM with the realization that this knowledge is essential to their future careers. This module shows DFM in practice, providing students with many successful cases of DFM at work in industry design teams. These successful case studies also illustrate a team approach, showing students the important need for teamwork skills in industry.

#### **Module 2 - Design for Machining**

The objective of this module is to focus on the application of DFM in machining processes such as milling and turning. Three units related to machining processes are discussed in this module, which are as follows:

- An overview of common machining processes, major principles to reduce machining costs and machining time, and important design-for-machining consideration examples
- A discussion of transforming work materials through machining processes to meet design needs

- An introduction to creating early cost estimates for designers using machining processes for the product

#### **Module 3 - Design for Assembly (DFA)**

The objective of this module is to provide the knowledge and skills necessary for students to understand Design for Assembly (DFA) tools. This module enables students to effectively judge a product's ease of assembly and subassembly by analyzing the product design. This module is composed of four units:

- Design-for-Manual-Assembly (DFMA) product design hints
- DFMA rules & checklist
- DFMA estimating assembly time
- DFMA worksheet & costing

#### **Module 4 - Project-orientation for DFM practice**

The objective of this module is to provide students with an opportunity to combine the knowledge and skills they learned in the previous modules and apply them to a final project. Many industrial products were prepared for students to use to practice DFM, including drawings, assembly information and cost information about each product (see Figure 1 for an example of one of these products). A team of 4-6 students take on the traditional roles in a DFM process in their redesign of the product, such as design engineer, manufacturing engineer, sales engineer, and so on. There are three lessons in this module in which students learn to redesign their product systematically by:

- evaluating an existing design in terms of a target production cost;
- applying their knowledge of DFM to redesign the product using computer-aided design tools;
- estimating the cost of the redesign to prove the effectiveness of their proposed new product.

As an example, Figure 1 shows two pepper grinders. One is the original product, and the other is the proposed new product design from a group of students using the knowledge they learned from the DFM modules. Table 1 shows the costs saved with the new

proposed product design shown in Figure 1. This activities-oriented final project provides students with real-life learning situations that better prepare them for future employment than traditional curricula do.

These DFM curriculum modules were developed through the cooperative efforts of three different Midwestern institutions and with industrial experts serving as advisors to this development. Although the development team is confident in the design of this new curriculum, there is a need for conducting pilot tests to continuously and improve the modules. The procedure and outcomes from pilot testing of the DFM curriculum are presented in the following section.

**Pilot-test procedure and outcomes**

After the DFM curriculum was developed through the cooperative efforts of three institutions (one university in Iowa and two community colleges in Iowa and South Dakota), this curriculum was further pilot tested at a community college in Spring 2002 and at another in Fall 2002.

**Pilot test in spring 2002**

After the curriculum was first developed, the spring 2002 pilot test focused on the curriculum’s teaching content. The questions that the curriculum developers had in mind from this pilot test were:

- Is the teaching sequence logical to instructors and students?
- Is the time allotment appropriate?
- Is the content interesting to students?
- Are there any PowerPoint slides and/or PowerPoint presentation scripts that do not make sense?
- Are the assignments relevant to the lessons?

Considering these questions, pilot test surveys were developed to ascertain the success of the modules in the classroom and to assist in further module development. The surveys were created for both the students and the instructor, each to be utilized in the analysis of the curriculum’s organization, comprehensibility, and logic.

Figure 1. An example of proposed new product designs by students. The left pepper grinder is the original design of a pepper grinder. The right one is the proposed new design.

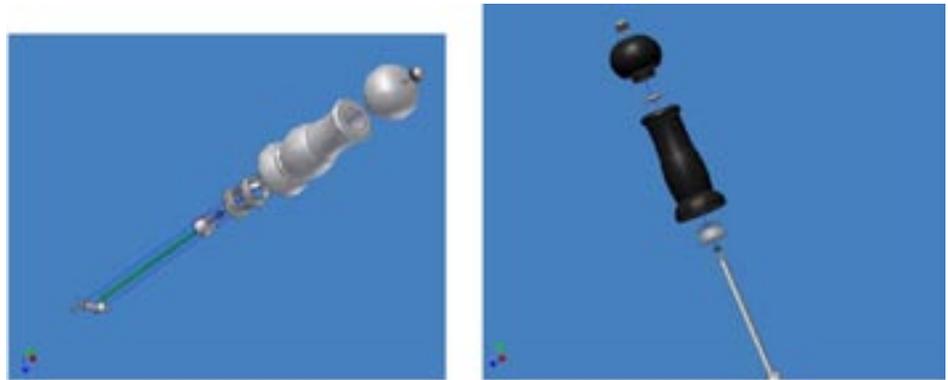


Table 1. Original cost of the old product design

Comparison Chart				
	Fabricated Cost	Purchased Cost	Assembly Cost	Total Cost
Original Product	\$3.27	\$5.12	\$0.30	\$8.69
Redesigned Product	\$2.7475	\$4.1525	\$0.10	\$7.00
Save Money	\$0.5225	\$0.9675	\$0.20	\$1.69

Table 2. Sample instructor lesson survey

Lesson Objective	Rating (1-5)	Comments
1. Understand what Design for Machining is.	5	Very clear.
2. Describe the goals for Design for Machining.	4	Could be more specific.
3. Understand examples of implementation of Design for Machining.	4	More examples

Table 3. Sample student lesson survey

M2D1								
Lesson Objective	Rating (1-5)	Stu#2	Stu#3	Stu#4	Stu#5	Stu#6	Stu#7	Avg
1. Understand what Design for Machining is.	4	5	5	5	5	5	4	4.71
2. Describe the goals for Design for Machining.	4	5	4	4	4	5	4	4.29
3. Understand examples of implementation of Design for Machining.	4	5	5	4	5	5	4	4.57

Overall 4.52

Comments:

1. I had no clue about anything in this chapter before we started going over it. Now I understand it.
2. All Machining processes were explained well.
3. It was good.

Each lesson has an accompanying survey with a list of the lesson objectives that the students should know following the tutorial. Students were asked to rate the effectiveness of the lesson material with a ranking of 1 to 5, 5 being most effective. Likewise, the instructor was also asked to rate the materials and explain any errors or highlight lessons that they felt were ineffective. Examples of an instructor lesson survey and a student lesson survey are shown in Tables 2 and 3 on page 4.

With the knowledge obtained from the lesson surveys, modification to the module content was made.

In addition to the instructor and student surveys, class sessions were video-taped, allowing for further analysis of a lesson's success. For example, the taped videos can be reviewed to observe any differences in dialogue between the script and the instructor, which could show areas for improving the script. If any lesson is given a poor score in the surveys, the information acquired from the tape will assist in understanding what needs to change to improve the effectiveness of the lesson. In addition, each lesson's actual time was recorded to compare the difference between the estimated lesson times and the actual lesson times, so the lesson time allotments can be more realistic.

These collected surveys and transcribed tapes were used to modify the curriculum. In the meantime, the curriculum developers also designed a student satisfaction survey to be administered at the end of pilot testing to see whether the curriculum satisfied the students (see Table 4). The results showed that the overall quality of curriculum topped the student satisfaction list, meaning that the students enjoyed the DFM contents included in the curriculum.

**Pilot test in Fall 2002**

After the first pilot test of the curriculum, the contents were modified according to the responses from the class. The modified curriculum was then pilot tested again at a different community college. The second pilot test, like the

**Table 4. The results of the student satisfaction survey (Rating Scale: 5 is excellent, 1 is poor)**

Rank	Item	Description	Rating
1	2..	The quantity of material covered was appropriate.	4.43
2	5.	The final project is relevantly designed to apply the whole knowledge of this course.	4.33
3	3.	The homework assignments were relevant.	4.29
4	1.	The course appeared to be well organized and presented logically.	4.14
4	4.	The reading assignments were appropriate.	4.14
4	6.	The assignments were always finished on time.	4.14
4	10.	The lessons were easy to understand and apply in the final project.	4.14
4	11.	The lessons were helpful to enhance my knowledge for my future career.	4.14
9	9.	This course has improved my ability to interpret and evaluate information.	3.86
10	7.	You always got feedback on time when you submitted an assignment for assessment.	3.57
11	8.	The grading system was clear and objective.	3.43

first, served to identify areas where the curriculum could be improved. In addition, the second pilot test was designed to evaluate the effectiveness of the curriculum in teaching DFM. The basis of this evaluation was a DFM knowledge test consisting of 18 knowledge-based DFM questions developed by the staff to measure student comprehension. To measure students' comprehension of the curriculum, the test was administered twice: once before the instruction (pre-test) and once again after the instruction (post-test).

Data was collected during the fall of 2002 at the second pilot test community college. Of the eighteen students participating in the pilot test, three were female and fifteen were male.

**Test Hypotheses**

After all the completed tests were returned to the project center, the data analysis for testing hypotheses was conducted as follows. This test was used to evaluate students' understanding (knowledge) of the DFM curriculum.

**Test on the number of the skipped ("I don't know") questions**

A. *Test on the percentage of skipped questions*

The test was designed with an "I don't know" option included in each test question so students who have a vague idea about a certain question can honestly show their knowledge. Therefore, the percentage of students choosing option (E), "I don't know", from the total questions will be compared in the pre- and post-tests.

$$H_0: \mu_{E-pre} = \mu_{E-post}$$

$$H_1: \mu_{E-pre} \neq \mu_{E-post}$$

The average percentage of students choosing option (E) on the pre-test is denoted as

$$\mu_{E-pre} = \frac{\sum_{i=1}^n E_{pre}^i}{n}, \text{ and that for the post-test}$$

$$\text{is defined as } \mu_{E-post} = \frac{\sum_{i=1}^n E_{post}^i}{n},$$

where i and n denote the i<sup>th</sup> subject and the total number of the subjects tested, respectively.

The percentage of the individual i<sup>th</sup> student choosing option (E) is given as the following equation for the pre-test and the post-test:

$$E^i = \frac{QE^i}{QT} \times 100\%, \text{ where}$$

$QE^i$  is the total number of questions that the student selected (E) “I don’t know” for the knowledge test for the subject  $i$ , and

$QT$  is the total number of questions used to test teamwork knowledge. In this study,  $QT$  is 18.

In addition to the hypothesis concerning the percentage of questions for which students chose option (E), a second hypothesis concerning the percentage of questions for which students chose correct answers was also tested as follows.

**B. Test on the percentage of correct answers**

$$H_0: \mu_{\text{pre-correct}} = \mu_{\text{post-correct}}$$

$$H_1: \mu_{\text{pre-correct}} \neq \mu_{\text{post-correct}}$$

$\mu_{\text{pre-correct}}$  = average percentage of correct answers for pre-test for all the  $n$  subjects.

$\mu_{\text{post-correct}}$  = average percentage of correct answers for post-test for all the  $n$  subjects.

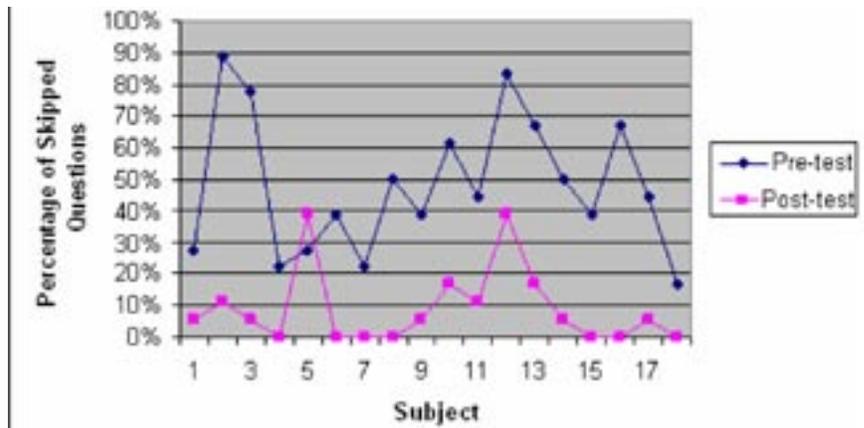
**Results**

**The percentage of skipped (option (E) “I don’t know”) questions.**

Students chose option E (I don’t know) much more frequently in the pre-test (see Figure 2) than in the post-test. In the pre-test, nine of 18 students chose option E for more than half of questions, with one student skipping as many as 16 out of 18 questions. In the post-test, more than 75% of the students skipped two or fewer questions. Comparing the pre-test to the post-test, with the exception of one student whose percentage of skipped questions increased from the pre-test to the post-test, the percentage of students who chose, “I don’t know” decreased in the post-test.

A paired-samples t-test showed that participants skipped significantly fewer questions on the post-test than on the pre-test ( $t = 7.854$ ,  $p < .01$ , as shown in Table 5.)

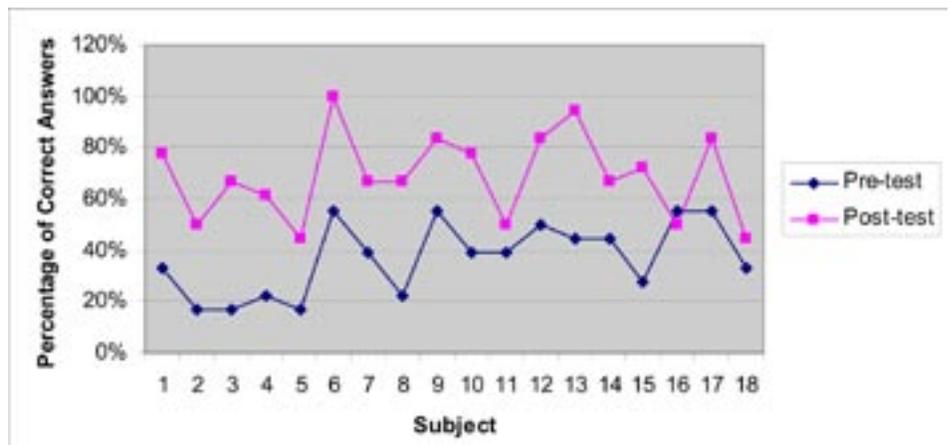
**Figure 2. The comparison between the percentages of skipped questions on the pre-test and on the post-test.**



**Table 5. A paired-samples t-test of percentages of skipped questions between the pre-test and the post-test.**

	Pre-test	Post-test
Mean	48.1%	9.0%
Variance	4.8%	1.5%
Observations	18	18
df	17	
t Stat	7.854025	
t Critical one-tail	1.739606	
P(T<=t) one-tail	2.34E-07	

**Figure 3. The comparison between the percentages of skipped questions on the pre-test and on the post-test.**



**Table 6. Summary of paired-samples t-test for the knowledge test**

	Pre-test	Post-test
Mean	37.0%	68.8%
Variance	2.0%	2.8%
Observations	18	18
df	17	
t Stat	-9.0032	
t Critical one-tail	1.739606	
P(T<=t) one-tail	3.53E-08	

### **The percentage of correct answers**

Most of the participants answered more questions correctly in post-test than in the pre-test with the exception of one student, who had less correct answers in the post-test than in the pre-test (shown in Figure 3). A paired-samples t-test showed that the participants correctly answered significantly more questions in the post-test compared to the number in the pre-test ( $t = -9.0$ ,  $p < .01$ , as shown in Table 6).

### **Discussion**

Most students skipped a large number of questions when taking the DFM knowledge pre-test during the first week of the semester. However, most students only skipped a few questions when taking the post-test at the end of the semester, even though some of their answers were incorrect. The students also significantly perform better on the post-test than on the pre-test in terms of the number of correct answers. The higher answer rate and higher correct answer rate could be attributed to the students' exposure to the curriculum during the 12 weeks of instruction.

### **Conclusion**

This study investigated a new way of teaching technical education students

DFM knowledge and skills using two pilot tests and the examination of the outcome of the pilot tests with an assessment instrument, the DFM knowledge test. Nine students participated in the second pilot test during the fall of 2002. Results comparing the students' DFM knowledge before and after the twelve-week exposure to the Advance Technical Education (ATE) curriculum indicated significant improvement in students' knowledge and skills. The result of the DFM evaluation indicated improvement in DFM skills and techniques among students. These findings suggest that students learn DFM better from coursework that incorporates content knowledge and practical, real case examples.

The initial success of teaching the DFM contents of the curriculum at two community colleges calls for further study of the following areas of the DFM curriculum:

1. The effectiveness of teaching the same DFM content to community college students with different geographic backgrounds.
2. The effectiveness of teaching the same DFM content to different technical education students in different academic settings, such as four-year universities and high schools.

3. The effectiveness of teaching the same DFM contents via the World-wide Web.

### **References**

- Anderson, D. (1990). Design for manufacturability—Optimizing cost, quality, and time-to market. CIM Press: Lafayette, California.
- Black, J. T. & Hunter S. L. (2003). Lean Manufacturing Systems and Cell Design. Dearborn, Michigan, Society of Manufacturing Engineers.
- Boothroyd, G., Dewhurst, P. & Knight, W. (2002). Product Design for Manufacture and Assembly second edition – revised and expanded. New York: Marcel Dekker.
- Bralla, J. G. (1999). Design for Manufacturability Handbook. New York: McGraw-Hill.
- Bertoline, G. R. & Wiebe, E. N. (2003). Fundamentals of Graphics Communication. New York: McGraw-Hill
- Przirembel, C. (1995). Integrating the Product Realization Process (PRP) into the Undergraduate Curriculum, ASME International, New York. (ISBN 0-7918-0126-8)
- O'Driscoll M. (2002). Design for Manufacture. *Journal of Materials Processing Technology*, Vol. 122, pp 318-321.