NYSCATE MODULE GUIDE 7/30/02 FIELD TEST VERSION

Design for Manufacture

TABLE OF CONTENTS

NYSCATE MODULE GUIDE
Design for Manufacture

I. INTRODUCTION AND OVERVIEW

ABSTRACT
By exploring the best way to manufacture an item, this module provides students with the opportunity to learn at a variety of levels about design for manufacturing.

- At the first, most obvious level, students learn about different manufacturing technologies, materials, assembly techniques, finishing, and packaging.

- Students also have opportunities to apply and sharpen specific skills and concepts in science and mathematics, and to use their reasoning and creative skills.

- At a higher, more important level, students gain an understanding of learning-by-doing and learning-by-necessity. These important concepts are used in the real-world working environment.

- The big picture is that students learn important, fundamental concepts about what engineering is. They learn about evaluating different parameters and making trade-offs to determine the best way to accomplish specific goals.

Students accomplish these learning objectives by designing a product to be mass-produced. To solve this Design Challenge, students need to learn about materials and manufacturing methods. Then they need to evaluate design options and make decisions based on information about manufacturing methods and considerations.

Knowledge and Skill Builders (KSBs) are completed to support the Design Challenge. Some KSBs provide background information while others provide opportunities to apply the information. For instance, students are asked to “reverse engineer” a product and to speculate about how a product might be manufactured. They then tour a manufacturing facility to test their speculations.

GRADE LEVEL
Second year of community college

TIME ALLOCATION IN 45-MINUTE PERIODS

Stretched over one semester, roughly two weeks of time:

Four to six one-hour class periods
Two lab periods of two to three hours each

EXISTING COURSES ENHANCED BY THE MODULE

Any basic engineering or engineering exploration courses

SOURCES

For an idea of what is out there:
Assembly magazine (www.assemblymag.com)
PHD Automation products (www.phdinc.com)
Basics of manufacturing technology (www.ee.washington.edu/conselec/CE/kuhn/manufact/95x2.htm)
Manufacturing Center (www.manufacturingcenter.com)

II. DESIGN CHALLENGE OVERVIEW

SETTING THE CONTEXT FOR STUDENTS

Introduction
The field of manufacturing engineering is an exciting, fast-changing field that encompasses many areas of expertise. Keeping abreast of the latest electronic, control, manufacturing, and management concepts allows for continuous improvement of efficiencies and products, which are the only true guaranties of business security.

Your team of three to four people has been charged with designing a product to be manufactured. Since the product must be produced in large quantities, you are to evaluate and select different materials and manufacturing techniques that optimize the mass production process.

After learning about and evaluating the parameters, and comparing at least two different product styles, you are to make a model of the item. The model, which can be a virtual model, does not have to be made of the same materials or by the same methodologies you proposed; but it should enable you to illustrate the key features you evaluated and selected.

Design Challenge
You are to design a desktop CD holder, taking into account factors to optimize its manufacture.

Build a model of one of the styles you have analyzed. Obviously, the model does not have to be made of the same materials or use the same methodologies recommended in your report, but it should illustrate some of the major decisions you made and defended. This model might be a physical model or, if you already have adequate computer design skills, a 3-D virtual model.

Prepare a written report. In the report, your team is to compare and contrast at least two product styles. For example, you might look at a drawer-type CD holder versus a flip-lid style. Your report should include an evaluation of the possibilities presented in the list of methodologies below. In addition, you should justify the design decisions you made regarding manufacturing methodologies (materials, assembly techniques, etc.). For details, see Consolidated Outline of Manufacturing Methods for Students, found in the Additional Support for Teachers section.

Specifications
The CD holder must have the capacity to hold at least 20 standard-sized CDs on a desktop.

Plan to produce a lot of these; using as much automation as possible during the manufacturing process is likely to pay off.

Constraints

Do not overconcern yourself with features of the CD holder. Assume that there is a large demand for holders, and any reasonable features you choose will sell in the marketplace. The holder can be a drawer style, stackable, open style, flip style, etc. It can be cheap, expensive, purely functional, or decorative. Do not focus on features that are important to you personally. Your main concern should be to design a quality holder that can be manufactured in quantity at a reasonable cost.

III. GOALS AND LEARNING OUTCOMES

After completing this module, students will:

- be familiar with a variety of manufacturing methodologies such as injection molding, blow molding, metal casting and sheet stamping and bending, assembly techniques and automation, surface finishing, and packaging techniques;
- understand each methodology's applicable materials, and advantages and disadvantages including relative costs and effects;
- be familiar with a variety of materials used to manufacture and package products; and
- understand the advantages and disadvantages of the materials in the design, manufacturing, and packaging of products.

In this module the teacher:

- prompts acquisition of mathematical analysis, scientific inquiry, and informed design processes;
- fosters cooperative learning as students work in design teams;
- provides opportunities for improving communication skills through the use of the Design Journal or Design Folio, Design Report, and group presentation;
- introduces students to the design process through an engaging Design Challenge;
- involves individuals and groups as they compose, construct, test, improve, and present their design solutions;
- helps students refine what they already know about informed design and more specifically designing for manufacturing;
- guides students as they identify and investigate factors relevant to design for manufacturing decisions; and
- provides opportunities for improving communication skills through the use of the Design Journal or Design Folio, Design Report, and group presentation.

IV. TIMELINE CHART

SESSION	FOCUS MODEL COMPONENT (For Teacher)	INFORMED DESIGN LOOP COMPONENT (For Student)	ACTIVITY
1	Focus Discussion on Problem Context	Clarify Design Specifications and Constraints	Present Design Challenge. Define and go over examples of design for manufacturing (DFM).
1	Organize for Informed Design		Review the informed design process. Complete KSB T1: The Informed Design Cycle, if necessary. Clarify what is required of students. Form design teams.
2	Coordinate Student Progress	Research and Investigation	Assign and discuss KSB T9: Reverse Engineer a Product and KSB T10: Find a Good Example of DFM. If time does not permit students to do both KSBs, assign only one. Complete KSB T2: Product Design Considerations.
3–5	Coordinate Student Progress		Complete KSB T3: Manufacturing Methods – Materials. Complete KSB T4: – Construction Elements. Complete KSB T5: – Assembly Techniques. Complete KSB T6: – Coating. Complete KSB T7: – Packaging. Complete KSB T8: – Automation.
6, Lab	Coordinate Student Progress	Generate Alternative Designs Choose and Justify Optimal Design	To have students apply knowledge gained in KSBs T2–T8, work on KSB T9: Reverse Engineer a Product and KSB T10: Find a Good Example of DFM (or one of these KSBs). Design teams create sketches and/or models of alternative design solutions. Design teams select and defend their choices of a preferred alternative.
7 (Field	Coordinate		Continue work on KSB T9: Reverse

Trip optional)	Student Progress		Engineer a Product. Design teams continue work on the Design Challenge independently.
8, Lab	Coordinate Student Progress	Construct a Working Model	Discuss KSB T9: Reverse Engineer a Product. Have informal presentations for KSB T10: Find a Good Example of DFM. Design teams work on Design Challenge models.
9	Unite Class for Thinking about Accomplishments	Test and Evaluate the Design Solution	Present Design Challenge models. Discuss design features. Hand in written reports.
10	Sum Up Progress on Learning Goals		Evaluate individual student work, give grades, and share results with students.

V. MATERIALS AND RESOURCES

MATERIALS AND SAFETY CONSIDERATIONS

Safety considerations
While building a prototype or disassembling an item to be studied, follow precautions for using tools, adhesives, and paints.

When touring a manufacturing facility, follow all safety precautions required. If you have questions about what is required, ask.

Resources
A Design Folio (DF) or Design Journal for each student is required.

Depending on the types of models the students will create, some construction materials will be required. This might be as simple as foam board, glues, tapes, etc. It might include CAD systems if virtual models are to be made.

The instructor will need to develop a relationship with a local manufacturing firm. Most areas have some kind of manufacturing locally. If your area does not, maybe a video show or documentary, homemade or professionally made, could be used.

VI. PROCEDURAL SUGGESTIONS

PEDAGOGICAL FRAMEWORK REFERENCE

A separate document, the NYSCATE *Pedagogical Framework,* provides an in-depth understanding of the NYSCATE challenge statements, the FOCUS on Informed Design pedagogical model for teachers, student Knowledge and Skill Builders (KSBs), the informed design loop for students, and more.

SUGGESTIONS

Here suggested strategies are presented within the context of the NYSCATE FOCUS on Informed Design, a pedagogical model for teachers. The FOCUS components are: **Focus** discussion on the problem context, **Organize** for informed design, **Coordinate** student progress, **Unite** the class in thinking about what has been accomplished, and **Sum up** progress on the learning goals (see NYSCATE *Pedagogical Framework*, p. 7, for more on this model).

This module contains one Design Challenge, but there are two KSBs that include major activities: KSB T9: Reverse Engineer a Product, and KSB T10: Find a Good Example of Designing for Manufacture. The challenge and these two KSBs provide the reason for students to learn the content of the remaining KSBs, which provide specific information for students to consider in designing a product for manufacturing.

*Session 1: **Focus Discussion on the Problem Context***

Presenting the Design Challenge. To focus students on design for manufacturing, distribute to the class some simple product such as a paper cup or pencil. You might use one or several different products. While each student has a product in hand, ask him or her to consider how the product might be redesigned in some small way. After collecting some ideas, ask if the redesigned products would be easier or more difficult to manufacture, and then ask why or why not. Would the redesign add to the cost? Would any improvement outweigh any added cost? Would potential customers agree?

Present the Design Challenge to the class and discuss it until it is

INTRODUCTORY PACKET

Overview of the Module and Design Challenge

HERE'S WHAT YOU WILL DO

In the NYSCATE module *Design for Manufacture,* you will work in a group to:

- understand and investigate possible solutions to a given problem;
- investigate the problem by completing Knowledge and Skill Builder (KSB) activities, and by using information resources that you identify;
- prepare a report showing how you considered important factors in making your design decisions;
- base your design and redesign upon technological, scientific, and mathematical concepts;
- see that your design meets specifications and constraints;
- use appropriate tools and materials to build a model of your design, which is useful in illustrating, analyzing, and defending your design decisions;
- develop and use a repeatable and reliable method for testing your design; and
- make or propose improvements to your design on the basis of your analysis and testing.

PROBLEM CONTEXT

Introduction

The field of manufacturing engineering is an exciting, fast-changing field that encompasses many areas of expertise. Keeping abreast of the latest electronic, control, manufacturing, and management concepts allows for continuous improvement of efficiencies and products, which are the only true guaranties of clear.

Session 1: ***Organize for Informed Design***

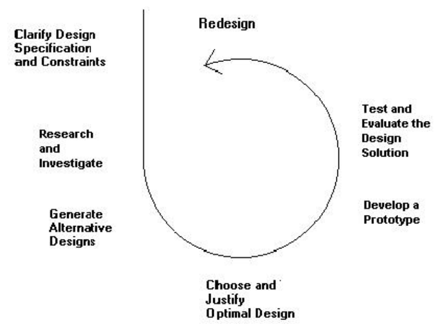
The informed design process. If you know the students are unfamiliar with the informed design process, have them complete KSB T1: The Informed Design Cycle. Some students may have been involved in design projects before, but keep in mind that informed design stresses avoiding trial and error by researching and investigating a topic before and while one designs and constructs. The cycle of steps can provide a general guide for student work as well.

Student requirements. At this point make clear what is required of students: when the work will be done, what will be graded, and the standards used for grading (see NYSCATE *Pedagogical Framework*, p. 10, for more on this topic).

Technology Knowledge and Skill Builders (KSBs)

KSB T1: The Informed Design Cycle

A method is shown (see informed design loop below) to achieve informed technological design. The cycle includes several phases. In this model, the phases together are referred to as the design cycle. The model involves repeatable phases that engage you in the design process.



You are to work in a manner similar to that of adult professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the same order each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitoring performance against desired results and making changes as needed. Usually, following design criteria leads to trade-offs taking place. Seldom is true perfection obtained.

Further information on the phases of the informed design cycle follows:

- *Clarify design specifications and constraints.* Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

Design teams. Form design teams of two to four students each. You should take a hand in this so no students are left out and all teams have adequate human and physical resources to work with. Heterogeneous teams are generally recommended (see NYSCATE *Pedagogical Framework*, p. 12, for more on this topic).

Session 2: ***Coordinate Student Progress***

Application exercises. Assign and discuss KSBs T9 and T10. These

KSB T9: Reverse Engineer a Product
Reverse engineer a product and then learn about its actual manufacturing techniques. The product will be determined by the instructor. Optimally, it will be the result of a collaboration with a local manufacturing facility. After the item is examined, you (individually or in groups) create a written report proposing methods to manufacture and assemble the product. Consideration is given to other similar items that might be manufactured at the same facility. Notes are kept in individual Design Folios (DFs) or Design Journals. You then go on a field trip to the manufacturing facility, listen to a presentation from a manufacturing firm, or view a video presentation to see how the items are actually manufactured. Add to your original report comments on manufacturing methodologies that were or were not expected. Suggestions and ideas for improvements / automation are included. The whole class then discusses reports and ideas.

KSB T10: Find a Good Example of Designing for Manufacture
Each of you should find an example of an existing product that is an interesting example of how a product was designed to optimize manufacturing. These products can be presented at any time throughout the course. A brief show-and-tell can be given in front of the class. Some examples will be provided.

exercises include seatwork and a field trip to focus students on the issues involved in maximizing a product design for manufacturing. The Design Challenge differs from these KSB exercises in that it requires the design of an actual product and the making of a model. It is best if students can complete both KSB T9 and KSB T10, but if time does not permit, assigning one could suffice. Students would most likely find KSB T9, which includes a field trip, the most challenging and interesting. These KSBs are assigned here but provide an ongoing context for applying the information students learned in KSBs T3–T8.

General product design considerations. Have students complete

KSB T2: Product Design Considerations

The following are items to consider when designing a product. Since the scope of this project does not include all these factors, do not spend too much time analyzing them. Give brief consideration and make decisions with regard to the CD holders you will be designing:

Product Design Considerations:

- Intended customer use / marketability
  - Cheap model versus “executive” model
- Overall cost
- Durability / length of service
  - How important is it that this lasts?
  - Throw-away versus “heirloom”
- Style (ornate, plain, etc.)
- Environmental (“green”) considerations
  - Production of waste / hazardous waste
  - Reclamation / reworking / recycling of unused materials
  - Environmentally friendly packaging

Designing for manufacture (a concept that has been left off the list above) is just one aspect of product design

KSB T2: Product Design Considerations. This KSB provides a general framework for the series of KSBs on specific considerations, which follow.

Sessions 3–5: ***Coordinate Student Progress***

Informing details. Complete KSB T3: Manufacturing Methods – Materials; KSB T4: – Construction Elements; KSB T5: – Assembly Techniques; KSB T6: – Coating; KSB T7: – Packaging; KSB T8: – Automation. These KSBs provide detailed information about the factors that

KSB T3: Manufacturing Methods – Materials

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.
You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, pool your knowledge through discussion.
Materials:

- Plastic
  - Injection molding
  - Blow molding
  - Vacuum forming
  - Extruding
  - Sheets formed
- Metals
  - Casting
  - Machining
    - CNC machines
  - Extruding
  - Forming sheets
    - Stamping / die-cutting
    - Bending
- Other materials
  - Cloth
  - Wood
  - Glass

KSB T4: Manufacturing Methods – Construction Elements

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Construction elements:

- Hinges
  - Traditional pin and rolls
  - Flexible materials
  - Molded crimped hinges
- Closures
  - Hardware
  - Snaps and latches
- Handles
  - Attached
  - Incorporated into item
- Parts count reduction by using common components
- Part shapes that allow nesting / stacking to reduce storage volume

KSB T5: Manufacturing Methods – Assembly Techniques

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.
Assembly techniques:

- Snap-together components
- Fasteners
  - Screws
  - Pop-rivets
- Glue
  - Consider solvents and how they apply to the areas of regulations, safety, and health.
- Welding (metal or plastic)
- Heat sealing, ultrasonic heat sealing

KSB T6: Manufacturing Methods – Coating

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.
You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.
Coating:

- Painting
  - Spray
  - Powder coating
  - Electrostatic painting
  - Consider solvents and how they apply to the areas of:
    - Regulations
    - Safety and health
- Stamping
  - Spray printing
  - Transfer printing
  - Silkscreen printing
- Decals

KSB T7: Manufacturing Methods – Packaging

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Packaging:

- Packaging techniques
  - Packaged in cardboard
  - Packaged in plastic bags
  - Shrink-wrapped
  - Blister-packed
- Packaging that can be used for a variety of similar items
- Packaging / shipping density
- Environmental concerns
  - Minimizing packaging materials to be discarded
  - Options for packing fillers
- Packaging customer appeal
  - Information / pictorial, written, product viewing, feel, trial
  - Attention getting
- Store handling, display
  - Shelf space
  - Display
  - Checkout, bar code placement, etc.
- Warehouse and store storing, handling

KSB T8: Manufacturing Methods – Automation

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Automation:

- Material handling
  - Parts collecting
  - Part transfers
    - From one machine / step to the next
  - Part orienting
    - Parts feeders
    - Pick-and-place
  - Part storage
    - Temporary
      - Accumulators – belt, tower accumulators
      - Dancers
    - Longer term
      - Warehousing
      - Tracking
    - Containers
- Consider automation and how it applies to the following areas:
  - Assembly
  - Packaging
  - Inspection / QC / QA
- Reconfigurable work cells versus dedicated equipment:
  - Reconfigurable centers can be converted to similar products.
  - Dedicated – optimized for one (or a few) applications

should be considered in designing a product for manufacturing. They provide information, guidance in gaining information from other sources, and some student exercises; in addition, they call for teacher-led discussions to clarify, integrate, and help apply the information to the exercises in KSBs T9 and T10.

*Session 6, Lab I: **Coordinate Student Progress***

Applying the information to the exercises. Return to KSB T9 and T10 assignments. Discuss student presentations about how the products focused on in these KSBs were manufactured. Whenever possible, return student thinking to the factors considered in KSBs T2–T8.

Design Challenge work: Generating and choosing from alternatives. Give design teams some time to explore possibilities by generating, sketching, and modeling alternative designs for the CD holder. The students should have been working on the Design Challenge, especially the preparatory research and investigation phase, outside of class sessions. This phase is supported by completing KSBs T2–T8 and by the independent investigative work of teams. But students most likely would appreciate the opportunity to work closely with their team in the laboratory setting with materials handy. Discussions within teams will be helpful, but whole class discussions may also be useful.

When teams are ready, ask them to bring their exploratory work to a close by choosing a preferred design from the alternatives and preparing a justification for their choice. Their choice and justification should be shared with the class.

Session 7: ***Coordinate Student Progress***

Field trip. After students have had a chance to speculate about how a particular local product is manufactured (as assigned in KSB T9), and to discuss their ideas with the class, take them on a field trip to a local factory where they can evaluate their speculations directly. This session is optional if you have chosen not to do KSB T9. Of course, if time is available, it could be spent on KSB T10 or the Design Challenge.

Session 8, Lab II: ***Coordinate Student Progress***

Culminating application exercise. Discuss KSB T9: Reverse Engineer a Product. Have informal presentations for KSB T10: Find a Good Example of Designing for Manufacture. As before, encourage students to consider the factors dealt with in KSBs T2–T8. These presentations should be brief and not media laden as this can distract from their purpose. Later, when sharing their Design Challenge solutions, students will have sufficient time to make a more formal, multimedia presentation.

Model building. At this time, design teams should be given a chance to work on their Design Challenge models with available materials. Since some model-building materials may have to be brought to class by students, it will be important to let students know ahead of time that they will be working on model building during this session.

Each team should build at least one model. Obviously, it does not need to be made of the same materials or use the same methodologies recommended in your report, but it should show evidence of the reasoning presented in the report. This model might be a physical model or, if students already have adequate computer design skills, a 3-D virtual model.

Session 9: ***Unite Class for Thinking about Accomplishments***

Presentation of Design Challenge models. This should be a more formal presentation than students have given in previous parts of the module. You will have to schedule presentations and make sure that multimedia equipment is available. You should also ensure that students are prepared to listen and ask questions when other team presentations are made. A lively interaction is usually rewarding for both the presenters and audience (see NYSCATE *Pedagogical Framework*, p. 27, for more on this topic). You might want to review the goals of this module before the session, as this is your last opportunity to direct student thinking toward accomplishing these goals. In general, the session should be conducted in a positive atmosphere; more attention should be focused on accomplishments than on criticism.

Collect all written assignments. Of course, in collecting assignments you may have to deal with issues of incomplete or late work. Your policies in this regard should have been spelled out in writing, in a clear and firm manner, at the beginning of the module or course.

Session 10: ***Sum Up Progress on Learning Goals***

Grading work. Before the last session of the module, all work will have to be graded in a manner consistent with the description provided in the first session. You may find the suggestions and scoring rubrics provided in the NYSCATE *Pedagogical Framework* useful (see NYSCATE *Pedagogical Framework*, p. 28, for more on this topic).

Feedback. Of course, students will want to know their grades, but specific feedback is often more important in helping to meet the learning goals. It is very helpful if students can meet with you regarding their progress individually, even if only for a very few minutes. Certainly, a portion of a class session can be devoted to your general reaction to student work and to student feedback on the module.

VII. ADDITIONAL SUPPORT FOR TEACHERS

OVERVIEW OF MODULE CONTENT

This module is designed to be flexible. Examining some of the KSBs either more or less in depth can vary the level and time requirements of the course. Some KSBs could be eliminated and some can be created.

Some notes (a version for students and a version for the instructor) are included in the handout section. These are a consolidation of the KSBs relating to manufacturing methods.

BUILDING KNOWLEDGE AND SKILL

The challenge your students face involves designing a CD holder that optimizes its potential for manufacturing. Many will want to proceed by trial and error. To prevent this, you must convince them that they need to find out what they now know as a group and what they will need to know about the process of design, and about design for manufacturing, in order to complete the challenge properly. The Knowledge and Skill Builders (KSBs) are meant to help students become more informed in both of these areas. Refer to the NYSCATE *Pedagogical Framework* for additional information on the informed design process (p. 6).

LEARNING STANDARDS THAT RELATE TO *DESIGN FOR MANUFACTURE*

(This section is being developed)

ASSESSMENT STRATEGIES FOR *DESIGN FOR MANUFACTURE*

Assessment of student design work should consider many factors and focus on the design process (documented in Design Folio [DF] or Design Journal) as well as the finished product (design solution). Each component of design-related student activity is represented in preliminary rubrics (scoring guides) found in the NYSCATE *Pedagogical Framework* (p. 28). That set of rubrics is generic to all NYSCATE design activities. However, the rubrics can be tailored to a particular assignment and should be discussed with students in advance so that they are aware of the evaluation criteria.

A sample from the set of rubrics is presented here for the design solution:

The Design Solution

A. An accurate sketch of your final design, as built, was drawn.

4. Drawing was on graph paper to scale with all elements included. Isometric view or multiple views (top, side, and front) were shown.
3. Drawing was on graph paper to scale with all elements included. Drawing showed the design in two dimensions (a flat view).
2. Drawing was on graph paper approximately to scale with most elements included.
1. Drawing was not to scale and important elements were missing.

B. Materials and tools were planned and used appropriately in constructing project.

4. Listed materials and tools are present, as well as a description of how they should be used.
3. Prepared complete list of materials required and tools necessary to fabricate with these materials.
2. List of materials was essentially complete; some tools required were not mentioned.
1. Mentioned only a few materials and no tools.

C. The solution worked. It met the design specifications and constraints.

4. The solution solved the problem statement; this was explained in the write-up along with how the specifications and constraints were addressed and/or how the design was modified to assure their being met.
3. The solution solved the problem statement and the constraints and specifications were met.
2. The solution solved the problem but not all constraints and specifications were met in doing so.
1. The solution did not solve the problem; constraints and specifications were not met.

D. The design was creative.

4. The solution was unique; never or seldom has this design been formulated.
3. The solution was functional, but not unique. Similar solutions were common.
2. The solution was similar to others; it may have been a modification or interpretation of someone else's solution.
1. The solution appears to have been copied from someone else's work.

In addition to your assessment of student design process and products, you should assess the quality of students' Design Journals (or DFs), Design Reports, and group presentations to the class. You might include multiple choice, short answer, or extended response questions that provide assessment of design understandings, content knowledge, and technical skill.

CONSOLIDATED OUTLINE OF MANUFACTURING METHODS FOR STUDENTS

Materials:
- Plastic
  - Injection molding
  - Blow molding
  - Vacuum forming
  - Extruding
  - Sheets formed
- Metals
  - Casting
  - Machining
    - CNC machines
  - Extruding
  - Forming sheets
    - Stamping / die-cutting
    - Bending
- Other materials
  - Cloth
  - Wood
  - Glass

Construction elements:
- Hinges
  - Traditional pin and rolls
  - Flexible materials
  - Molded crimped hinges
- Closures
  - Hardware
  - Snaps and latches
- Handles
  - Attached
  - Incorporated into item
- Parts count reduction by using common components
- Part shapes that allow nesting / stacking to reduce storage volume

Assembly techniques:
- Snap-together components
- Fasteners
  - Screws
  - Pop-rivets
- Glue

Consider solvents and how they apply to the areas of regulations, safety, and health.

Welding (metal or plastic)

Heat sealing, ultrasonic heat sealing

Coating:

- Painting
  - Spray
  - Powder coating
  - Electrostatic painting
  - Consider solvents and how they apply to the areas of:
    - Regulations
    - Safety, and health
- Stamping
  - Spray printing
  - Transfer printing
  - Silkscreen printing
- Decals

Packaging:

- Packaging techniques
  - Packaged in cardboard
  - Packaged in plastic bags
  - Shrink-wrapped
  - Blister-packed
- Packaging that can be used for a variety of similar items
- Packaging / shipping density
- Environmental concerns
  - Minimizing packaging materials to be discarded
  - Options for packing fillers
- Packaging customer appeal
  - Information / pictorial, written, product viewing, feel, trial
  - Attention getting
- Store handling, display
  - Shelf space
  - Display
  - Checkout, bar code placement, etc.
- Warehouse and store storing, handling

Automation:

- Automation of all previous areas
- Reconfigurable work cells
- Dedicated equipment

CONSOLIDATED OUTLINE OF MANUFACTURING METHODS FOR INSTRUCTORS

What is “design for manufacture”?

- When designing an item, taking into consideration how the item is going to be produced
- More of a concern in higher volumes / mass production
- Eliminating fasteners – using snap-together parts instead of having to machine screw-holes, etc.
- Making parts shaped so they can be made more efficiently — for example, using tapered pen cap that can be injection molded
- Reducing different parts required by using like components
- Making different products similar, so their production can use reconfigured equipment rather than new equipment — for example, using similar wheels for different “happy meal” cars

Overview of methods of manufacturing:

- Materials (plastic, metal, etc.)
- Construction elements (hinges, knobs, handles, etc.)
- Assembly techniques (snap-together components, fasteners, etc.)
- Coating (paint, print, etc.)
- Packaging (types of packaging)
- Automation (reconfigurable equipment)

Materials:

- Plastic
  - Injection molding
  - Blow molding (milk jugs, “big wheels” frame)
  - Vacuum forming (soda cups)
  - Extruding (snap-in molding)
  - Sheets formed (irregularly-shaped items, placed over mold)
- Metals
  - Casting
  - Machining
    - CNC machines
  - Extruding
  - Forming sheets
    - Stamping / die-cutting
    - Bending
- Other materials
  - Cloth

Wood
Glass

Construction elements:
- Hinges
  - Traditional pin and rolls
  - Flexible materials
  - Molded crimped hinges
- Closures
  - Hardware
  - Snaps and latches
- Handles
  - Attached
  - Incorporated into item
- Parts count reduction by using common components
- Part shapes that allow nesting / stacking to reduce storage volume

Assembly techniques
- Snap-together components
- Fasteners
  - Screws
  - Pop-rivets
- Glue
  - Consider solvents and how they apply to the areas of regulations, safety, and health.
- Welding (metal or plastic)
- Heat sealing, ultrasonic heat sealing

Coating:
- Painting
  - Spray
  - Powder coating
  - Electrostatic painting
  - Consider solvents and how they apply to the areas of:
    - Regulations
    - Safety, and health
- Stamping
  - Spray printing
  - Transfer printing
  - Silkscreen printing
- Decals

Packaging:

- Packaging techniques
  - Packaged in cardboard
  - Packaged in plastic bags
  - Shrink-wrapped
  - Blister-packed
- Packaging that can be used for a variety of similar items
- Packaging / shipping density
- Environmental concerns
  - Minimizing packaging materials to be discarded
  - Options for packing fillers

Automation:

- Automation of all previous areas
  - Material handling
  - Parts sorting and orienting
  - Printing machines
  - Consistent packaging that can be automated
- Reconfigurable work cells versus dedicated equipment

EXAMPLE OF DESIGN FOR MANUFACTURING ELEMENT FOR KSB10: BRADY LOCKOUT/TAGOUT DEVICE

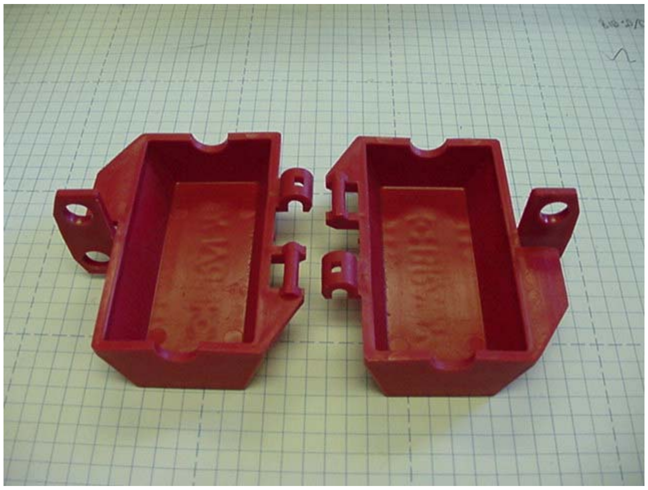
Following is an item that exhibits some design for manufacturing considerations. It is a lockout / tagout device produced by Brady.

The function of the item is to enclose the plug on an electrical device's cord, and to allow a lockout device to keep it closed. The device is shown at the left, around a cord, with a lockout device that allows multiple people with locks to keep it closed. This way, power can be applied to a piece of equipment only after everyone who locked it out has cleared it by removing his or her lock. This is a safety requirement in industrial environments.

The point here is how the cord cover is manufactured. Rather than making an item that requires assembly with hinges, an elegant design was used.

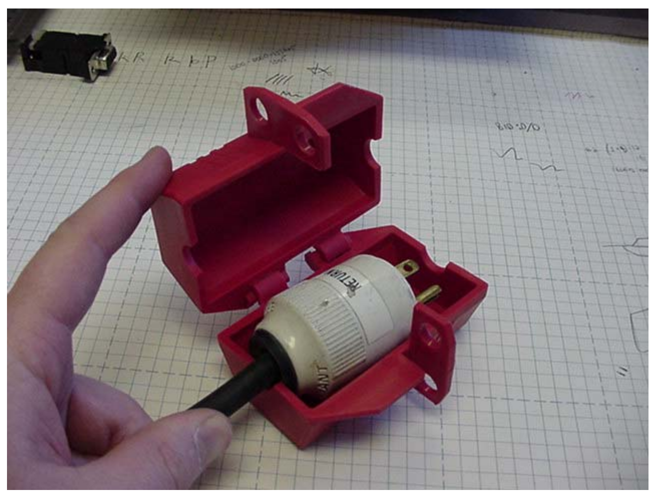
One part is manufactured. There are no left / right halves to match up. Each half is identical.

These can be injection molded.



Two of the parts are used. The identical halves are aligned so they can be snapped together.

No other components — fasteners, hinges, glue, etc. — are required for assembly.



The item is ready for use. You can see the hinges after snapping together.

No printing is required, as the manufacturer's name and part number are molded into the side during the injection-molding step.

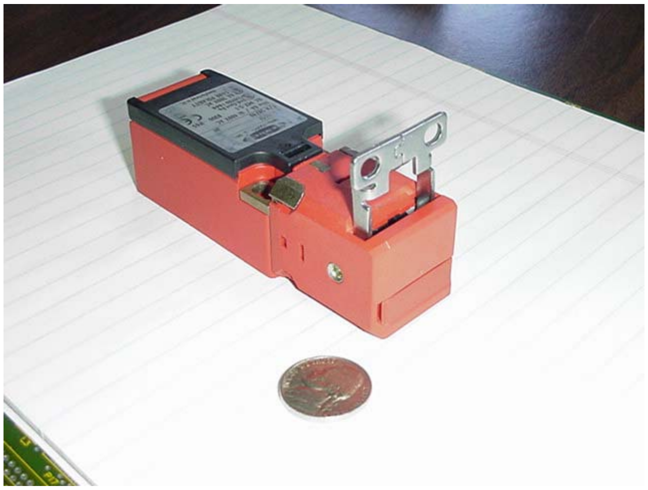
Although the molds used in the injection molding are fairly complex (they have movable stops), this factor is outweighed by the simple assembly.

Reduced part count, no printing, and simple assembly make this a good example of an item that incorporates good "design for manufacturing" concepts.

EXAMPLE OF DESIGN FOR MANUFACTURE ELEMENT FOR KSB10: BANNER KEYED SWITCH

Following is an item that exhibits some design for manufacturing considerations. It is the "key" in a keyed switch produced by Banner.

The purpose of this device is to prevent the use of a machine except when its cabinet door is closed. An irregularly-shaped key is mounted on a machine door, with the switch body mounted on the machine. The switch is turned on only by closing the door. The switch is difficult to operate with the door open, as it requires an item with the correct shape to be inserted into the switch body.



Although it is difficult to see in the photograph, the key is formed from one flat piece of metal. It is stamped out, and then bent. The two ends are brought together and fastened.

The two ends are fastened in a very clever way. In this detail, at the end of the arrowhead, you can see what looks like a puzzle piece.

When the piece is stamped, one end has the “innie” puzzle piece and the other end has the “outie” puzzle piece. The piece is formed, the puzzle piece is assembled, and a pointed punch stamps the outie puzzle piece. This causes it to expand so it is securely pressed and stuck into the other puzzle piece.

This key is a good example of an item that was designed for manufacture because the irregular 3-D shape is created by simply die-cutting a piece of flat stock, forming it, then punching it to fix it. No machining, welding, or fasteners are required. Material use is efficient.

VIII. STUDENT HANDOUT SECTION

Student handouts begin on the next page.

Note: The following Knowledge and Skill Builders are meant to be assigned in a flexible way. Generally, the sequence after KSB T2 is not critical. Some KSBs may last more than one session, and some will take only a portion of a class.

INTRODUCTORY PACKET
Overview of the Module and Design Challenge

HERE'S WHAT YOU WILL DO

In the NYSCATE module *Design for Manufacture,* you will work in a group to:

•understand and investigate possible solutions to a given problem;
•investigate the problem by completing Knowledge and Skill Builder (KSB) activities, and by using information resources that you identify;
•prepare a report showing how you considered important factors in making your design decisions;
•base your design and redesign upon technological, scientific, and mathematical concepts;
•see that your design meets specifications and constraints;
•use appropriate tools and materials to build a model of your design, which is useful in illustrating, analyzing, and defending your design decisions;
•develop and use a repeatable and reliable method for testing your design; and
•make or propose improvements to your design on the basis of your analysis and testing.

PROBLEM CONTEXT

Introduction
The field of manufacturing engineering is an exciting, fast-changing field that encompasses many areas of expertise. Keeping abreast of the latest electronic, control, manufacturing, and management concepts allows for continuous improvement of efficiencies and products, which are the only true guaranties of business security.

Your team of three to four people has been charged with designing a product to be manufactured. Since the product must be produced in large quantities, you are to evaluate and select different materials and manufacturing techniques that optimize the mass production process.

After learning about and evaluating the parameters, and comparing at least two different product styles, you are to make a model of the item. The model, which can be a virtual model, does not have to be made of the same materials or by the same methodologies you proposed; but it should enable you to illustrate the key features you evaluated and selected.

Design Challenge

You are to design a desktop CD holder, taking into account factors to optimize its manufacture.

Prepare a written report. In the report, your team is to compare and contrast at least two product styles. For example, you might look at a drawer-type CD holder versus a flip-lid style. Your report should include an evaluation of the possibilities presented in the methodologies list below. In addition, you should justify the design decisions you made regarding manufacturing methodologies (materials, assembly techniques, etc.). For details, see Consolidated Outline of Manufacturing Methods for Students, found in the Additional Support for Teachers section of this module.

Build a model of one of the styles you have analyzed. Obviously, the model does not have to be made of the same materials or use the same methodologies recommended in your report, but it should illustrate some of the major decisions you made and defended. This model might be a physical model or, if you already have adequate computer design skills, a 3-D virtual model.

Specifications
The CD holder must have the capacity to hold at least 20 standard-sized CDs on a desktop.

Plan to produce a lot of these; using as much automation as possible during the manufacturing process is likely to pay off.

Constraints
Do not overconcern yourself with features of the CD holder. Assume that there is a large demand for containers, and any reasonable features you choose will sell in the marketplace. The holder can be a drawer style, stackable, open style, flip style, etc. It can be cheap, expensive, purely functional, or decorative. Do not focus on features that are important to you personally. Your main concern should be to design a quality holder that can be manufactured in quantity at a reasonable cost.

MATERIALS

Your instructor or team members may provide materials and tools. Your instructor must approve in advance any materials and tools provided by members of your team.

STUDENT REQUIREMENTS

You will be expected to:

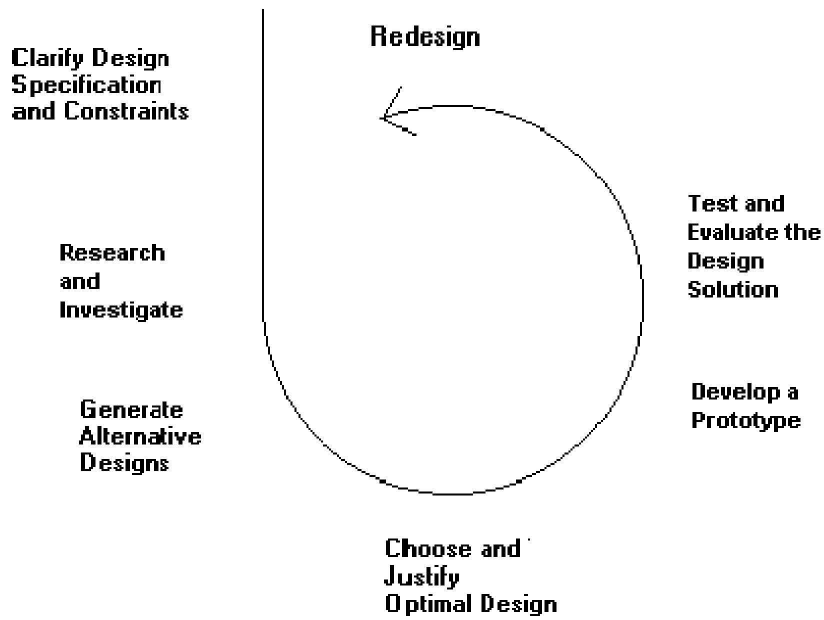
•maintain either a Design Folio (DF) or Design Journal in which you will gather and record information as you complete the Design Challenge for this module;
•complete a final Design Report that summarizes your work and findings. This report is described above in the Design Challenge section;
•construct a physical or CAD model of your design;
•develop a group presentation to explain how your group met the Design Challenge; and
•be assessed on the quality of your work on Knowledge and Skill Builders (KSBs), your Design Journal or Design Folio, Design Report, model, and group presentation.

Your instructor will assess your understanding of the Knowledge and Skill Builders and evaluate the quality of your Design Folio or Design Journal, your Design Report, your model, and your group's presentation.

Technology Knowledge and Skill Builders (KSBs)

KSB T1: The Informed Design Cycle

A method is shown (see informed design loop below) to achieve informed technological design. The cycle includes several phases. In this model, the phases together are referred to as the design cycle. The model involves repeatable phases that engage you in the design process.



You are to work in a manner similar to that of adult professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the same order each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitoring performance against desired results and making changes as needed. Usually, following design criteria leads to trade-offs taking place. Seldom is true perfection obtained.

Further information on the phases of the informed design cycle follows:

- *Clarify design specifications and constraints.* Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

- *Research and investigate the problem*. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues, and questions that relate to addressing this Design Challenge.

- *Generate alternative designs*. Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

- *Choose and justify optimal design.* Defend your selection of an alternative solution. Why is it the optimal choice? Use engineering, mathematical, and scientific data, and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

- *Develop a prototype.* Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

- *Test and evaluate the design solution*. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data, and analyze the data to show how well the design satisfies the problem constraints and specifications.

- *Redesign the solution with modifications*. In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

Develop your understanding

1. Review the informed design cycle and explain how you might use the various phases to guide your design efforts. Identify any procedural changes you would add, delete, or change. Defend your recommendation(s).

2. Review the NYSCATE Design Folio (DF) and determine if you would select it or the Design Journal to help document your work.

3. Pick one example of a product or system that was poorly designed. Explain possible reasons why the manufacturer might have allowed it to be produced with design flaws. Explain consequences (both positive and negative) that might result from a less-than-optimal design.

4. Provide an example of a product or system that you think could benefit from an improved design.

KSB T2: Product Design Considerations

The following are items to consider when designing a product. Since the scope of this project does not include all these factors, do not spend too much time analyzing them. Give brief consideration and make decisions with regard to the CD holders you will be designing:

Product Design Considerations:
- Intended customer use / marketability
  - Cheap model versus "executive" model
- Overall cost
- Durability / length of service
  - How important is it that this lasts?
  - Throw-away versus "heirloom"
- Style (ornate, plain, etc.)
- Environmental ("green") considerations
  - Production of waste / hazardous waste
  - Reclamation / reworking / recycling of unused materials
  - Environmentally friendly packaging

Designing for manufacture (a concept that has been left off the list above) is just one aspect of product design.

KSB T3: Manufacturing Methods – Materials

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, pool your knowledge through discussion.

Materials:

- Plastic
    - Injection molding
    - Blow molding
    - Vacuum forming
    - Extruding
    - Sheets formed
- Metals
    - Casting
    - Machining
        - CNC machines
    - Extruding
    - Forming sheets
        - Stamping / die-cutting
        - Bending
- Other materials
    - Cloth
    - Wood
    - Glass

KSB T4: Manufacturing Methods – Construction Elements

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Construction elements:

- Hinges
  - Traditional pin and rolls
  - Flexible materials
  - Molded crimped hinges
- Closures
  - Hardware
  - Snaps and latches
- Handles
  - Attached
  - Incorporated into item
- Parts count reduction by using common components
- Part shapes that allow nesting / stacking to reduce storage volume

KSB T5: Manufacturing Methods – Assembly Techniques

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Assembly techniques:
- Snap-together components
- Fasteners
    - Screws
    - Pop-rivets
- Glue
    - Consider solvents and how they apply to the areas of regulations, safety, and health.
- Welding (metal or plastic)
- Heat sealing, ultrasonic heat sealing

KSB T6: Manufacturing Methods – Coating

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Coating:

- Painting
  - Spray
  - Powder coating
  - Electrostatic painting
  - Consider solvents and how they apply to the areas of:
    - Regulations
    - Safety and health
- Stamping
  - Spray printing
  - Transfer printing
  - Silkscreen printing
- Decals

KSB T7: Manufacturing Methods – Packaging

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Packaging:
- Packaging techniques
  - Packaged in cardboard
  - Packaged in plastic bags
  - Shrink-wrapped
  - Blister-packed
- Packaging that can be used for a variety of similar items
- Packaging / shipping density
- Environmental concerns
  - Minimizing packaging materials to be discarded
  - Options for packing fillers
- Packaging customer appeal
  - Information / pictorial, written, product viewing, feel, trial
  - Attention getting
- Store handling, display
  - Shelf space
  - Display
  - Checkout, bar code placement, etc.
- Warehouse and store storing, handling

KSB T8: Manufacturing Methods – Automation

Following is an outline of items relating to an aspect of manufacturing methodology. The lists are not all-inclusive.

You are to prepare for the KSB ahead of time (independently or in groups) by finding out the basics of the items listed. You should think of products that are examples of the different items. Then, under the guidance of the instructor, you can pool your knowledge through discussion.

Automation:

- Material handling
    - Parts collecting
    - Part transfers
        - From one machine / step to the next
    - Part orienting
        - Parts feeders
        - Pick-and-place
    - Part storage
        - Temporary
            - Accumulators – belt, tower accumulators
            - Dancers
        - Longer term
            - Warehousing
            - Tracking
        - Containers
- Consider automation and how it applies to the following areas:
    - Assembly
    - Packaging
    - Inspection / QC / QA
- Reconfigurable work cells versus dedicated equipment:
    - Reconfigurable centers can be converted to similar products.
    - Dedicated – optimized for one (or a few) applications

KSB T9: Reverse Engineer a Product

Reverse engineer a product and then learn about its actual manufacturing techniques.

The product will be determined by the instructor. Optimally, it will be the result of a collaboration with a local manufacturing facility.

After the item is examined, you (individually or in groups) create a written report proposing methods to manufacture and assemble the product. Consideration is given to other similar items that might be manufactured at the same facility. Notes are kept in individual Design Folios (DFs) or Design Journals.

You then go on a field trip to the manufacturing facility, listen to a presentation from a manufacturing firm, or view a video presentation to see how the items are actually manufactured.

Add to your original report comments on manufacturing methodologies that were or were not expected. Suggestions and ideas for improvements / automation are included.

The whole class then discusses reports and ideas.

KSB T10: Find a Good Example of Designing for Manufacture

Each of you should find an example of an existing product that is an interesting example of how a product was designed to optimize manufacturing.

These products can be presented at any time throughout the course. A brief show-and-tell can be given in front of the class.

Some examples will be provided.

KSB T11: Estimate / Calculate Materials Required

As a team, make calculations to estimate quantities of materials required to construct a CD holder.

Examples:

> For a CD holder that is made primarily of injection-molded components, measure the thickness of existing similar holders. Calculate the volume of plastic required. Make estimations to accurately incorporate snaps, textures, etc.
>
> For holders made of flat stock, calculate the combined area of all the components. Consider standard sizes of flat stock, and determine how many pieces can be efficiently cut from one sheet.
>
> Estimate the cost to the manufacturer of these materials, excluding their own labor and other manufacturing costs.

Make a bill of materials for different quantities of components (include fasteners, if appropriate).