

# Automated Control System

*using Informed Design  
to Build a System That  
Automatically Performs  
a Routine Task*



**NYSCATE**  
NEW YORK STATE CURRICULUM  
for Advanced Technology Education

*Integrated MST Design Activities for  
High School and Community College Students*

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The University of the State of New York  
The State Education Department



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Building Knowledge and Skill

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Introductory Packet

**KSB T1: Designing the Source Dispensing Subsystem**

**KSB T2: Assembling the Source Dispensing Subsystem**

**KSB T3: Designing the Packaging Measuring Subsystem**

**KSB T4: Assembling the Packaging Measuring Subsystem**

**KSB T5: Testing the Packaging Measuring Subsystem**

**KSB M1: Determining System Effectiveness**

# Introduction and Overview

## Abstract

This module is one of 13 NYSCATE modules that feature the integration of mathematics, science, and technology (MST) through an emphasis on design. The module introduces the concepts that are central to automated control systems by challenging students to design and build an automated control system to accomplish a simple task.

The Design Challenge charges students with building an automated system for delivering a predetermined amount of product to a package for distribution and sale. Students are given latitude in determining the exact methods they will employ for addressing this challenge. To simulate the challenges that would exist in similar situations in an industrial setting, students are asked to work within a set of external constraints placed upon the final design.

Rather than proceed by trial and error alone, students are expected to make design decisions based on mathematical and scientific principles that they consciously apply. The module features mathematical, scientific, and technological Knowledge and Skill Builder (KSB) activities that design teams complete in order to be informed as they design, construct, and test their solutions.

## Grade Level

This module is appropriate for students enrolled in community college technology programs.

## TIME ALLOCATION IN 55-MINUTE PERIODS

The work that is recommended for the basic module should take approximately 13 class periods of 55 minutes each. However, individual teachers may choose to consolidate the work into fewer periods by using lab periods that are longer than 55 minutes each, or by assigning some of the work to be done outside the usual class or lab periods.

## EXISTING COURSES ENHANCED BY THE MODULE

This module has been specifically designed to facilitate student learning in a college freshman-level electrical technology course.

Since this is a module that emphasizes the design process, it may also fit well or be adapted to fit well into most community college technology education or introductory engineering design courses. Opportunities also abound for team teaching the module in these subject areas.

# Design Challenge Overview

## SETTING THE CONTEXT FOR STUDENTS

The Design Challenge charges students with building an automated system for delivering a predetermined amount of product to a package for distribution and sale. Students are given latitude in determining the exact methods they will employ for addressing this challenge. To simulate the challenges that would exist in similar situations in an industrial setting, students are asked to work within a set of external constraints placed upon the final design.

Note that the following information in this section is also provided to students in the Introductory Packet, Problem Context section of Handout 1.

## Introduction

Your local marble company has experienced an increase in sales over the last few years. This increase in sales has resulted in pressure on the packaging facility. Currently, an employee packages marbles manually. The employee counts out the number of marbles required for each package. The owner of the company has decided to automate this process. Her goal is a fully automated packaging system, but, understanding the need to start slowly, she wants to test a simple version of the system in which the empty package may be manually placed on the packaging device and the product source may be manually stocked.

## Design Challenge

You are asked to design and build a prototype system to demonstrate that 1) marbles can be delivered automatically to a package from a source and that 2) the system will detect and stop filling the package when a specified amount of the product has been delivered.

1. For the first part of the challenge, designing the delivery subsystem, you will work as a whole class. With the stock and container components provided, you will design a class strategy for transferring marbles continuously from the larger stock container to the smaller packaging container.
2. For the second part of the challenge, designing the packaging subsystem, you will work as a member of an assigned design team; you will design a subsystem to control the transfer of a specified number of marbles to the package. Working in your team, you will document the specifications, circuitry, and performance for your portion of the system.

## Specifications

1. The packaging container must hold 20 marbles.
2. The marbles are obtained automatically from a larger bin designated as the source bin.
3. Upon receiving a generated signal, marbles begin moving from the source bin toward the package.
4. The packaging container, which may be manually placed into position, begins receiving marbles. The system must determine when the appropriate number have been transferred.
5. A stop signal is automatically generated to halt the flow of marbles from the source bin.
6. When the next empty packaging container is in the receiving position, the process repeats.
7. The system must cycle successfully five consecutive times.

## Constraints

Success is defined as five repetitions at not more than 5% error.

## Goals and Learning Outcomes

During the module the teacher:

- provides an engaging Design Challenge;
- fosters cooperative learning as students work in design teams;
- facilitates student acquisition of skills and knowledge in automated control systems, and in the

science and mathematics concepts that support this technology;

- prompts scientific inquiry and mathematical analysis;
- guides students as they identify and explore factors relevant to design performance;
- provides opportunities for improving communication

skills through the use of the Design Journal or Design Folio, Design Report, and public presentation of student work; and

- works with groups as they cooperatively compose, construct, test, improve, and present their design solutions.

# Materials and Resources

Provide the class with materials needed to complete the challenge, such as the materials listed here. Also provide electronic test equipment such as multimeters and oscilloscopes, and safety equipment such as shields and safety goggles or glasses.

Additional materials will be necessary to complete the Knowledge and Skill Builders (KSBs) that help prepare students for the Design Challenge (see NYSCATE *Pedagogical Framework* [pp. 6–7] for more information on KSBs). These materials are listed within the individual KSBs.

source bin  
packages  
control devices  
assembly boards  
motors  
wire  
marbles

## Safety Considerations

In this module, electricity is used to power an automated system. While the module may be completed with low-voltage circuits that pose little hazard of electrical shock, careful supervision and direction should be given to students who opt to use solutions that involve voltages that may be high enough to pose a threat of electrical shock.

Also, care should be exercised in the use of fabrication tools (for cutting, drilling, fastening, etc.) that might be available for students to use in building their automated system. Proper use of eye protection and safety guards and shields should be stressed.

**RESOURCES** Access to World Wide Web

# Timeline Chart

PERIODS	FOCUS MODEL COMPONENT (for teachers)	INFORMED DESIGN LOOP COMPONENT (for students)	ACTIVITY
1	Focus discussion on problem context.	Clarify design specifications and constraints.	Have students perform manually the task they are to automate in the Design Challenge. Through discussion focus student attention on feedback control theory and automated manufacturing operations. Introduce and clarify the Design Challenge.
2	Organize for informed design.		Discuss student requirements: maintenance of a Design Folio or Design Journal, the completion of KSBs, the Design Report, and the group presentation.  Review the informed design process.  Form design teams.
3 - 4	Coordinate student progress.	Research and investigation.	Student design teams gather and share information on the problem.
5 - 6 Lab	Coordinate student progress.	Generate alternate designs. Choose and justify optimal design. Construct a working model. Test and evaluate the design solution.	Students should complete KSB T1 (Designing the Source Dispensing Subsystem) and KSB T2 (Assembling the Source Dispensing Subsystem).  On the basis of evaluations of design solutions, the class chooses the best dispensing subsystem and assembles it for use by all design teams in the design of the packaging subsystem.
7 - 8 Lab	Coordinate student progress.	Generate alternative designs. Choose and justify optimal design. Construct a working model. Test and evaluate the design solution.	Student design teams complete the Design Challenge.  Student teams complete KSB T3 (Designing the Packaging Measuring Subsystem), KSB T4 (Assembling the Packaging Measuring Subsystem), KSB T5 (Testing the Packaging Measuring Subsystem), and KBS M1 (Determining System Effectiveness).
9 - 10 Lab	Unite the class in thinking about their accomplishments.		Students prepare their individual Design Reports and team presentations.
11 - 12	Unite the class in thinking about their accomplishments.		Student teams make formal presentations of their work to the class.
13	Sum up progress on learning goals.		Evaluate and grade students' work.  Give feedback to the class and individual students.  Discuss how student work and the module might be improved.

# Procedural Suggestions

## 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 the NYSCATE *Pedagogical Framework*, pp. 7–9, [www.nyscate.net](http://www.nyscate.net) for more on this model).

### PERIOD 1: FOCUS STUDENTS ON THE CONTEXT AND THE DESIGN CHALLENGE (55 MINUTES)

Discuss feedback control theory with the class and its application to automated controls. Have students describe automated manufacturing operations they have observed. Encourage them to identify specific subsystems controlling these processes.

Provide packaging containers and marbles to the class. Have the students manually fill the packaging containers with 20 marbles and observe the container’s size, weight, volume, and other physical characteristics that may be applicable to the automation process.

### PERIOD 2: ORGANIZE FOR INFORMED DESIGN (55 MINUTES)

Introduce and clarify the student requirements after determining whether you will expect the students to use the Design Folio or the Design Journal. These documents are provided in the NYSCATE *Pedagogical Framework*, along with guidelines for the Design Report and group presentation.

Review and discuss the process of design (see the NYSCATE *Pedagogical Framework* for an elaborated discussion of the design process). Elicit from students what they know about good design and who engages in design. Ask for examples of good design and poor design.

Tell the class that completing a series of KSBs will help them feel comfortable addressing the Design Challenge (see the NYSCATE *Pedagogical Framework* for a discussion of KSBs and their use).

Assign students to small design teams (two to four students each) for addressing the challenge.



Students working in small teams

### PERIODS 3 – 4: COORDINATE STUDENTS’ INITIAL GATHERING AND SHARING OF INFORMATION ON THE PROBLEM (55 MINUTES EACH)

Using the World Wide Web, students should visit the International Society of Measurement and Controls site ([www.isa.org/journals/mc/fundamentals/](http://www.isa.org/journals/mc/fundamentals/)) for information on motion fundamentals.



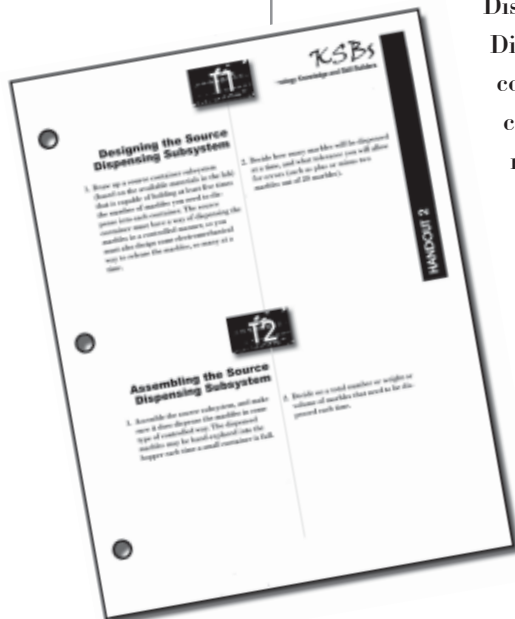
## PERIODS AND LABS 5 – 6: COORDINATE CLASS DEVELOPMENT OF THE SOURCE DISPENSING SUBSYSTEM (55 – 90 MINUTES EACH)

If you feel that your students have not had much experience with the design process and working on Design Challenges, you might consider having the whole class design the dispensing subsystem. The design teams could consider and propose alternative designs or design components to the whole class. The class could evaluate these ideas and decide which ones to use, and then assemble the unit as a class. This experience could be used to teach or reinforce characteristics of the design process, and to underscore the need for effective group communication and cooperation. It may help teams to work quite independently on the next phase, developing the packaging subsystem.

Design teams should complete KSB T1: Designing the Source Dispensing Subsystem, and KSB T2: Assembling the Source Dispensing Subsystem. The teams develop and refine the source container of the marbles, and determine how the marbles will be continuously dispensed. This segment will depend on what materials are in the lab, and what materials can reasonably be obtained through the normal purchasing procedures of the lab setup. Students will document their activities, showing how they evolve from a theoretical design to a nuts-and-bolts drawing, using practical parts and pieces that are either immediately available or easy to obtain through normal purchasing procedures. They should also document (in the Design Journal or Design Folio) what changes or adaptations need to be made to the material at hand so that the goal can be accomplished; a written argument and step-by-step diagram showing how the parts might work together should be included.

Teams will have to:

- Choose the hopper, tub, pail, tube, funnel, or other device that will store the marbles.
- Describe (by words and/or diagram) how the marbles will be made to “flow”; i.e., describe the start-stop mechanism.
- Describe electromechanical setups that might cause a start or stop.
- Consider what parts and pieces the lab has to offer, such as the following:
  - stepping motors
  - low-RPM AC motors
  - DC motors whose speed is easy to control by voltage settings
  - solenoids, cams, and straight connecting strips of metal or wood that can be combined to convert rotary motion into linear motion
  - digital pulses
  - limit switches and other microswitches that can operate at 120 V AC, or low-voltage DC
  - position-sensing mechanisms such as a three-way microswitch riding on a cam attached to the shaft of a motor.
- Consider parts and pieces that probably need to be purchased, such as the following:



- marbles
- tubing
- switches
- hoppers (pails, buckets, funnels, etc.)
- connecting hardware.

Each design team must be ready to present its total design of the source dispensing subsystem to the total group, so the group can pick and choose which source subsystem will work the best for the class.

**PERIODS AND LABS 7 – 8: COORDINATE STUDENTS’ DESIGN, ASSEMBLY, TESTING OF THE PACKAGING MEASURING SUBSYSTEM, AND THEN TEST THE EFFECTIVENESS OF THE COMBINED DISPENSING AND PACKAGING SYSTEM AS A WHOLE (55 – 90 MINUTES EACH)**

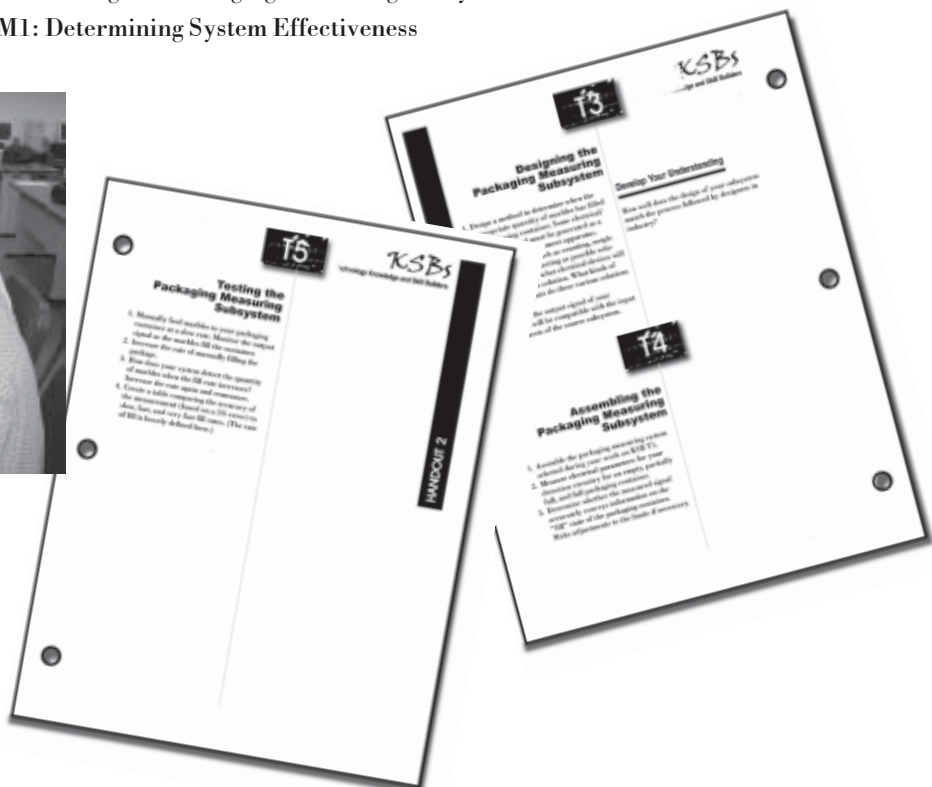
The packaging container can be any sort of container. A stiff cup or pail will probably work best, but a suitably designed system could use a plastic bag. Each student group will be producing the feedback signal necessary to halt the flow of marbles into the packaging container. The students will need to take into account two actions:

1. How to determine if the packaging container is full according to specifications.
2. How to account for any marbles on the way to the package from the source bin, if applicable.

The students may choose to detect the number of marbles in the package in several ways including by weight, by volume, by count, by elapsed time, by photo detection, or by other means.

The following KSBs need to be completed and the results documented in the Design Folio or Design Journal:

- KSB T3: Designing the Packaging Measuring Subsystem
- KSB T4: Assembling the Packaging Measuring Subsystem
- KSB T5: Testing the Packaging Measuring Subsystem
- KSB M1: Determining System Effectiveness



Students testing the packaging measuring subsystem

**PERIODS AND LABS 9 – 10: UNITE THE CLASS IN THINKING ABOUT THEIR ACCOMPLISHMENTS ON THE BASIS OF INDIVIDUAL AND TEAM RECORDS, AND IN THINKING ABOUT REPORT PREPARATIONS AND GROUP PRESENTATIONS** (55 – 90 MINUTES EACH)

Provide students with the Design Report guidelines from the NYSCATE *Pedagogical Framework*.

Continue to work as a facilitator as groups record their progress and results. Assist students in structuring and writing their Design Reports, which are to be submitted by each individual student. The Design Report should include a discussion

of possible redesigns with justifications for the redesign decisions. (In the engineering environment, minor changes in design are called *engineering changes [ECs]*. These differ from a redesign in that ECs are small, documented changes to an existing design strategy.)

Facilitate team preparation of a class presentation of their work and final design. The use of computer presentation software and demonstrations should be encouraged. The engineering design documentation might include photographs, video recordings of the system in operation, and a description of the methods used to develop the system (see the NYSCATE *Pedagogical Framework* for a discussion of design presentations).



Students discussing a possible redesign

**PERIODS 11 – 12: UNITE THE CLASS IN PLANNING GROUP PRESENTATIONS OF COMPLETED WORK** (55 MINUTES EACH)

To help teams reach closure, to encourage them to do quality work, to sharpen their communication skills, and to improve their skills in reviewing the work of others, the prepared presentations should be delivered to the whole class or other, appropriate public forum. After each design team presents, time should be allowed for audience questions and reaction. Peer review reaction forms might be used to evaluate presentations.

**PERIOD 13: SUM UP PROGRESS ON THE LEARNING GOALS** (55 MINUTES)

Evaluate and grade student work. Review the learning goals and assess progress on them for individuals, teams, and the class. Return work to students and discuss what has been accomplished and what individuals, teams, or the class might work on in the future. Be sure to provide *constructive* feedback in all cases.

Ask students to evaluate the module. You might do this in a formal written survey, but at any rate have a public discussion of how the module might be improved. Ask students to be self-reflective, and encourage suggestions. You might share your own reactions to the experience. Again, be constructive.

# Additional Support for Teachers

## OVERVIEW OF MODULE CONTENT

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A brief description of some of the important concepts used in this module follows:

**START-STOP MECHANISMS** are switches that cause an electrical device such as a motor to turn off or on.

**SENSING MECHANISMS** must be able to detect whether a desired physical state has been reached, such as the height of water in a vessel, how many degrees a motor shaft has turned, or whether an object is in the desired position before some other action takes place.

**FEEDBACK LOOPS** are frequent electrical changes in voltage and/or current from the output of a system that when sent back to the input of the system, cause the input to increase (positive feedback) or decrease (negative feedback) its activity. Negative feedback is more of a controlling mechanism that helps the entire system to stay within prescribed bounds, whereas positive feedback alone can cause a runaway situation.

**CONVERTING CIRCULAR MOTION TO LINEAR MOTION** is frequently used in industry to allow a linear push or pull (such as removing an object from an assembly line) to be obtained from the circular motion of a motor shaft. This is accomplished by attaching a cam to the motor shaft and a linear rod to the other end of the cam so that as the motor shaft turns the cam in a circular motion, the cam pulls or pushes the connecting rod in a linear motion, similar to the wheel and piston arrangement on a locomotive. A conveyor belt is another example of a device that converts circular to linear motion.

**SPEED CONTROL** can be accomplished by adjusting the input voltage of a DC motor, or by changing gear ratios in an AC motor, or by changing the frequency of the pulses in a stepping motor.

**SOLENOIDS** are electromechanical devices that cause a shaft to move under the influence of a magnetic field.

**LIMIT SWITCHES** are frequently used in industry to detect when a system has reached a preset condition. Examples include detecting when a garage door is fully opened or when a sump pump needs to turn on.

## BUILDING KNOWLEDGE AND SKILL

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The challenge your students face involves designing an automated product dispensing and packaging system. Many will want to proceed by trial and error alone. 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 automated control devices and systems, 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 (pp. 10–11).



## Overview of the Module and Design Challenge

### Here's What You Will Do

In the NYSCATE module *Automated Control System*, you will work in a group to:

- understand and explore possible solutions to an identified problem
- research that problem and gain additional information on it by completing Knowledge and Skill Builder (KSB) activities
- apply the components of the design process and use appropriate tools and materials to design a solution to the given problem. (Your design and redesign must be based upon science and mathematics concepts.)
- see that your design addresses specifications and is developed within existing constraints
- collect, plot, and compare data. Use mathematical models such as graphs and equations to analyze your data.
- make improvements to your design on the basis of your data analyses
- develop and implement a repeatable and reliable method for testing your design
- propose redesign improvements based on testing your design and the application of the related science and mathematics concepts.

### Problem Context

#### INTRODUCTION

Your local marble company has experienced an increase in sales over the last few years. This increase in sales has resulted in pressure on the packaging facility. Currently, an employee packages marbles manually. The employee counts out the number of marbles required for each package. The

owner of the company has decided to automate this process. Her goal is a fully automated packaging system, but, understanding the need to start slowly, she wants to test a simple version of the system in which the empty package may be manually placed and the product source may be manually stocked.

#### DESIGN CHALLENGE

You are asked to design and build a prototype system to demonstrate that 1) marbles can be delivered automatically to a package from a source and that 2) the system will detect and stop filling the package when a specified amount of the product has been delivered.

1. For the first part of the challenge, designing the delivery subsystem, you will work as a whole class. With the stock and container components provided, you will design a class strategy for transferring marbles continuously from the larger stock container to the smaller packaging container.
2. For the second part of the challenge, designing the packaging subsystem, you will work as a member of an assigned design team; you will design a subsystem to control the transfer of a specified number of marbles to the package. Working in your team, you will document the specifications, circuitry, and performance for your portion of the system.

#### SPECIFICATIONS

1. The packaging container must hold 20 marbles.
2. The marbles are obtained automatically from a larger bin designated as the source bin.
3. Upon receiving a generated signal, marbles begin moving from the source bin toward the package.
4. The packaging container, which may be manually placed into position, begins receiving marbles. The system must determine when the appropriate number have been transferred.



# Introductory Packet

5. A stop signal is automatically generated to halt the flow of marbles from the source bin.
6. When the next empty packaging container is in the receiving position, the process repeats.
7. The system must cycle successfully five consecutive times.

## CONSTRAINTS

Success is defined as five repetitions at not more than 5% error.

## Materials Needed

Materials needed to complete the challenge include:

- source bin and packages
- control devices
- assembly boards
- motors
- wire
- marbles

Also, electronic test equipment such as multimeters and oscilloscopes, and safety equipment such as shields and safety goggles or glasses, should be available.

## Student Requirements

You will be expected to:

- maintain either a Design Folio or a 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;
- develop a group presentation to explain how your group met the Design Challenge;
- be assessed on the quality of your work on MST Knowledge and Skill Builders (KSBs), your Design Journal or Design Folio, Design Report, 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, and your group's presentation.



## **Designing the Source Dispensing Subsystem**

1. Draw up a source container subsystem (based on the available materials in the lab) that is capable of holding at least five times the number of marbles you need to dispense into each container. The source container must have a way of dispensing the marbles in a controlled manner, so you must also design some electromechanical way to release the marbles, so many at a time.
2. Decide how many marbles will be dispensed at a time, and what tolerance you will allow for errors (such as plus or minus two marbles out of 20 marbles).



## **Assembling the Source Dispensing Subsystem**

1. Assemble the source subsystem, and make sure it does dispense the marbles in some type of controlled way. The dispensed marbles may be hand-replaced into the hopper each time a small container is full.
2. Decide on a total number or weight or volume of marbles that need to be dispensed each time.

T3

KSBS

Technology Knowledge and Skill Builders

## Designing the Packaging Measuring Subsystem

1. Design a method to determine when the appropriate quantity of marbles has filled the packaging container. Some electrical/electronic signal must be generated as a result of the measurement apparatus.
2. Explore methods such as counting, weighing, and photo-detecting as possible solutions. Determine what electrical devices will be used for each solution. What kinds of electrical outputs do these various solutions produce?
3. Consider whether the output signal of your subsystem will be compatible with the input requirements of the source subsystem.

### Develop Your Understanding

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How well does the design of your subsystem match the process followed by designers in industry?

T4

## Assembling the Packaging Measuring Subsystem

1. Assemble the packaging measuring system selected during your work on KSB T1.
2. Measure electrical parameters for your detection circuitry for an empty, partially full, and full packaging container.
3. Determine whether the measured signal accurately conveys information on the “fill” state of the packaging container. Make adjustments to the limits if necessary.





## Testing the Packaging Measuring Subsystem

1. Manually feed marbles to your packaging container at a slow rate. Monitor the output signal as the marbles fill the container.
2. Increase the rate of manually filling the package.
3. How does your system detect the quantity of marbles when the fill rate increases? Increase the rate again and remeasure.
4. Create a table comparing the accuracy of the measurement (based on a 5% error) to slow, fast, and very fast fill rates. (The rate of fill is loosely defined here.)



## Determining System Effectiveness

1. Allow the dispenser to work for five consecutive times and collect enough data to see if the dispenser is working properly.
2. Remember that you set up the effectiveness criteria in KSB T1 when you decided how many marbles to place in each container and what tolerance you would allow. Calculate the rate of packaging error and relate it to the allowed tolerances.
3. Record your results in your Design Journal or Design Folio and discuss present problems and potential improvements in design.

## Develop Your Understanding

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Considering the cost per marble, discuss the impact of production costs of various tolerances of packaging number error. For example, what might be the cost if one percent of the packages had one extra marble and a total of 1,000 units were sold? if 1,000,000 units were sold? Discuss what the cost (or gain) might be if one percent of the units had one marble less than prescribed.



