NC-NET Employability Skills Resource Toolkit

Module 4: Problem-Solving and Decision-Making

Overview

Every day we are faced with hundreds of decisions to make and problems to solve from the time we wake up until the time we go to bed. What will I wear today? What will I eat for breakfast? There has been a major accident on the freeway I take to work; should I take an alternate route? In every workplace, decision-making and problem-solving can have a major impact that affects the financial success of the enterprise.

The activities in this module ask students to think formally about how decisions are made by exploring strategies for solving problems both individually and in teams.

In the first activity, Broken Squares, teams of students work together to solve a problem. Restrictions on how students are allowed to communicate reinforce the importance of teamwork and communication skills discussed in other modules in this series. The activity is fairly short, but if group members don't observe and help others, it can become frustrating.

The second activity, Making Individual Decisions, emphasizes the fact that students make decisions daily. In it, students think about ways they might make decisions and in what situations these processes would be most effective. Students also discuss the idea that refusing to make a decision actually yields a decision by default.

The third activity, Make a Plan, describes strategies for tackling more complex problems. Students work through the planning method as a class or in small groups. Later they may address problems presented by the class or on the student handouts. Discussion of problem-solving strategies is encouraged throughout.

The fourth activity, Seven-Step Quality Improvement Problem-Solving Model, discusses techniques used in business and industry to solve problems.

The final activity, Tools for Preventing Problems, discusses the use of statistical tools to examine processes and identify potential problems before they become big problems. This activity contains a hands-on activity simulating a bottle-filling process. Students collect data, analyze it, and suggest changes to make their process more precise.

Presentation Materials

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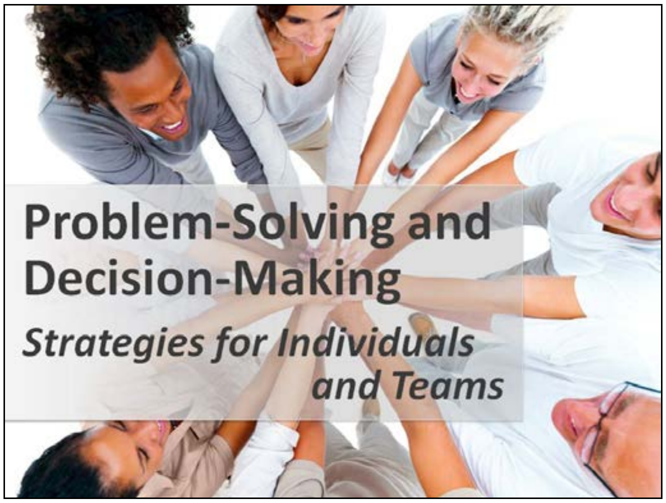

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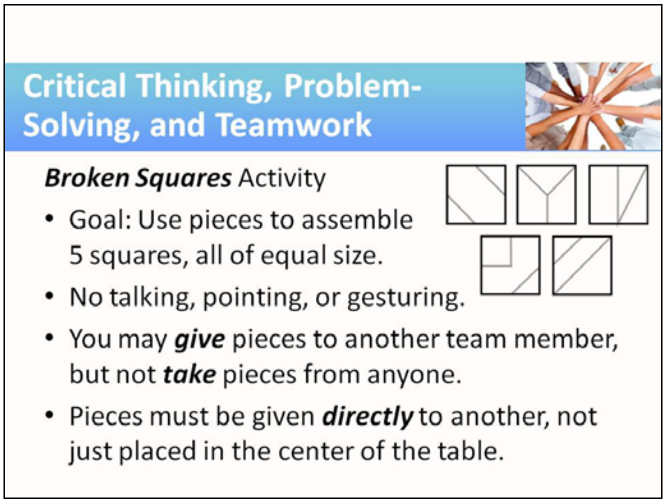

- In the Broken Squares activity, students work together to solve a problem. Communication restrictions in the game introduce the importance of interpersonal communication within teams.
- Monitor the activity and enforce the guidelines.
- As teams finish, they should sit quietly and observe the remaining groups still at work.

SLIDE	TEACHER NOTES

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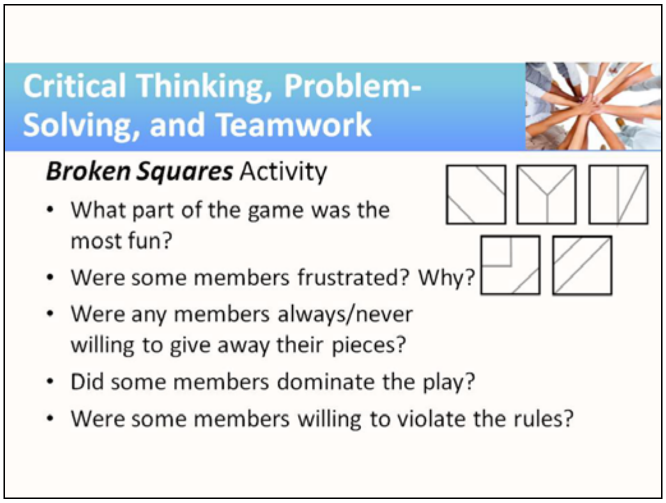

- Discussion of the activity will help group members understand the teamwork processes that took place during the game. Team members should reflect on their actions and identify interpersonal skills used in problem-solving during the game.

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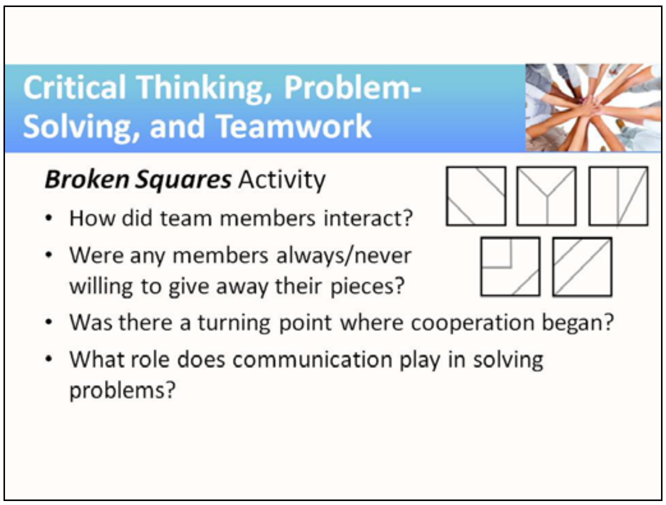

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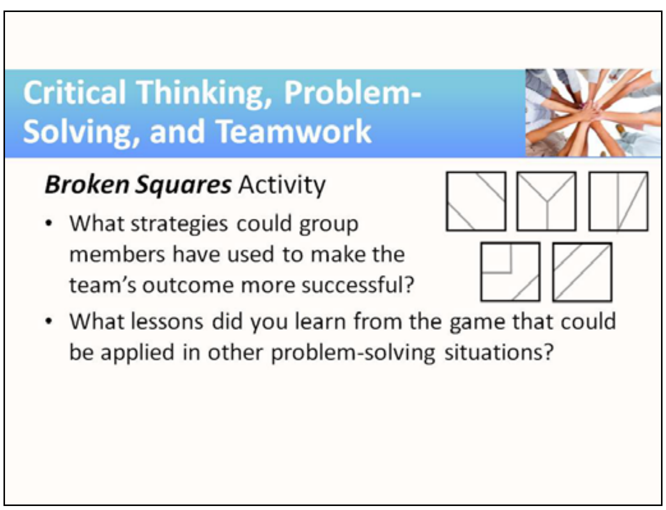

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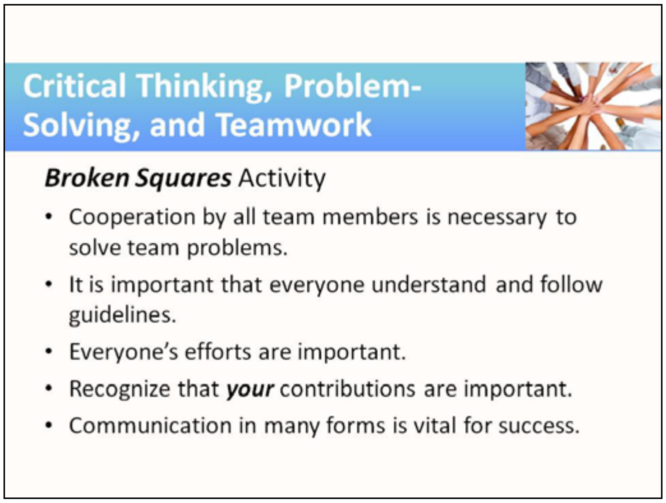
7		• Here are some conclusions for this activity.
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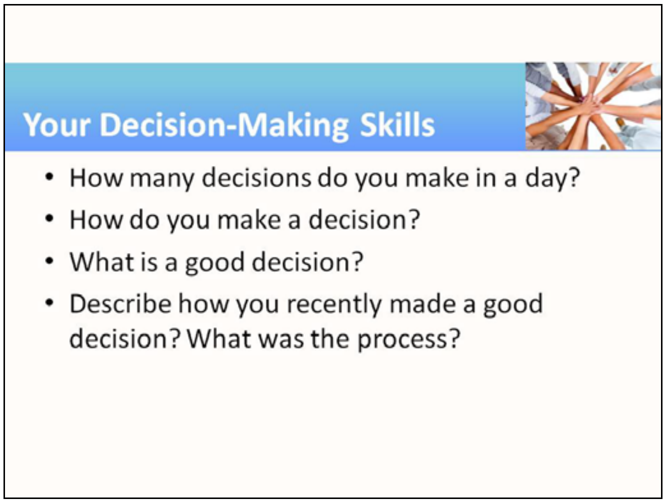
9		• Discuss students' typical decision-making processes. Many of them may match those found on the following slide (and described in more depth in the module content).

SLIDE

TEACHER NOTES

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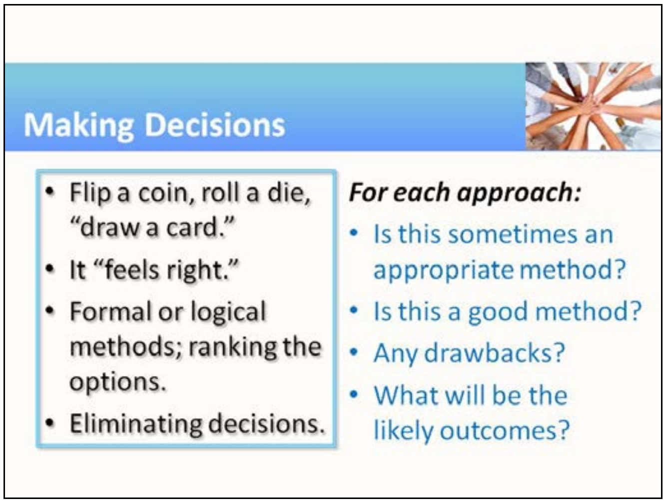

Consider the approaches listed…

- **Flipping a coin, etc.** These random results may be appropriate for low-risk situations where any choice is acceptable. While there may be consequences, it is a quick way to make unimportant decisions. The probabilities of each outcome can be mathematically determined (e.g., coin flip means 50% chance for each outcome).
- **"Feels right."** People often decide based on emotions, but seldom consider that emotions depend on many factors, like fatigue, hunger, stress, personalities, etc. If one can stay aware of the impact of emotions, you'll probably be more satisfied with the decision—especially personal decisions.
- **Logical choice.** Making or brainstorming a list of all possible options and analyzing the consequences or relative merits of each one (mathematically, for example) generally yields an emotionally neutral, though not always pleasant, outcome. It is probably too time-consuming for everyday decisions.
- **Eliminating the options.** Some people make choices by reducing the number of options, until the list is reduced to one or two choices, which they perceive as being easier (emotionally). Example: Relying on a standard operating procedure, which means that someone else has already made the decision

SLIDE	TEACHER NOTES

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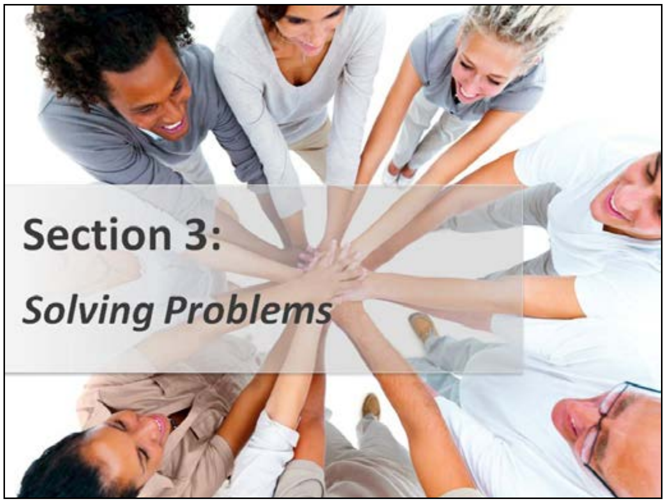

- Creating a methodical problem-solving plan is often difficult for students. This section of the module presents several different strategies students can practice in the module activities.

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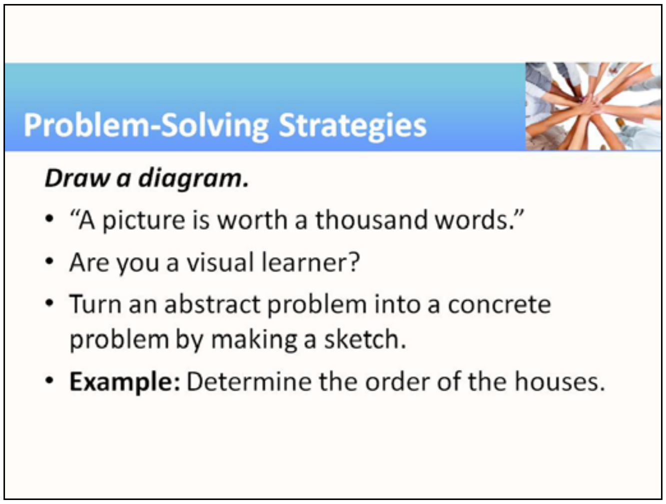

- **"Draw a diagram" example:** Five houses on the block. One is blue, one is green, two are red, and one is yellow. Both red houses are to the left of the green house. The blue house is between two red houses, and the yellow house is the first house on the block. What is the order of the houses on the block? A sketch will quickly reveal the correct pattern.

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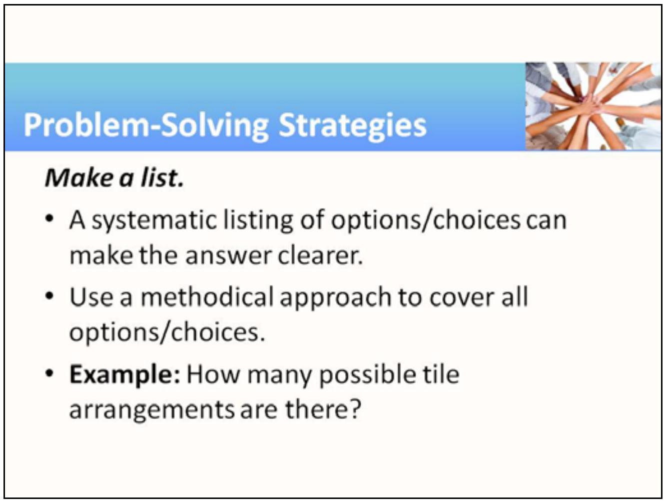

- **"Make a list" example:** Four colored tiles—red, yellow, blue, and green—are to be mounted side-by-side for a store display. How many possible color sequences are there? Simply listing the possible sequences will yield the answer without the need for a clever math formula and calculation.
- On the other hand, here the power of math can be helpful. This is an application of *n!* (*n* factorial). When you have *n* different items, there are *n!* possible arrangements, if the order is significant (that is, AB is different from BA). There are $4! = 4•3•2•1 = 24$ possible ways to arrange the tiles, as can be verified by listing the possible arrangements: RYGB, RYBG, RGYB, RGBY, and so forth.

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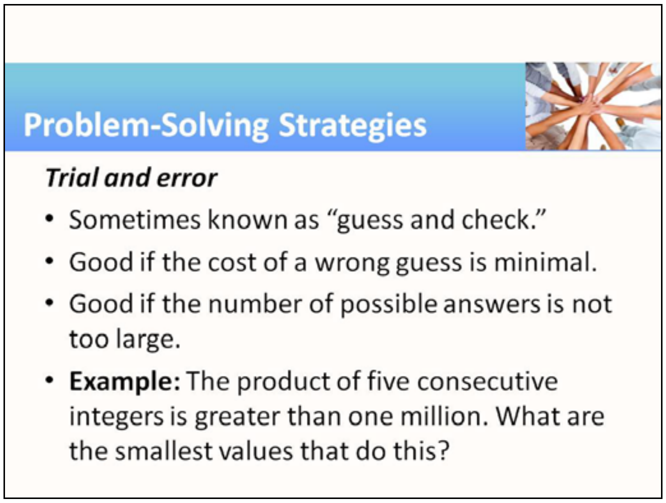

- **“Trial and error” example:** One could solve an algebraic expression (hard) or just try several sets of five consecutive values with a calculator, notice a trend, and eventually close in on the answer (14•15•16•17•18=1,028,160).
- **Another example:** A radio station’s high-low jackpot. Callers guess the jackpot value and are told they’re high or low. Keeping track of the results will eventually yield the correct answer. Often “guess and check” is a perfectly legitimate problem-solving technique.
- Many professional trade workers apply this technique. For example, a carpenter may start with an approximate length of lumber that is close to the desired amount, repeatedly check the result and trim away a little more, being careful not to trim away too much, until the result is satisfactory.

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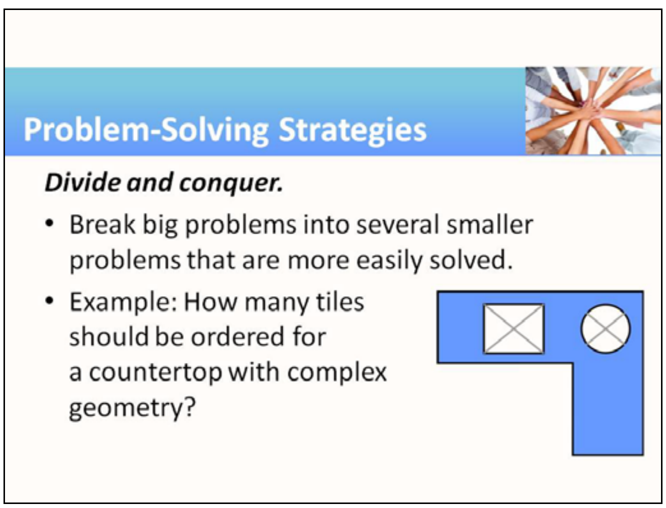

- **“Divide and conquer” example:** Ordering tiles for a countertop with a complex geometry is best solved by breaking the complex geometry down into manageable regions. Using the example on screen, identify rectangular regions and then subtract the area of the rectangular and circular regions. Notice that a diagram plays an important role here, too.

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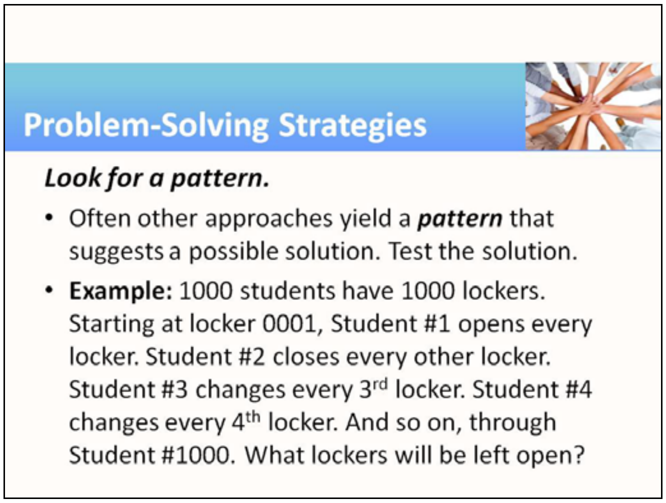

- **"Look for a pattern" example:** We could make a table of all 1000 lockers, but if we just look at the first few lockers (25, for example) it will become evident that the lockers that will remain open are perfect squares (#1, 4, 9, 25, 49, etc.). Thus, there is no need to actually diagram all 1000 lockers. The answer is that the locker numbers that are perfect squares will be open after all 1000 students have taken their pass at open/closing the lockers.
- Similarly, the Fibonacci series that occurs amazingly often in nature seems quite bizarre and unpredictable, until one detects the pattern.

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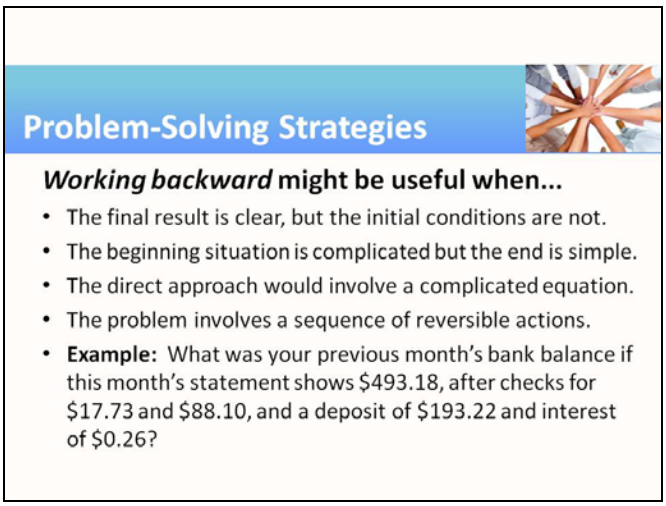

- **"Working backward" example:** Rather than developing a formula to calculate the previous month's balance, we can start with the current balance and ***reverse the actions*** throughout the month. So, reversing the checks means adding (rather than subtracting) those amounts. Reversing the deposits means subtracting (rather than adding) those amounts. Thus, $493.18 + $17.73 + $88.10 – $193.22 – $0.26 = $405.53, and so the previous month's statement balance was $405.53.
- "Working backward" might be the best strategy when we pause to consider the problem, rather than jumping right into the typical approach. For example, few people consider starting at the finish of a maze and working backwards to reach the start. Or consider the childhood puzzle showing three fishermen with tangled fishing lines winding all over the page, one of which is connected to a big fish in the opposite corner. To answer the question "Which fisherman will catch the fish?" the best strategy is to start at the fish and follow the line back to the winning fisherman—*working backwards!*

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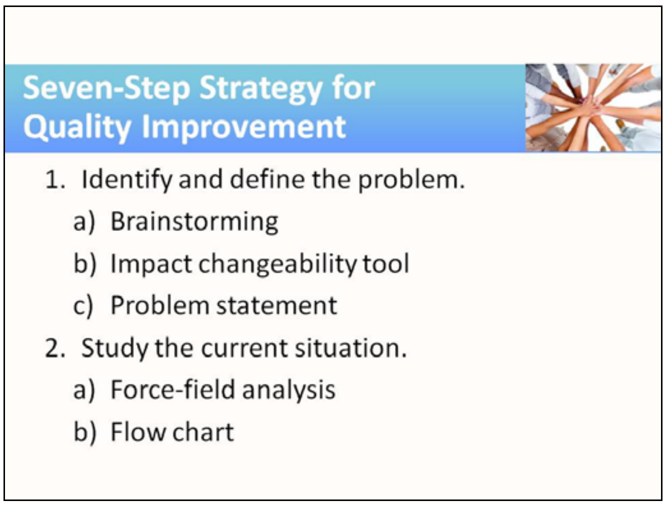
19		• See the complete plan presented in the student handout. Many slight variations of such problem-solving plans exist. They all typically include variations of the essential four steps: 1) understand the problem, 2) develop a plan, 3) implement the plan, and 4) check the outcome. • Impact changeability tools help teams prioritize problems to address based on the degree of impact the process has on the whole system. • A force-field analysis is essentially a more complex pros/cons or risk/benefit analysis. • A flow chart is a start-to-finish graphic representation of tasks within a whole process.

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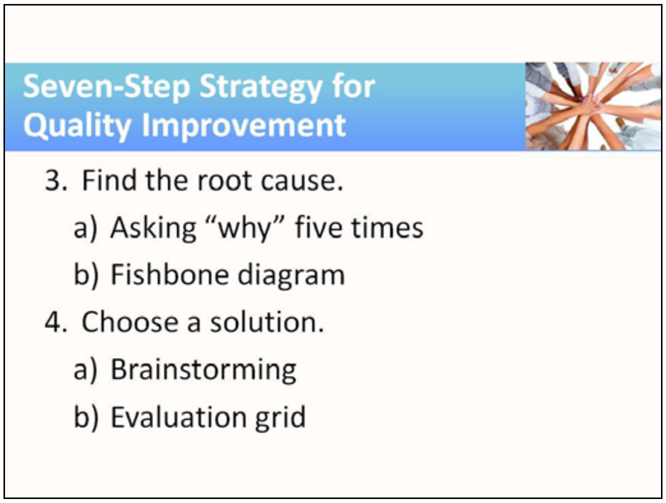

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- Asking "why" repeatedly helps determine a chain of events leading to a problem.

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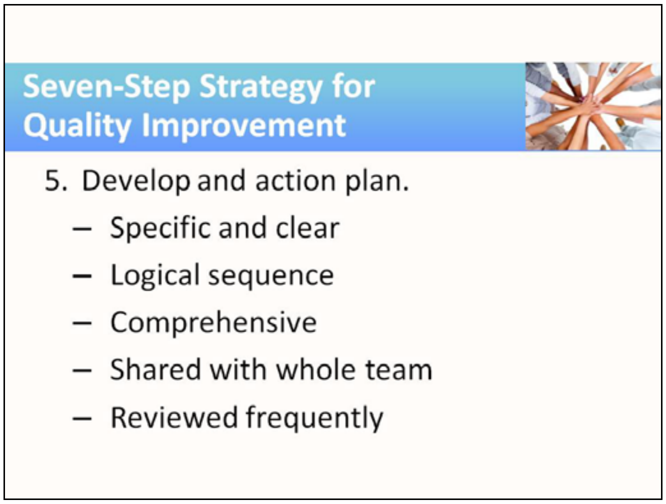

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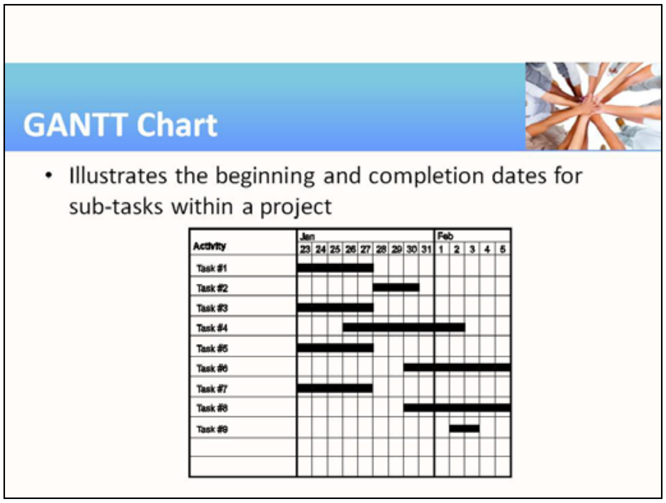

- Gantt charts illustrate the start and finish dates of the many steps and milestones of a project. There are many varieties of Gantt charts, some using shapes, colors, and symbols to communicate different aspects of project progress. They all have in common the concept of precedence and dependency of multiple subtasks. Usually (but not always) progress correlates with the underlying timeline. The task flow sometimes is separated from the time/schedule flow.
- Gantt charts were invented by Henry Gantt around 1910, and were considered revolutionary at the time. Today, they are common in business and project planning and presentations.

	SLIDE	TEACHER NOTES

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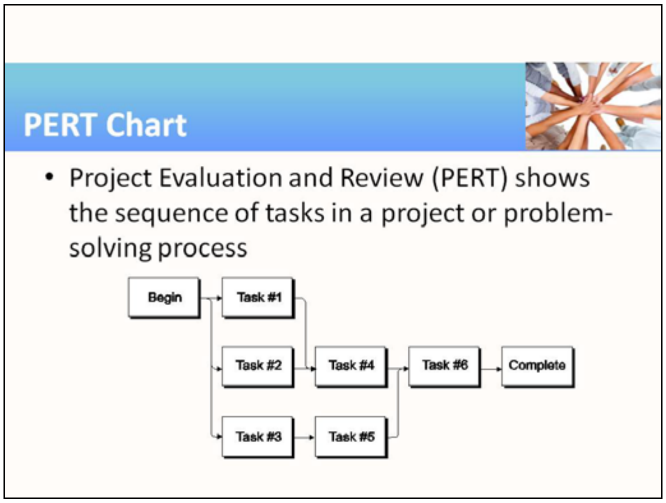

- PERT charts were originally designed to simplify the planning and scheduling of large and complex military projects in the late 1950s.

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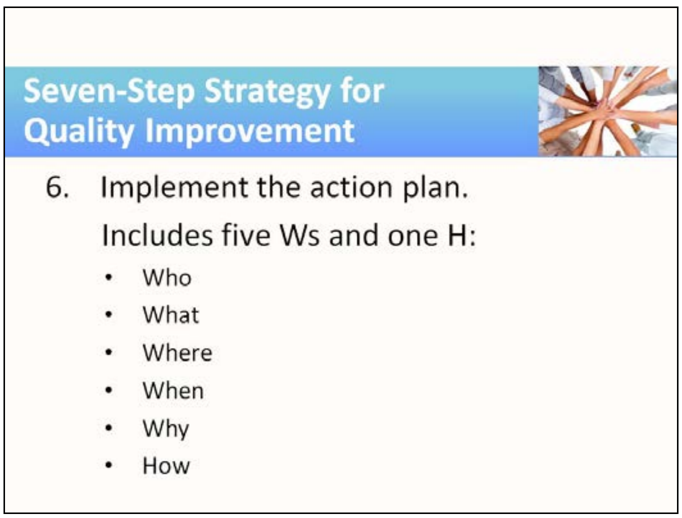

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- An action plan clearly outlines Who will do What; Where; When; Why; and How.

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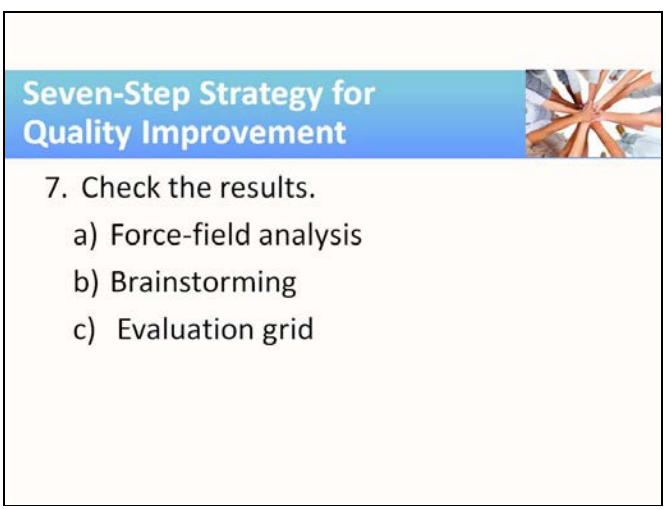

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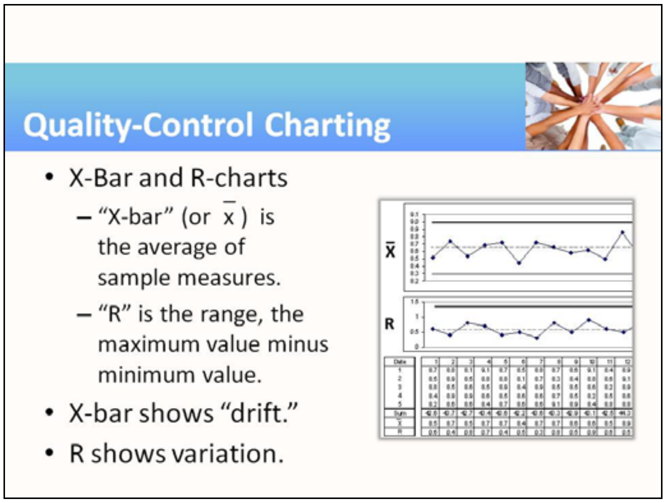
26		• Ongoing processes (typically factory production and assembly lines) can be monitored by workers who periodically take sample measurements that are chosen as indicators of the health of the production process. While much can be analyzed in such measurements, quality control practice is to focus on two major statistics: the average (X-bar) and the range (R). The average and range of a small number of measurements (typically 4-5) are relatively easy to calculate, record, and chart, and provide good early indicators of unwanted changes in calibration and variation of the process, preventing (hopefully) greater problems down the road.

Teaching Resources

ACTIVITIES

The following activities can be completed in class to emphasize specific aspects of problem-solving and decision-making skills. The activities can be used "as is," or they can be adapted and tailored to fit a specific course. Suggestions for tailoring the activities precede each activity, with examples from several different subject areas/career pathways. The suggested modifications provide instructors with ideas for adapting the activity for integration into content they are already teaching. Modifying the activities allows infusion of employability skills with minimum impact on the time used to teach subject content.

ACTIVITY: BROKEN SQUARES—CRITICAL-THINKING, PROBLEM-SOLVING, AND TEAMWORK

Instructor Preparation

For this activity, students will work in groups of five. “Extra” students can serve as observers. (Give them a copy of the Observer Instructions.) Prepare five envelopes with puzzle pieces for each group. The directions for making the puzzles are included in the Materials section below.

Objectives

Students will:

1. Identify behaviors that may contribute to or detract from the ability of groups to solve problems.
2. Describe the importance of good communication between team members.

Materials

- Enough sets of “broken square” pieces for each student in each group to make a square. Templates are included at the end of this activity. See instructions for assembling sets of pieces.
- Work space, such as a small table, for each team
- Handout—Instructions for Observers

Directions for Making a Set of Squares

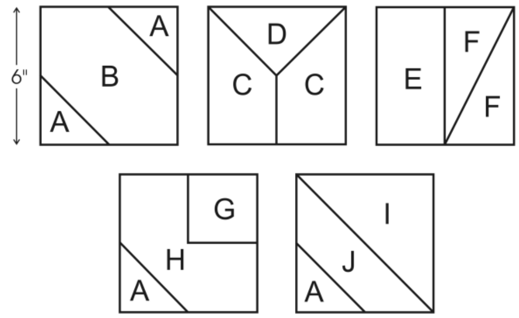
One set consists of five envelopes containing pieces of cardstock or poster board that have been precut into different patterns (template included). When properly arranged, the pieces form five squares of equal size. One set should be given to each group of five students.

Make one set of puzzle pieces by using the square templates provided. Photocopy the five pages of six-by-six square templates onto poster-board or cardstock paper. To create the pieces, carefully cut along the lines indicated. ***NOTE:*** If you photocopy the templates, white out or cover the letters on the template masters before copying them. Number five 6" X 9" clasp envelopes 1, 2, 3, 4, and 5 for each set. (Each team of five students will receive the entire set of envelopes.) The precut pieces should be placed in the numbered envelopes as follows:

Envelope Number	Pieces
1	I, H, E
2	A, A, A, C
3	A, J
4	D, F
5	G, B, F, C

The pieces in each envelope will not form a square by themselves. The purpose of this activity is for students to realize the need for teamwork to accomplish a common goal. Therefore, it is imperative that the pieces be cut and placed in the envelopes as directed above.

The completed squares are put together as shown in the following figure.



Activity Guidelines

Randomly divide students into groups of five. "Extra" students can serve as observers. (Give them a copy of the observer instructions.) Hand out one set of five envelopes to each team of five students.

Direct the teams not to begin or open the envelopes until after the instructions have been read.

Read aloud or print out the following instructions for each team:

> Each team member has been given an envelope that contains pieces of a puzzle that will form a square. When the signal has been given to begin, the team objective is to use the puzzle pieces to make five perfect squares of equal size.

Specific guidelines that must be followed:

- No talking, pointing, or gesturing
- Team members may give pieces to other team members but a team member cannot take pieces from other team members.
- Team members may not place their pieces in the center of the work area for other team members to take; pieces must be given from one team member directly to another team member.

If there are observers in the groups, their job is to enforce the above guidelines.

Once the students understand the instructions and any questions have been answered, give the signal to begin.

The instructor should facilitate the activity by monitoring the teams and enforcing the guidelines. As teams complete the task, they should be instructed to sit quietly and observe the other groups working until all groups have finished.

When all groups have finished the game, the instructor should ask the following questions to summarize the activity. If the groups had observers, ask the observers to answer the questions first. Then allow the rest of the group to reply.

- What were the different interactions between the team members?
- Were certain team members willing to give away puzzle pieces?
- Were certain team members not willing to give away puzzle pieces?
- Did certain team members seem to be frustrated? If yes, then how did it affect the group?
- Did certain team members seem to want to dominate the activity? If yes, how did it affect the group?
- How many people were actively working as a team to put the pieces together?
- Was there a specific point at which the team started to work more cooperatively?
- Did any team members attempt to violate the rules to help other members solve their puzzles?

Group Reflection Questions

Discussion of the activity helps group members understand the teamwork processes that took place during the game. Individual team members should reflect on their actions during the game and be able to apply interpersonal and teamwork skills to other problem-solving situations in the future.

Ask students the following questions:

- What part of the game was the most fun? Why?
- What part of the game was the most frustrating? Why?
- What types of strategies could group members have used to make the team's outcome more successful?
- What role does communication play in solving problems?
- What lessons can you learn from this game that would be helpful in working in other problem-solving situations?

Close this activity by reviewing key points related to problem solving as a group:

- Cooperation by all team members is necessary to reach solutions to team problems.
- It is important for all team members to understand and follow established guidelines.
- The effort of all individuals is important to successful problem-solving.
- Individuals should recognize their own potential contributions.
- Communication, in various forms, is vital to success in problem-solving.

Students should be encouraged to review their actions in the game and work on improving the interpersonal skills that will make them successful problem solvers.

Handout—Instructions for Observers

As an observer you should make sure that each team member is following the guidelines established by the instructor.

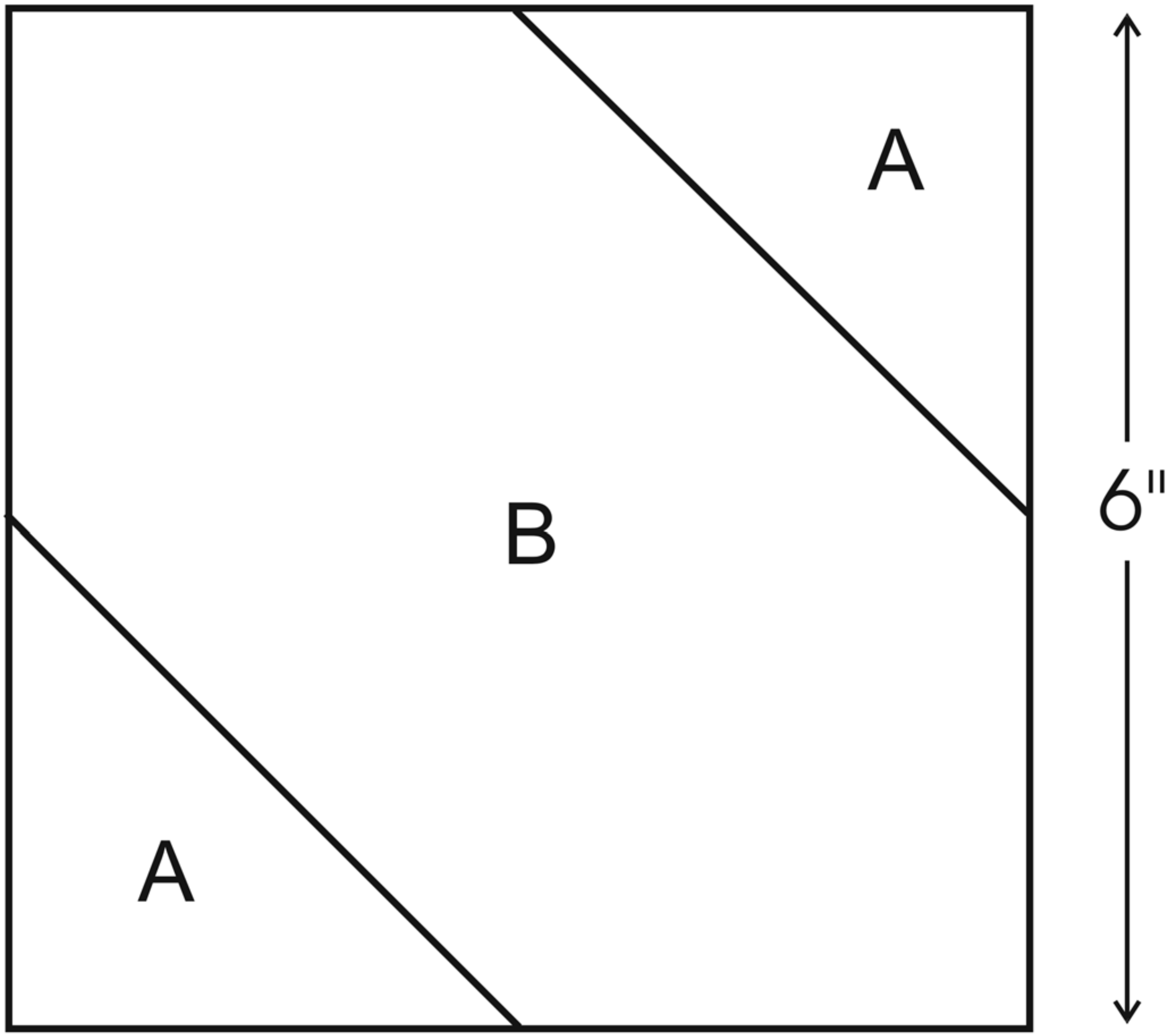
- No talking, pointing, or gesturing.
- Team members may give pieces to other team members, but team members cannot take pieces from other team members.
- Team members may not place their pieces in the center of the work area for other team members to take; pieces must be given directly to other team members.

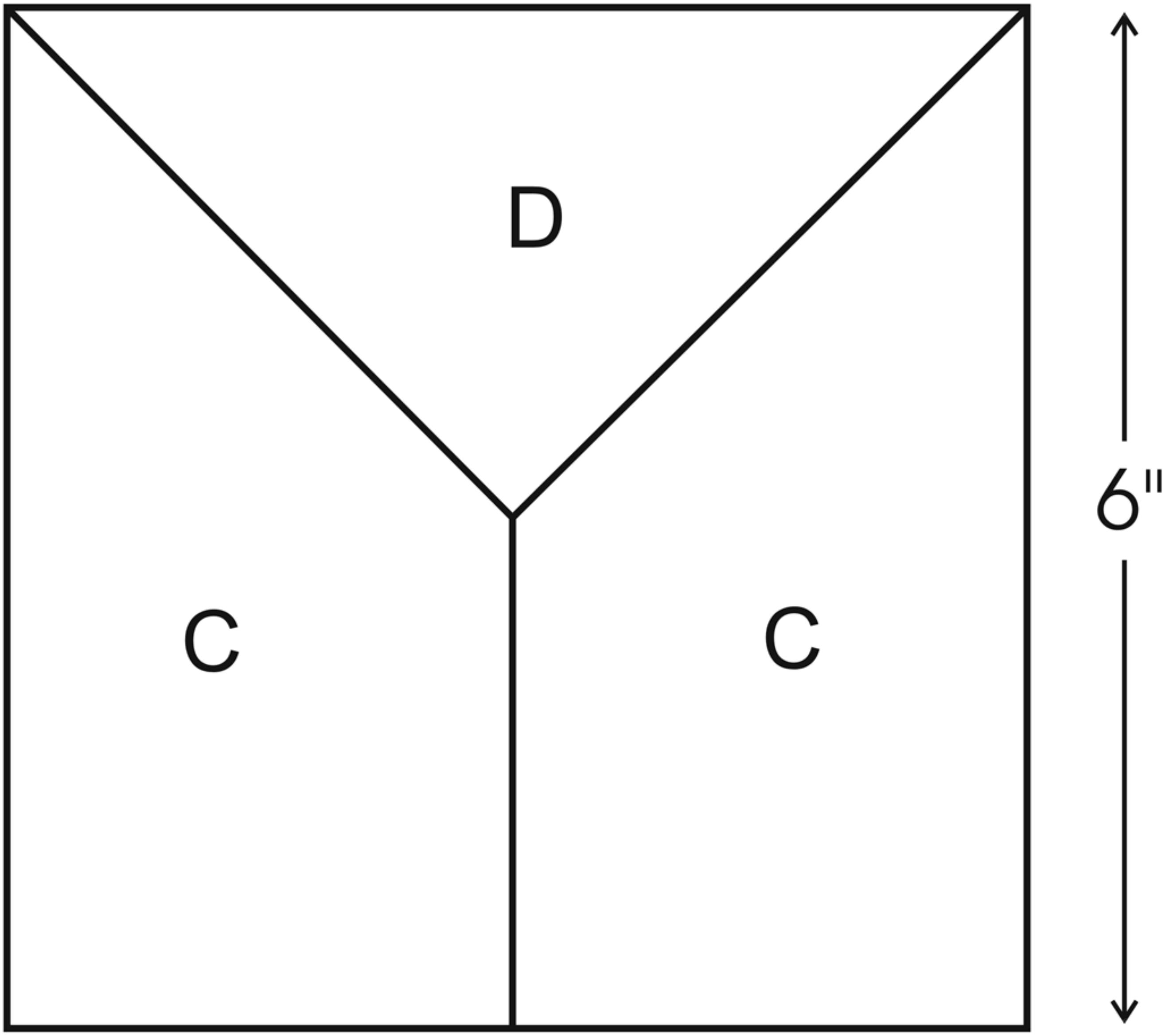
Monitor the group during the game and enforce the guidelines.

Observe the process and note the following:

- What are the different interactions between team members?
- Are certain team members willing to give away puzzle pieces?
- Are certain team members not willing to give away puzzle pieces?
- Do certain team members seem to be frustrated? If yes, how is it affecting the group?
- Do certain team members seem to want to dominate the activity? If yes, how is it affecting the group?
- How many people are actively working as a team to put the pieces together?
- Is there any specific point at which the team starts to work more cooperatively?
- Do any team members attempt to violate the rules to help other members solve their puzzles?

Templates for Broken Squares Activity

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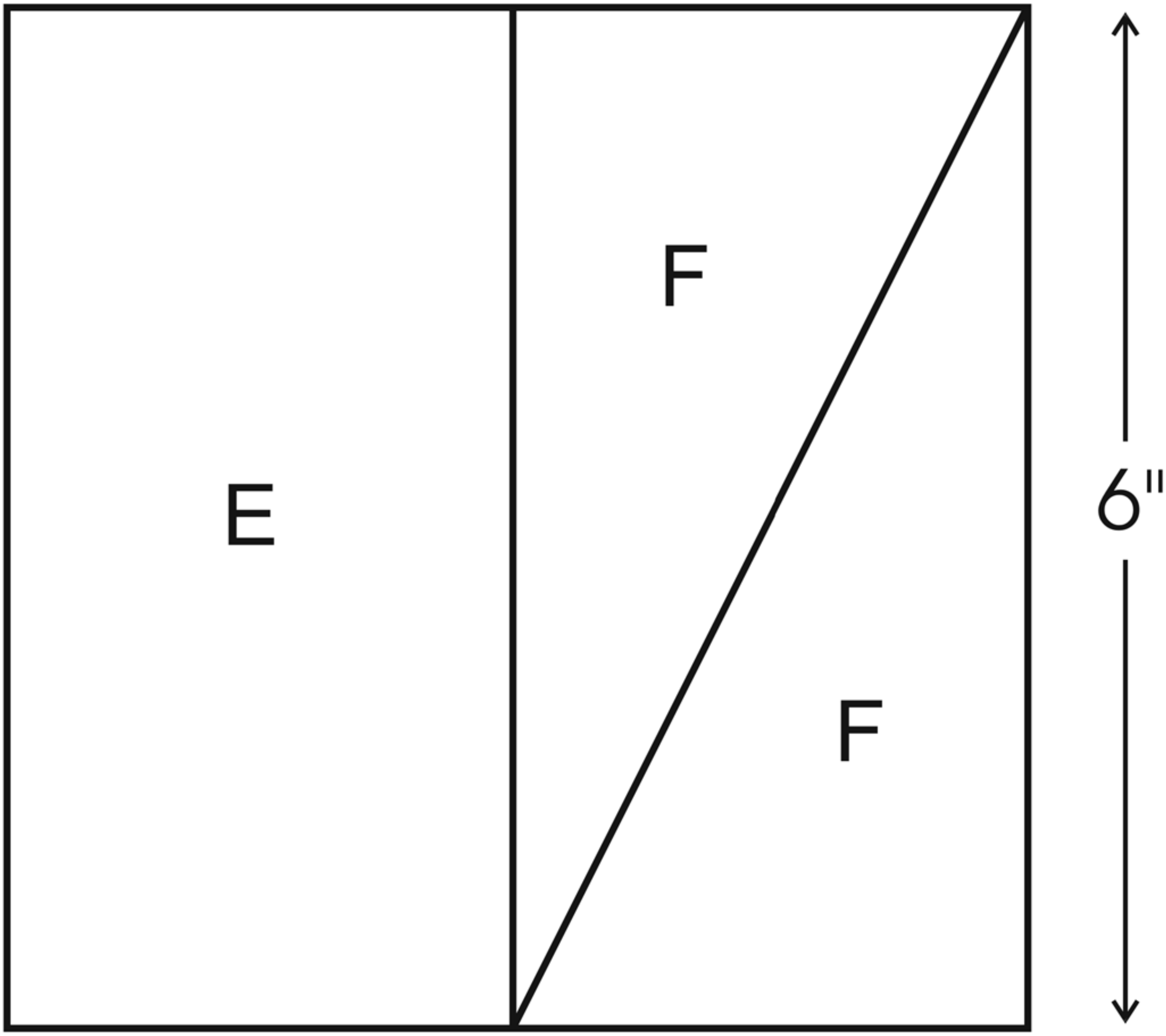
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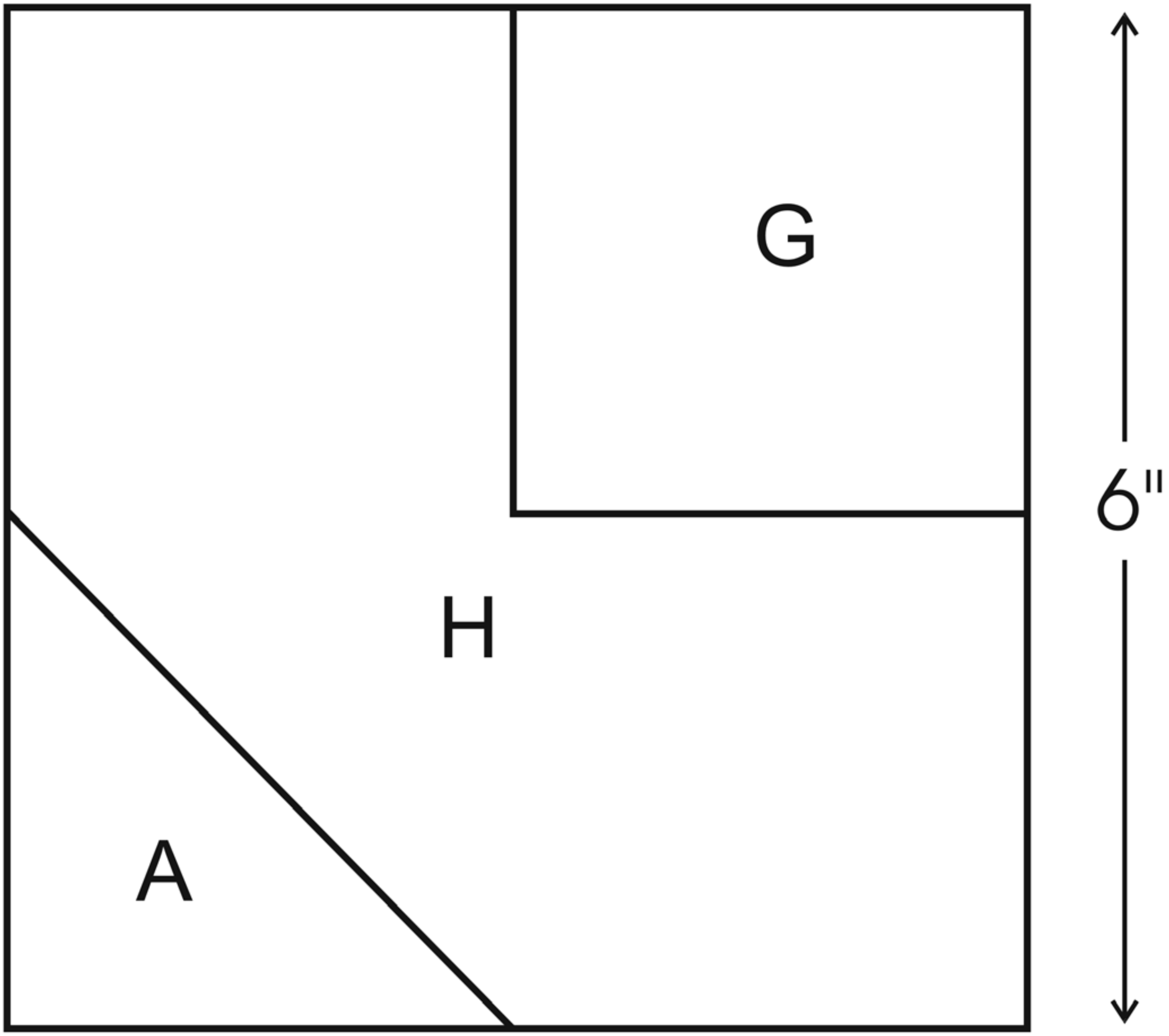
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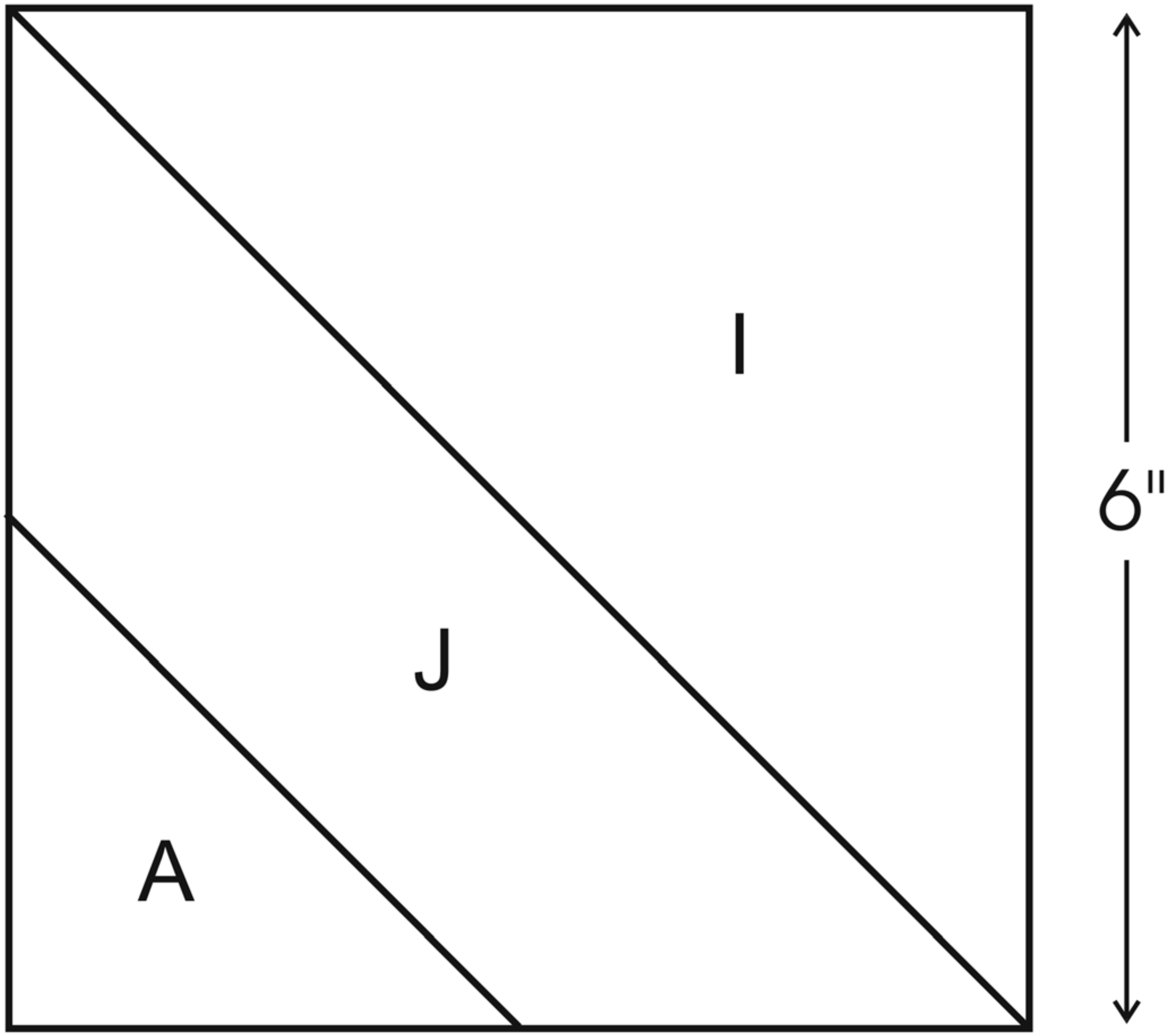
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ACTIVITY: MAKING INDIVIDUAL DECISIONS

Instructor Preparation

Decision-making is sometimes considered a form of problem-solving. Some people make hasty decisions based on emotional choices and regret them later. Others "overthink" simple decisions to the point of having anxiety attacks. Still others make intuitive decisions quickly and effectively with very little effort.

Most decisions are made unconsciously without a formal process. These are generally based on experience, habits, and personal preferences. They include decisions like what to eat for lunch, what to wear, or what movie to watch on TV. In these cases, the consequences of a poor decision are not devastating. On the other hand, some decisions—choosing a career, choosing a major in college, choosing a life partner, or choosing to drink alcohol—can be life changing and can affect others as well as the person making the decision. Making good decisions requires a thoughtful approach.

In this activity, students will rate how well they think they make decisions. Next, they will examine several methods for making decisions, individually or within groups.

Because the decisions we make individually are often more personal, the instructor might allow students to identify their own issues on which decisions should be made. Alternatively, the instructor may want to identify specific, course-related issues for students to consider. Below are a few suggestions to guide topic selection.

- CTE Courses: Have students make choices related to possible careers, e.g., choosing between two or more job offers or determining whether they want to work for themselves or for someone else.
- In a composition class, ask students to write a paper envisioning the impact their decision might have had on their lives ten years in the future.
- In an election year, ask students to determine who they will vote for in an upcoming election and prepare a persuasive paper to convince others that their candidate is the best choice.
- Ask students to describe the impact of someone else's choice on their lives.

Objectives

Students will:

1. Evaluate their effectiveness at making decisions.
2. Investigate several methods for making decisions.
3. Choose one of the methods to use in making a decision.

Materials

- Access to computers with Internet connection

Activity Guidelines

The instructor should engage students in a discussion about making decisions, using the following questions as a starting point:

- How many decisions do you think the average person makes in a day?
- Have you ever gotten into a car with friends to go eat and no one wants to decide where to go?
- What is a good decision?
- How do you make a decision?
- Can you think of a good/bad decision you have made recently? Describe how you went about making the decision and its results.
- Do you consider yourself a good decision-maker?

Have students go online to Mind Tools[1] (http://www.mindtools.com/pages/article/newTED_79.htm) and complete the *"How Good Are Your Decision-Making Skills?"* self-evaluation tool. After students have completed the evaluation, have them meet in groups of 2–4 and discuss their results. Use the information in the accompanying article and their results from the self-evaluation to determine at which step(s) of the process they could make improvements. Afterwards have students share with the class on a voluntary basis. The instructor can promote class discussion by asking questions such as:

- Which of the steps is the most problematic for you?
- What tips would you give those who have trouble making decisions?

After a discussion of the self-evaluation, describe the following strategies for making a decision. Ask students to consider the following questions:

- When are these methods appropriate?
- What is good about the technique?
- What are potential drawbacks?
- What are the likely outcomes of the process?

Flip a Coin or Random Drawing—Flipping a coin is used for yes-no decisions or decisions requiring a choice between two options. Random drawing is used when there are more than two choices. These options are appropriate in low-risk situations where both choices are acceptable to you and the outcome of the decision in not life-altering. Examples might be: "Do I buy this candy bar or not?" "Do I go to the game or to the movies?" "Which of three movies that I want to see should I choose?" While it may be argued that all decisions have consequences and that the decision to buy a candy bar might be life-threatening for a diabetic or be symptomatic of a lifetime of bad decisions leading to obesity, for the average person these decisions have no long-term effects. This technique is good because it is a quick

[1] While Mind Tools does have a subscription section, the tools referenced in this activity are free.

way to make unimportant decisions. If a single coin flip is used for making an important decision, there is a 50% chance of making a bad choice.

It Feels Right—Emotions can play a big role in making decisions. For example, going grocery shopping when tired and hungry can lead to overbuying and making poor choices about what to buy. On the other hand, emotions must be taken into effect when weighing possible outcomes. If the possible outcome of a choice is something that might lead to a desirable result but might also lead to future regrets, that choice should be carefully weighed. One example might be making a high-risk financial investment that has the potential of making the investor extremely wealthy if it goes well or bankrupting him if it fails. Being aware of your emotional state during all phases of the decision-making can help build a more reliable "gut instinct." This method influences most of our decisions, particularly personal decisions.

Formal or Logical Methods of Decision-Making—When there are major decisions to make, it is wise to be more methodical or logical in making them. One method involves brainstorming and evaluating possible decision outcomes. Brainstorm possible outcomes of each of the decision choices and write them all down. Be sure to think of both short-term and long-term outcomes. Ask others for additional possible outcomes to consider. Once this decision list is compiled, mark each outcome as positive or negative by putting a plus or minus sign by the outcome or assigning a weighted value to each outcome using a scale of 1 to 5 or 1 to 10. Other weighting methods entail estimating the probability of a particular outcome occurring and using that as a multiplier for the desirability of an outcome. This method is too time-consuming for daily decisions.

Eliminating Decisions—Decision-making can be time consuming. While not a method of decision-making per se, it is sometimes helpful to reduce the number of decisions to be made daily by creating routines or standard operating procedures. For example, to avoid having to decide each day what to prepare for dinner, many people select their favorite recipes and enter them on the calendar. Planning ahead means that when they shop they know what they need to buy for each recipe and they also know how much preparation time is required for each meal. Ask students to think about decisions that they have to make now or in the future. Ask them to select the method(s) that they will use to make the decision. Alternatively, present the students with a list of decisions to be made and ask them to discuss the methods that would be appropriate.

Group Reflection Questions

Review the lesson with the students. Answer any questions students might still have. Have students discuss the following:

- What did you learn about decision-making that was most helpful to you?
- What factors help or hinder you in making decisions?
- Do you prefer making decisions individually or as a group? Why?
- How does decision relate to problem-solving?
- How is not making a decision actually a decision? Is this a good or bad thing?

ACTIVITY: MAKE A PLAN

Instructor Preparation

For many people the hardest part of problem-solving is designing a plan to tackle the problem. Luckily, many different strategies can be used. Some are as simple as trial and error, while others can involve mathematical modeling of the problem. This activity will explore different strategies. Students should be encouraged to try many different strategies throughout the course. Remind them that problem-solving is a skill that can be improved with practice. When discussing student work, point out problems that were solved and discuss the strategies that are being used effectively. Conversely, explain why a particular strategy might not be suited for a given problem.

This lesson focuses on the following six strategies:

- Draw a diagram
- Make a list
- Trial and error
- Divide and conquer
- Look for a pattern
- Work backward

Emphasize that these strategies may be used in combination.

Objective

1. Use a variety of strategies to solve problems.

Materials

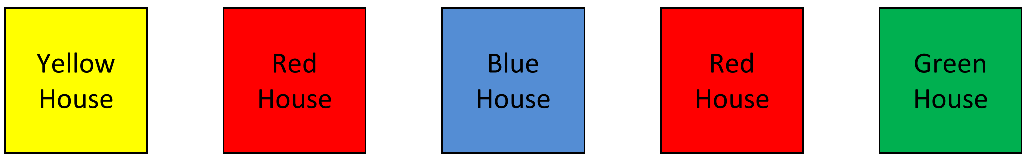
- Paper and/or graph paper
- Student Handout

Activity Guidelines

- Demonstrate each of the following strategies by working through them with your students. These strategies can be covered in one lesson or integrated into other appropriate content and applied to problems within that content.
- The student handout provides students with opportunities to practice the strategies. Have students discuss their strategies with one another or as a class. Having to describe the strategies in this way shows students that they really did use a strategy. It allows other students to learn strategies they may not have thought of, and most critically it allows the instructor to hone in on any false assumptions that students may have made that might cause problems later.

Draw a Diagram

It is said that a picture is worth a thousand words. This is especially true when it comes to solving problems. If you are able to visualize a problem and illustrate it, many times the solution will become obvious. For example, you are told that there are five houses on the block, one is blue, one is green, two are red, and one is yellow. Then you are told that both red houses are to the left of the green house; the blue house is between two red houses, and the yellow house is the first house on the block. What is the order of the houses on the block? This may be confusing at first reading, but if you draw a sketch of the block, you can quickly determine the order.



Make a List

Just as drawing a picture of a problem can often make a solution obvious, sometimes a systematic list can be used to find an answer. For example, suppose you have four different colored tiles: Red, Yellow, Blue, and Green. You are mounting them in a straight line on a display for a store. How many possible sequences are there? Creating a table of possible sequences can help you to find the solution:

RYGB	YRGB	BRYG	GRYB
RYBG	YRBG	BRGY	GRBY
RGYB	YGRB	BYRG	GYRB
RGBY	YGBR	BYGR	GYBR
RBGY	YBRG	BGRY	GBRY
RBYG	YBGR	BGYR	GBYR

Ask students to discuss how they came up with their answer. Ask them if it would work if they had 10 or 50 different tiles to mount. How many possible sequences would they have?

This example provides a good opportunity for reinforcing or introducing the $x!$ as a mathematics concept. Lead students into discovering that whenever you have x items to arrange in order and each item can only be used once, you have $x!$ possible solutions. That is, multiply the number of possible choices for the first slot by the number of choices available for the second slot, by the number of the choices for the third slot and so forth. If there is only one item, there is only 1 placement. If there are two items you have two choices for the first spot, and once that is made, you have only one choice remaining for the last spot. So $2 \times 1 = 2$. With three items for three slots you have $3 \times 2 \times 1 = 6$. For the example problem there were $4 \times 3 \times 2 \times 1 = 24$ choices, as shown by the table.

Trial and Error (also called Guess and Check)

When a solution isn't obvious at first, it is sometimes easier to try to zero in on an answer by guessing and checking the solution to see if it works. This is the method used, for example, when radio stations have high-low jackpots. The radio station picks a sum of money. Callers phone in and guess an amount.

The DJ will tell them if their guess is correct or is too high or too low. Each time another caller makes a guess (if they have been keeping track of the high and low values of others) they will be getting closer to the correct amount.

The instructor might want to play a game of high-low with his/her students. The instructor should pick a number between one and one hundred. Ask each student in turn for a guess until someone guesses the correct answer.

Divide and Conquer

This problem-solving method involves breaking a complex problem into smaller pieces that are simpler and then solving each smaller problem to find the solution to the bigger problem. Example: A store is having a new countertop put in the facility's restroom. The countertop is to be tiled with 2.25″ square tiles with 0.25″ of grout between squares for a total of 2.5″square per tile. The countertop is 11 feet long by 30″ deep. There will be three sinks with rectangular cutouts evenly spaced in the countertop. Each sink measures 15″ × 20″. Between the sinks are two 10″ square cutouts for trash disposal. How many tiles should be ordered for the job allowing for 10% waste?

Guide students in solving the problem by breaking the problem down into simpler steps. Ask them to identify information they already have and then information they need. (This is an opportunity to introduce or reinforce the mathematics concept of known and unknown variables.) Ask students how they would break the problem down into simpler steps. They will probably devise steps such as calculating how many tiles it would take to tile the entire countertop, subtracting the tiles that aren't needed because of the sinks and waste receptacle openings, and maybe even adding 10% for breakage allowance. A diagram of the countertop may help them to understand the problem better.

Look for a Pattern

Sometimes a pattern emerges that helps solve a problem if you begin plotting data. The Fibonacci Sequence is a famous example of such a pattern. Fibonacci, an Italian mathematician, posed a problem that illustrated this sequence. Have students use Fibonacci's problem and see if they detect the pattern.

Problem: A farmer is given a pair of baby rabbits on the first of January, one male and one female. In one month, they become sexually mature and breed. The rabbits have a one-month gestation period, so they produce a litter at the beginning of the third month. Each time a pair of rabbits reproduces, the litter consists of one pair of rabbits, one male and the other female. If no harm comes to any of the rabbits, how many rabbits will the farmer have at the end of the year? (Note: This was Fibonacci's problem as he envisioned an ideal rabbit population, not based on actual rabbit reproduction abilities.)

Students might begin to solve the problem by plotting how many pairs of rabbits are born each month. After seven or eight months, naming and listing the rabbit pairs becomes very cumbersome. However, if the students look at the total pairs of rabbits, they should be able to discern a pattern. Each month the total number of pairs is equal to the sum of the previous two months. Students then should be able to complete the total pairs of rabbit column through the rest of the year.

Month	Total Pairs of Rabbits	Initial Pair	A's Litters	B_1's Litters	B_2's	B_3's	$C_{1.1}$'s	B_4's	$C_{1.2}$'s	$C_{2.1}$'s	etc	etc
1	1	A	0									
2	1	A	0									
3	2	A	B_1									
4	3	A	B_1,B_2									
5	5	A	B_1,B_2B_3	$C_{1.1}$								
6	8	A	$B_1,B_2B_3B_4$	$C_{1.1}C_{1.2}$	$C_{2.1}$							
7	13	A	$B_1,B_2B_3B_4B_5$	$C_{1.1}C_{1.2}C_{1.3}$	$C_{2.1}C_{2.2}$	$C_{3.1}$	$D_{1.1.1}$					
8		A	$B_1,B_2B_3B_4B_5B_6$	$C_{1.1}C_{1.2}C_{1.3}C_{1.4}$	$C_{2.1}C_{2.2}C_{2.3}$	$C_{3.1}C_{3.2}$	$D_{1.1.1}D_{1.1.2}$	$C_{4.1}$	$D_{1.2.1}$	$D_{2.1.1}$		
9												
10												
11												
12												

Note: Fibonacci's sequence can begin with any two numbers. His sequence has applications in nature, architecture, and many other areas. It is also related to the Golden Ratio. Ask students to research Fibonacci sequence and/or the Golden Ratio and share examples with the class.

Examples of this "look for a pattern" problem-solving method include both simple "what comes next?" problems and more complex calculations used to predict population numbers, the national debt, and so forth.

Work Backward

Many times we must work backward to find a solution to a problem. Here's an example of this kind of problem.

Josh, Jamie, and Ava each have some money. Josh has the most, so he gives each of his friends an amount equal to what they each had to start with. Jamie then has more than her friends, so she gives each of them an amount equal to what they each currently have. Finally, Ava ends up with the most money. She gives each of her friends an amount equal to what they currently have. Then Josh, Jamie, and Ava each have $32. How much money did each person begin with?

Students might want to create a table to show the money each person has at each step in the sharing process.

	Ava	Jamie	Josh
End	$32	$32	$32
	64	16	16
	32	56	8
Start	16	28	52

Working backward, start with Ava. She gave each of her friends an amount equal to what they currently had. They each had $32, so she must have given them each $16 for a total of $32. Since there is a total of $96 dollars in play, she would have had $64 dollars in the previous round. In the previous round, Jamie gave each of her friends an amount equal to what they currently had, or one half of the amount they now have. So she gave Josh $8 and Ava $32, leaving her with $56. Josh started the process by giving each of his friends an amount equal to what they had or half the current amount. So Ava had $16, Jamie had $28, and Josh had $52 at the beginning of the day.

Group Reflection Questions

Discuss the following with your students:

- How does knowing a variety of problem-solving strategies prepare you to be a better problem solver?
- What are some of the problems you have solved, for this course or another, where you have used one or more of the methods discussed?
- Is problem-solving something you prefer to do alone or with others? Why?

Handout—Make a Plan

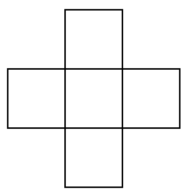
Solve the following problems. Be prepared to describe how you solved the problems.

1. Five teams compete in a bicycle relay race. Each team rides a different colored bike and wears matching colored jerseys. The top five teams were Red, Silver, Blue, Green, and Black in some order.
   - The Red team finished seven seconds before the Silver team.
   - The Black team finished six seconds after the Blue team.
   - The Green team finished eight seconds after the Blue team.
   - The Silver team finished two seconds before the Black team.

   In what order did the teams finish the relay? What strategy did you use?

2. You just installed a keyless lock on your front door. You have to choose a four-digit code on the ten-digit keypad that you will use to unlock the door.
   a. How many choices are there if you do not repeat a digit more than once?
   b. How many choices are there if you allow repeats?

3. Arrange the numbers 23, 24, 25, 26, 27 into the following diagram so that the sums of the numbers both horizontally and vertically add up to the same total.



4. What are the next three numbers in the following sequence? 1, 2, 4, 7, 11, 16, __, __, __
5. What letters come next in the following sequence? A, Z, C, X, E, V, __, __, __
6. A contractor hires five men to paint a house. At the end of the day the owner of the house pays the contractor for the work. The contractor takes $75 off the top for paint costs. He then pays each worker as follows: The first worker gets $\frac{1}{6}$ of the money; the second worker gets $\frac{1}{5}$ of the money that is left; the third worker gets $\frac{1}{4}$ of the money that is left; the fourth worker gets $\frac{1}{3}$ of the money that is left; the fifth worker gets $\frac{1}{2}$ of the money that is left; and the contractor keeps the remaining $45.00. How much did the homeowner pay the contractor for the job?
7. Jolene raises corn as a cash crop. On April 1, she needed some operating cash to plant her crop. She decided to sell 20,000 bushels of corn she would produce on the futures market. She received $7.10 per bushel and agreed to deliver 15,000 bushels of corn in October. She produced 30,000 bushels of corn. She received $7.70 per bushel for the 15,000 she did not sell on the futures market.
   a. What is her gross income from the corn crop?
   b. Instead of selling on the futures market, Jolene could have borrowed $106,500 at 8% simple interest with repayment due in October. (She would pay the $106,500 plus 8% of $106,500.) Would this have been a better alternative?

ACTIVITY: 7-STEP QUALITY IMPROVEMENT PROBLEM-SOLVING MODEL

Instructor Preparation

This activity features a problem-solving methodology that is used in business and industry to identify and correct issues related to quality. While the activity can be completed as a stand-alone lesson on problem-solving, it could also accompany complex problems from a specific course, the college itself, or the workplace. Ideas include:

- The manufacturing faculty for the credit program wants to assign additional projects for students to complete in a supervised environment outside of class. At night the manufacturing labs are used to train workers at local companies. Students complain that they can't get enough time in the labs to complete the projects during the day when there are supervised lab times. What might be done to accommodate students who need to use the labs in the evenings? In the daytime?
- Practically all business enterprises need to improve and/or maintain customer satisfaction. How might that customer service be improved in a construction company? In a medical office? In banking? In the hospitality industry? In another career pathway?
- The class is falling behind the course syllabus schedule for reasons such as frequent student tardiness, lack of student preparation, and instructor absences. Can the class catch up? What might prevent this from happening in future semesters?
- There are traffic flow issues on and around campus at specific times of day. How can they be alleviated?
- The college wants to increase the number of students involved in service-learning projects. How might they go about it?

Instructors teaching quality management may use lab activities with problems to be solved. The following is an outline of the seven-step problem-solving model upon which the student handout is based. The instructor should walk students through the process, providing additional strategies and examples, prior to student groups using the process to solve a problem. Note that the student handout contains more detailed content and instructions.

The Seven-Step Problem-Solving Model: OVERVIEW

1. Identify and define the problem
   a. Brainstorming
   b. Impact changeability tool
   c. Problem statement stem
2. Study the current situation
   a. Force-field analysis
3. Find root cause
   a. Asking five times
   b. Fishbone diagram
4. Choose solution
   a. Brainstorming
   b. Evaluation grid
5. Develop an action plan
   a. Action plan steps
   b. GANTT chart
   c. PERT chart
6. Implement the action plan
   a. Five Ws and an H
7. Check results
   a. Force-field analysis
   b. Brainstorming
   c. Evaluation grid

Objectives

Students will:

1. Identify problems.
2. Study the current situation.
3. Determine root causes of a problem by asking "why" five times.
4. Brainstorm solutions to the problem.
5. Develop and carry out an action plan to solve the problem.
6. Check results.

Materials

- Student Handout – 7-Step Quality Improvement Problem-Solving Model (1 per student)
- Whiteboard, SmartBoard, flipchart, or other mode of creating a diagram with the whole class

Activity Guidelines

Distribute the handout and ask students to refer to it as you facilitate use of the 7-step model.

Step 1: Identify and define the problem.

Ask students to suggest problems they might face in a work environment. Brainstorm a list. Follow the directions for the impact changeability tool described in Step 1 on the student handout to identify which problem students will solve.

One way to write the problem statement is in the form of a question: "In what ways might we, the team, _________________________ so that ______________________." For example, in manufacturing the problem statement might be: "In what ways might we, the team in the production department, reduce absenteeism so that our production percentage is increased by 35 percent?"

In sales, the problem statement might relate to percentage increase in customer telephone contacts and percentage increase in subscriptions. In hospitality, it might address speed of service. In medical billing and coding, increased accuracy might be a factor.

One way of prioritizing the problems or improvement opportunities is through a tool called *impact changeability.* This helps the team prioritize problem processes based on the degree of impact some task or process has on the whole system and on how easy the change would be.

Step 2: Study the current situation.

To gather as much information as possible, ask students to create a flowchart of the process related to their problem statement. A process flowchart, a beginning-to-end description of a task, is often useful for studying the current situation. The flowchart illustrates how things are done now.

After they have completed the process flowchart, have students answer the following questions:

- Where do the problems or errors (variances) occur?
- Where do the delays (non value-added time) occur?

- Is there obvious evidence of redundancy, rework, waste, or similar problems?
- What does the team do to obtain feedback from customers?

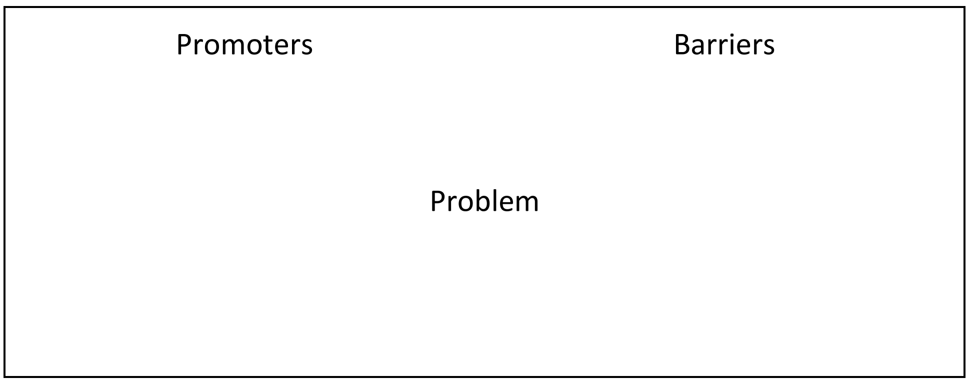
Another helpful tool for gathering information is a force-field analysis.

Force-Field Analysis

Facilitate completion of the second step of the seven-step problem-solving process through the use of a tool called force-field analysis. Force-field analysis provides a visual way for a team to identify *barriers to* and *promoters of* a goal.

Directions

1. In the center of a piece of chart paper, write the problem to be solved as identified and defined in Step 1. At the top of paper on the left side, write "Promoters" and on the left side write "Barriers."



2. Lead the students in thinking about possible promoters and barriers in their work environment related to the identified problem. Brainstorm a list of promoters that would support the team's goal. Then brainstorm a list of barriers that would hinder the team's goal.
3. Ask students to prioritize the ideas that would be the greatest promoters and the greatest barriers. The idea is to encourage the team to build on the promoters and minimize the barriers.

Step 3: Find root cause.

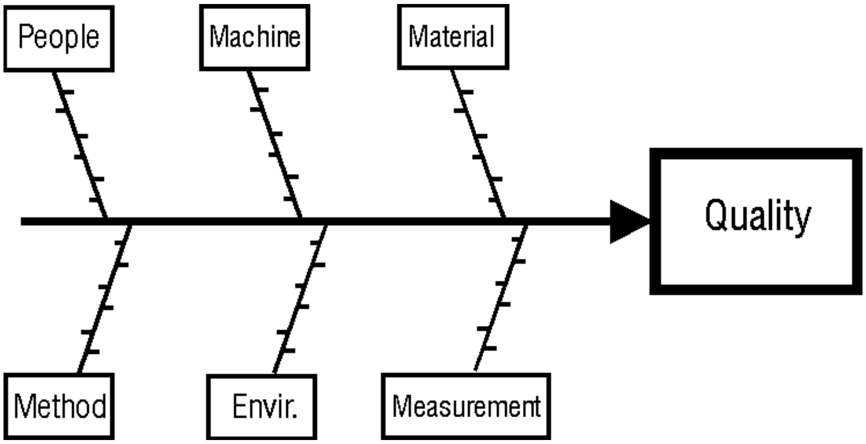
One tool for finding root cause is provided on the student handout—asking WHY five times. (See the example provided in the student handout.) After students have completed the five "whys" activity in their handout, introduce them to another helpful tool—the fishbone diagram. Draw the diagram step-by-step on a whiteboard, SmartBoard, or flip chart.

Fishbone Diagram

The third step of the seven-step problem-solving process is well facilitated with the use of a tool called a fishbone diagram. A fishbone diagram, sometimes called a cause-and-effect diagram, can help the team find the root cause of their identified problem. Explain that the name of the tool stems from its appearance.

Directions

1. Draw a box on the right side (the head of the fish) where students can see it. Write the problem statement in the box.
2. Draw a line from the box to the left side (the backbone of the fish).
3. Draw six lines on a diagonal from the straight line, three on the top and three on the bottom (the fins of the fish). Because the identified problem relates to quality control, write the broad categories of factors effecting quality on each diagonal line: People, Machines, Material, Method, Environment, and Measurement. Another way of thinking about the problem to be solved is to label the fish head *Effect* and the each of the six boxes *Cause*, which can then be broken down into their component causes for further examination. Note that fishbone diagrams can be used for many purposes including mind mapping for brainstorming or for synthesis of ideas within a larger topic.



4. Ask the students to identify all the "whys" for each category. Then ask "why" of those ideas, making subcategories of the original categories. Continue asking "why" until all causes are identified.
5. At this time, the team should note the ideas that require action for resolution of the problem.

Step 4: Choose a solution.

The student handout provides a general outline for choosing the best solution to the problem. Use the following tool.

Brainstorming and Evaluation Grid

The fourth step of the seven-step problem-solving process is well facilitated with the use of two techniques: brainstorming and an evaluation grid. Brainstorming can be done in numerous ways. We will use a method that encourages individual thinking. The evaluation grid helps to identify the best solution based on specified criteria.

Directions

1. Ask each student to write down as many alternative solutions to the problem as possible, without considering each one in too much detail. When enough time has passed, ask one student to suggest one idea. Record it on chart paper. Then ask another student to suggest a different idea. Continue in this manner until all students' ideas are on the chart paper. Allow students to pass if their ideas have already been suggested.
2. Gain consensus as to which of the top four or five ideas would most likely address the root causes. The purpose is to find ideas that, if implemented, would solve most of the root causes.
3. Next, ask the students to generate a list of criteria by which each idea will be judged. A criterion should be stated positively. For example, the solution would say the "least expensive" or "fairest to all concerned." Choose four or five criteria.
4. On chart paper, make a grid like the one below.

	Criterion	Criterion	Criterion	Criterion	Criterion	**TOTAL**
Solution 1						
Solution 2						
Solution 3						
Solution 4						
Score						

5. Start with the first criterion and rank each solution according to that criterion. Each solution should be ranked from one to five, five being the best solution according to that criterion. Continue evaluating all solutions according to each criterion. Add the rows to get a total score for each solution. The solution with the most points should be the best solution for solving the root causes. If two solutions are close in score, consider implementing both solutions.

Step 5: Develop an action plan.

Develop an action plan for putting the solution to work. Action steps should be clearly defined, volunteers requested for each step, and due dates agreed upon for completing each step.

The action plan should be:

- Specific and clear
- In a logical sequence
- Comprehensive
- Voluntary
- Shared with all of the team
- Reviewed frequently

The key steps in developing an action plan are the following:

1. Define what needs to be done.
2. Agree on when it needs to be done.
3. Agree on who will do it.
4. Develop a visual plan, a PERT or GANTT chart.
5. Review the plan periodically.

PERT and GANTT charts can be used to help develop the plan. The student handout provides examples. Use them to demonstrate how to plan the sequence and timing of tasks within the solution.

Step 6: Carry out the action plan.

The facilitation of an action plan is easily done by the use of the following tool, which builds on the PERT or GANTT chart information. With the five Ws and an H, the team decides *who* will be responsible for each step, *what* that person will do, *where* he or she will do it or get the resources necessary to do it, *when* the task should be completed, *why* it is important to complete this step, and *how* it will be completed. The following is a table for making the plans.

Five Ws and an H

Directions

1. Define the steps necessary to implement your solution.
2. Use a grid similar to that below to establish a plan. Write each step in the appropriate box across the top of the grid.
3. As a group, decide who will be responsible for each step. Describe what that person will do, where they will do it and/or where they can get resources, when the task should be completed, why it is important to complete this step, and how it will be completed.

	Step 1	Step 2	Step 3	Step 4	Step 5
Who					
What					
Where					
When					
Why					
How					

Step 7: Check the results.

Check the results of the solution's implementation by using force-field analysis. Then use brainstorming techniques to identify viable alternative solutions for overcoming any obstacles and follow up with an evaluation grid to select the best alternatives.

Group Reflection Questions

To wrap up this lesson, you may want to discuss the following questions as a class:

- How does your personal problem-solving model compare to this model?
- How will you apply some of the principles and strategies discussed in this module?
- What will you do to focus on your customer and quality, using a systems approach?
- How does group problem-solving differ from solving problems individually?

Handout—7-Step Quality Improvement Problem-Solving Model

A simple and effective problem-solving model includes the following seven steps. These seven steps should be adequate to solve most of the problems individuals or teams might face personally or on the job when addressing quality issues.

1. Identify and define the problem.

Collect existing problems or improvement opportunities, prioritize them, and select one to work on. One way of prioritizing the problems or improvement opportunities is through a tool called *impact changeability.* This helps the team prioritize problems to address based on the degree of impact the task or process has on the whole system and on how easy it would be to change that task or process.

Here's how you analyze impact and changeability. First, select a problem or process to examine.

1. Determine, by consensus, what impact the elimination of this problem/process would have.
   L—little impact
   S—some impact
   C—considerable impact

2. Determine, by consensus, how difficult it would be to change this problem/process.
   D—difficult
   M—moderate
   L—little or no effort

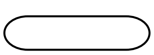
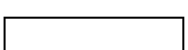
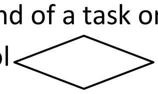
3. By consensus, agree on which problem the team is going to work on first.

The most important aspect of problem identification is to state the problem in such a way that everyone has the same understanding of it and specifically enough so that a solution can be found. It is always best, if possible, to describe the problems using data—numbers, percentages, frequencies, occurrences, and comparisons.

2. Study the current situation.

Study the problem from many points of view to gain a broad and thorough understanding of the current situation. Determine where, when, and how the problem occurs. Problem-solving requires careful and systematic thinking about problems, starting with gathering as much data as possible.

A process flowchart, a beginning-to-end description of a task, broken down by sub-tasks or processes connected by arrows in a sequence, is often useful for studying the current situation.

Use this symbol  to represent the beginning and end of a task or process; this symbol  to indicate instructions or actions; and this symbol  for decisions to be made.

After creating a process flowchart, answer the following questions:

- Where do the problems or errors occur?
- Where do the delays occur?
- Is there obvious evidence of redundancy, rework, waste, or similar problems?
- What does the team do to obtain feedback from customers?

Because you will need to collect data about the current situation consider the following:

- What data is needed?
- How will we collect this data?
- Who will collect it?
- When will it be collected?

3. Find root causes.

Gather data and select the most likely root causes. A fishbone diagram (which your instructor will walk you through) is one tool for thinking about possible contributing factors. It is important that this step focus on objective causes rather than fault-finding. One way of assembling data to determine the root cause is to ask WHY five times. In the table below, the problem statement is: A puddle is found on the factory floor. The first "why" question is "Why was there water on the floor?" Answering that question generates a new one, "Why was water dripping from the ceiling?" Each answer provides ideas for a solution and the solutions, cumulatively, lead to a future action.

For example:

A puddle is found on the factory floor.

Solution: Mop up the water

1. **Why** was there water on the floor?
   Answer: It was dripping from the ceiling
   Solution: Place a bucket under the drip.
2. **Why** was water dripping from the ceiling?
   Answer: A pane of glass was broken in the skylight.
   Solution: Replace the broken glass.
3. **Why** was the glass broken?
   Answer: A tree branch had broken the glass during a storm.
   Solution: Cut the branch away from the roof.
4. **Why** was the tree branch overhanging the roof?
   Answer: Trees had been planted too close to the sides of the building.
   Solution: Remove trees that are too close to the building.
5. **Why** were trees planted so close to the building?
   Answer: There was no policy governing their location.
   Solution: Establish standards to govern the placement of landscaping and trees.

4. Choose solutions.

Generate as many potential solutions as possible. Use consensus to select the solutions that are most likely to address the root causes. Create a grid and list the solutions. Next to each, list criteria by which the solution will be judged, for example "this is the least expensive solution" or "this is most likely to solve the problem permanently."

	Criterion	Criterion	Criterion	Criterion	Criterion	**TOTAL**
Solution 1						
Solution 2						
Solution 3						
Solution 4						
Total						

Start with the first criterion and rank each solution according to that criterion. Each solution should be ranked from one to four (total number of solutions), four being the best solution according to that criterion. Continue evaluating all solutions according to each criterion. Add the rows to get a total score for each solution. The solution with the most points should be the best solution for solving the root causes. If two solutions are close in score, consider implementing both solutions.

5. Develop an action plan.

Develop an action plan for putting the solution to work. Action steps should be clearly defined, volunteers requested for each step, and due dates agreed upon for completing each step.

The action plan should be:

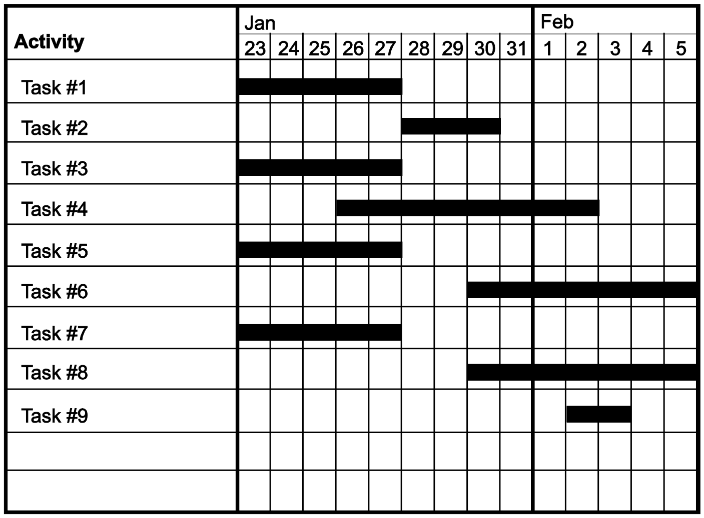
- Specific and clear
- In a logical sequence
- Comprehensive
- Voluntary
- Shared with all of the team
- Reviewed frequently

The key steps in developing an action plan are:

1. Define what needs to be done.
2. Agree on when it needs to be done.
3. Agree on who will do it.
4. Develop a visual plan—a GANTT or PERT chart.
5. Review the plan periodically.

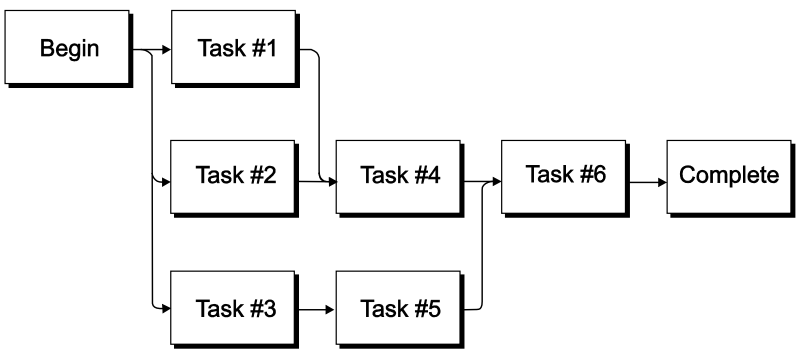
A GANTT chart illustrates the beginning and end dates of sub-tasks within a larger project.

Example GANTT Chart



A Program (or Project) Evaluation and Review (PERT) chart indicates the sequence of tasks in a project (or in solving a problem.)

Example PERT Chart



6. Carry out the action plan.

Building on the action plans created in Step 5, complete the following table as a team. Team members will then be aware of their responsibilities—what solutions they are to implement and when. Carry out the action plan with all team members contributing and involved in the process.

	Step 1	Step 2	Step 3	Step 4	Step 5
Who					
What					
Where					
When					
Why					
How					

7. Check results.

Compare the data collected before and after the action to find out whether the planned steps were accomplished and the planned results achieved.

To implement your solution you will need to

1. Accurately identify constraints or obstacles.
2. Identify viable alternative solutions for overcoming the obstacles.
3. Select and try the alternatives.
4. Support the reasoning behind the alternatives with data.

Identifying Potential Improvement Opportunities

Team problem-solving models are frequently used to make problem-solving efficient; to help everyone pull together in a common direction; to help team members avoid jumping to solutions before the facts are known; and to clearly identify the problem and make recommendations for improvements.

After gathering data from your customers, you will probably have identified some potential problems—the differences between the ideal state and the existing situation. As you study process inputs and outputs, you identify opportunities to improve cycle time; eliminate quality variances; eliminate waste; or reduce time, effort, and costs.

ACTIVITY: TOOLS FOR PREVENTING PROBLEMS

Instructor Preparation

Continuous quality improvement requires identification of potential problems before they arise. Measurements are made at regular intervals and the data plotted to ensure values fall within an acceptable range. If these values are plotted over time, trends may indicate that the process is out of control or that a problem is brewing. For example, when a patient goes to the doctor and the nurse takes her blood pressure and finds that it is high, the nurse has two options. If this is the first time the patient has had a high blood pressure reading, the nurse may wait a few minutes and take it again. If it is still too high, the doctor's office may reschedule the patient to come back in a week and have it taken again. If the patient comes back and the blood pressure is lower, the high reading will probably be considered an anomaly. If after a series of visits the high readings persist, the doctor may make recommendations to try to bring the patient's blood pressure down. The doctor may also have the patient take daily readings to track blood pressure over time to get a better picture of the effectiveness of the treatments.

In manufacturing situations certain trends may indicate equipment is failing or needs calibration, or that there is something else going wrong in the system. Once a trend is determined, workers can use problem-solving methods to identify the most likely cause and fix it before it negatively affects the system's end product.

In this activity students will assume the role of a quality technician working with a team to simulate a bottle-filling operation and will collect data, create control charts to identify potential problems, and determine how this data could be used to prevent problems.

The objective is to determine the ability to control the volume of product shipped in the bottles. Since water has a weight of 1 gram per ml, weight will be used to determine volume. This is important since the consumer is interested in receiving the full volume and the manufacturer is interested in controlling cost by not shipping excess volume.

Students will prepare a flowchart to show the process steps and measurement points. They will follow the flowchart and one member of the team will be assigned the job of process auditor to assure that the steps are being followed.

It is assumed that the filling station is running continuously. At half-hour intervals samples—the bottles filled by the team—are taken from the filling station for measurement. The team may use any appropriate procedure to fill the samples for measurement. The samples represent all bottles produced during the half-hour interval. One approach a team might take would be to have one member filling and two members weighing and recording. Remind students that it will also be important to recognize the variation in weight for empty bottles.

After all the data is collected, all members should work together to prepare a report including the flowchart, check sheet and histogram.

OPTIONAL EXTENSION ACTIVITY—Instructors in STEM-related or manufacturing career pathways may wish to have students prepare X-bar/R control charts using a sample size *n*=5. In this situation, each consecutive five bottles will be assumed to be the sample selected at half-hour intervals. *Note:* While the mathematics is not difficult, the number of variables (and their symbols) involved in completing control charts can appear overwhelming to some students.

Objectives

Students will:

1. Perform an experiment and explore product packaging by weight.
2. Construct flowcharts, checklists, histograms (and optionally, X-bar/R charts and/or run charts).
3. Understand how control charts can be used in statistical process control to identify problems and potential problems so that they can be corrected as quickly as possible.
4. Analyze control charts to identify causes of variation and devise a method to reduce the variation.
5. Record, report, and analyze data using statistical techniques.
6. Determine if product is within acceptable limits and meets customer expectations.
7. Perform calculations to find averages, range, upper control limits (UCL), and lower control limits (LCL) using quantitative samples.
8. Identify variations within the product.

Materials

Each group will need the following:

- 100 empty 12-ounce bottles per team (*Note:* Fewer bottles can be used and then emptied and refilled, but it will slow down the filling process.) Bottles must all be the same size and shape. Any readily available size can be used.
- Self-adhesive labels (small)
- Container to transfer water from tap to bottle (Provide a variety of containers such as beakers, measuring cups, pitchers, cans, and larger bottles so forth so students can choose.)
- Funnel (optional)
- Sink deep enough to allow students to collect water in measuring cups, cans, and so forth (can be shared by multiple teams)
- Towel to wipe bottle dry before measurement
- Electronic balance capable of measuring 1 kilogram ± 0.01 gram (Two per team would speed up the activity.)
- Calculator
- Handouts 1–5

Activity Guidelines

Preparation

Students must set up the area to be like a production line. A flowchart of the process steps would help in understanding the required production line design.

- Bring empty water bottles from home, or ask students to bring empty water bottles to class.
- Instructors should introduce students to control chart calculation and usage. The level of detail can be the same as given to manufacturing equipment operators. STEM and manufacturing instructors should cover as much information as they feel is necessary for their students to understand and complete the project. Other faculty who choose to use this project should study the information provided in the *Quality Control Handout*. Provide copies of this information, check sheets, data forms, and blank charts for the students to use in class.
- Review each team's arrangement of the tables and the assembly line students need to accomplish their assignment.
- The Blank Student Forms handouts include a Check Sheet, Histogram and X-bar/R Chart.

Activity Instructions

- Open the activity by having students discuss reasons for having quality control on a production line.
- Ask students what the consequences of poor quality control on the production line might be.
- Discuss the steps of process control and, if course-appropriate, the difference in descriptive and inductive statistics.
- Discuss types of data and how to organize data.
- Discuss glossary terms.
- Discuss sources of variation.
- Hand out the example flowchart and refer to the *Quality Control Handout*. Discuss the important elements or steps. Discuss the questions that are asked in the flowchart in the handout and follow up with a discussion of the questions that relate to a bottle-filling production flowchart.
- Show examples of and explain the check sheets, charts, or graphs that you will be using.
- Explain the Student Activity Bottle Filling Project and distribute materials.
- Provide students with copies of any check sheets, charts, and blank graphs they need. The following are provided:
  - Check Sheet
  - Histogram
  - X-bar/R Chart

- Instructors may wish to hand out a sample histogram for students to review. Sample data are included for this activity in the Examples section.
- Go over the flowchart in the Quality Control Handout or give students a separate flowchart found in the Examples. Have students read the instructions on the arrangement of the tables in the Student Activity sheet. Instruct students to work in their group to create a flowchart showing how to set up the area like a production line. Check the flowcharts to see if the students show that they have an understanding of the required line design and can accomplish the assigned task. The instructor should not make suggestions for improvement, as that is part of the student assignment. Just check to make sure they have a basic understanding.

Student Instructions

1. The student will prepare a flowchart to show the process steps and measurement points. They will follow the flowchart.
2. They will assign jobs within their team such as process auditor, weight finder, data recorder, and bottle filler.
3. The process auditor will ensure that the steps are being followed.
4. Determine net weight variation from water bottle to water bottle.
5. Create histograms and X-bar/R charts.
6. Have students analyze graphs and think of a more accurate method of measuring or filling the bottles that would result in reducing the variation.
7. Have students test their ideas if time allows.
8. Discuss results and prepare a Project Report including recommendations and conclusions.

Group Reflection Questions

Make sure to point out to students that where this activity ends is where the actual problem-solving begins. Once a problem or potential problem is identified, students have data and are ready to begin brainstorming possible causes of the problem.

Ask students to discuss the following:

- How did your team initially determine how much water to put in the bottles?
- Did the bottle-filler change his/her method of filling the bottle during the activity trying to improve speed, accuracy, or precision? What changes were made?
- What was the percentage of bottles that fell outside the upper control limit and the lower control limit? *Hint:* If students filled 100 bottles, each bottle would represent one percent of the total. Would that be acceptable in an actual bottling operation?
- What are other applications for this method of detecting problems?
- What is the benefit of early detection of problems?

Handout 1—Preventing Problems Activity Instructions

Background:

Quality Control uses tools such as charts and graphs to identify problems and suggest ways to continuously improve. These tools help determine if variations in measurements of a product are caused by small, normal variations that cannot be acted upon or by a larger issue that can be fixed. The type of chart used is based on the nature of the data.

Today you will be using flowcharts, histograms, and if directed, X-bar/R charts.

Scenario:

You are a quality technician working with a team at a bottle-filling station in a production line of a product shipped to a consumer. For this test, the product bottled will be ordinary tap water. The objective is to determine the ability to control the volume of product shipped in the bottles. Since water has a weight of 1 gram per ml, weight will be used to determine volume. This is important because the consumer is interested in receiving the full volume and the manufacturer is interested in controlling costs by not shipping excess volume.

It is assumed that the filling station is running continuously. At half-hour intervals samples (bottles filled by the team) are taken from the filling station for measurement. The samples represent all bottles produced during the half-hour interval. The team may use any appropriate procedure to fill the samples for measurement. One possible approach would be to divide the team with one member filling and two members weighing and recording the weight of both the empty and the filled bottles.

Your team will prepare a flowchart to show the process steps and measurement points. Then you will follow the process outlined by the flowchart, with one team member acting as the process auditor to ensure the steps are being followed.

After all the data is collected all members should work together to prepare the report. Histograms (and optional X-bar/R control charts) will be prepared using a sample size n=5. In this situation, each consecutive five bottles represent the sample selected at half-hour intervals.

Steps:

1. Read the scenario above. The instructor will assign teams of four to six students to complete the project.

2. Consider the steps that need to occur to accomplish the assignment. Bottles must be labeled and filled. The tare, gross, and net weights should be found and recorded. Data collection must be well organized.

3. You will work to create a flowchart showing how to set up the area to be like a production line. Steps of your procedure would be included within the flowchart.

4. The instructor will check the flowcharts to see if you can show that you have an understanding of the required line design, but will not make suggestions on how to improve it. Create and set up the production line.

5. Arrange table or tables, assign jobs, such as process auditor, bottle filler, weight finder, and recorder, and gather equipment.

6. Decide how far you will fill the bottles. There is no set fill line, just make sure you agree as a group. The object is to get the same amount of water in each bottle. Go to the tap water supply area, choose one of the containers to use and a funnel if necessary, and fill the empty bottles.

7. The student assigned as process auditor should make some notes about how they made sure the steps were being followed.

8. All students record the tare, gross, and subtract to get net weights on their own check sheets.

9. Use the check sheets to create a frequency distribution table and histogram. Your instructor will explain how to do this or provide you with a handout that explains how to do it.

Extension Activity (optional)

10. Use the data to prepare an X-bar and R control chart using n = 5 (five samples). In this situation, each consecutive five bottles will be assumed to be the sample selected at half-hour intervals. Every five numbers will be sample measurements recorded in the same column. The next five numbers are recorded in column 2, and so on. Follow the directions given to you by your instructor to make the X-bar and R chart.

11. Look at the chart and note the control chart limits. Are any points outside the limits? Is the spread from UCL to LCL wide? Can you think of a way to measure the water more accurately? What process change do you think would result in less variation? Can you describe these changes on a new flowchart? If a potential process change would reduce the variation, repeat the project using the revised procedure.

12. Discuss the results and prepare a report.

13. At the end of the testing, the bottles should be emptied and returned. Any excess water spilled on the floor should be wiped up. The table and floor should be wiped clean.

14. Turn in flowchart, check sheet, histogram, X-bar/R chart, and report.

Handout 2—Glossary for Quality Control

attribute data – Data that is not a measured value. It is classified as either conforming or not conforming, or the number of defects.

average – The arithmetic mean. Pertaining to a set of numbers x_1, x_2, . . ., x_n, the average or arithmetic mean is usually denoted by the symbol $\bar{x}$, is the sum $x_1 + x_2 + . . . + x_n$ divided by n.

boundaries – The upper and lower control limits that are calculated mathematically and entered on a control chart. They are used as criteria for signaling the need for action. Boundaries are set by calculating the mean, standard deviation, and range of a set of process data collected when the process is under stable operation. Then, subsequent data can be compared to this already calculated mean, standard deviation and range to determine whether the new data fall within acceptable bounds. For good process control, subsequent data collected should fall within three standard deviations of the mean.

cause-and-effect diagram – Also referred to as a fishbone problem-solving diagram. This is a simple tool for individual or group problem-solving that uses a graphic description of the various elements of a process to differentiate between the root cause of the problem and symptoms of the problem.

check sheet (or tally sheet) – A simple document that is used for collecting data in real-time and at the location where the data is generated.

control chart – A graphic comparison of a measured characteristic against computed control limits. It plots variation over time. A statistical process control graph that charts data and provides a picture of how a process is performing over time.

flowchart – A schematic representation or picture of a process which includes process steps, material movement, and decision points.

frequency distribution table/worksheet – A table showing the number of times a measurement is observed.

gross – The entire body or amount exclusive of deductions

histogram – A special bar graph that shows how much a certain product or product characteristic varies when we measure samples.

interval – The amount of time between two specified instants, events, or states.

Lower Control Limit (LCL) – The lowest horizontal line on a control chart. Measurements that fall below that line indicate a process that is out of control. It occurs at 3 standard deviations below the average or mean value.

mean – The average, represented by the X bar.

midpoint – The point halfway between the highest and lowest value in a range of numbers.

mode – The most frequent value.

net weight – The weight of the contents not including any packaging, etc.

Pareto chart – A simple tool for problem-solving that involves ranking all potential problem areas according to their cost. Typically, a few causes account for most of the cost, so problem-solving efforts should concentrate on these areas first.

Quality Control (QC) – Processes that ensure goods or services satisfy and/or exceed customers' needs and expectations.

R bar – The average of the range values for groups of data, represented as $\overline{R}$.

range – The difference between maximum and minimum values.

run chart – A run chart is also known as a run-sequence plot. It is a graph that displays observed data in a time sequence.

scatter diagram – The scatter diagram is one of the tools of quality. A scatter diagram is a graphical technique used to analyze the relationship between two variables.

Statistical Process Control (SPC) – The use of statistical techniques such as control charts to analyze a process or its outputs in order to take appropriate actions to achieve and maintain a state of statistical control and improved process and product.

standard deviation – A measure of the dispersion of a set of data from its mean. The greater the data spread, the higher the deviation. Standard deviation is calculated as the square root of variance. Standard deviation is represented by sigma, σ.

tare – Measure used in science, distribution, and packaging. It is the mass of the substance without any packaging or containers. Many balances include a tare button that allows you to place the container for a substance on the balance and then press the tare button which will zero the scale. When you add the substance or materials, the weight displayed is that only of the substance added after you pressed the tare button.

Total Quality Control (TQC) – Application of quality management principles to all areas of business from design to delivery instead of confining them only to production activities.

Upper Control Limit (UCL) – The highest horizontal line on a control chart. Measurements that fall above that line indicate a process that is out of control. It occurs at 3 standard deviations above the average or mean value.

variable data – Data which has a measured value. Examples of variable data are the length, width and caliper of a corrugated metal sheet.

variance – The statistical value for range.

X-bar – The average of the values of X, represented by $\overline{X}$.

X-bar/MR Control Chart (Individual and Moving Range Charts) – Chart used when the subgroup size is one. X-bar / Moving Range charts are generally used when:

1. The cost of the product or cost of testing is very expensive.
2. The sample is from a chemical process such as the liquid in a vat.
3. The process has demonstrated a low variance and warrants reduced testing and the associated cost savings.
4. The 3 sigma limits are process capability limits so the process is generally monitored to 2 sigma limits.

X-bar/R Chart (Averages and Range) – A continuous plot of subgroup averages. The most commonly used control chart pair is the X-bar and R chart. X-bar is the average of the values in small subgroups—a measure of location; R is the range of values within each subgroup (highest minus lowest)—a measure of spread.

DEFINITIONS OF SYMBOLS USED

n = the number of samples in a subgroup

X = the measured value

$\overline{X}$ = Average of the values of X

$\overline{\overline{X}}$ = X double bar the average of X bar

k = number of subgroups

R = Range: the difference from the maximum sample to the minimum sample in the subgroup

$\overline{R}$ = Average of range

UCL = Upper control limit

LCL = Lower control limit

Sigma σ = Standard deviation

Handout 3—Blank Student Forms

Check Sheet

CHECK SHEET SPC APPLICATION

LOCATION LINE

Characteristic measured UNITS

SPL NO	TARE	GROSS	NET	SPL NO	TARE	GROSS	NET	SPL NO	TARE	GROSS	NET	SPL NO	TARE	GROSS	NET
1				26				51				76			
2				27				52				77			
3				28				53				78			
4				29				54				79			
5				30				55				80			
6				31				56				81			
7				32				57				82			
8				33				58				83			
9				34				59				84			
10				35				60				85			
11				36				61				86			
12				37				62				87			
13				38				63				88			
14				39				64				89			
15				40				65				90			
16				41				66				91			
17				42				67				92			
18				43				68				93			
19				44				69				94			
20				45				70				95			
21				46				71				96			
22				47				72				97			
23				48				73				98			
24				49				74				99			
25				50				75				100			

Technician DATE

Histogram

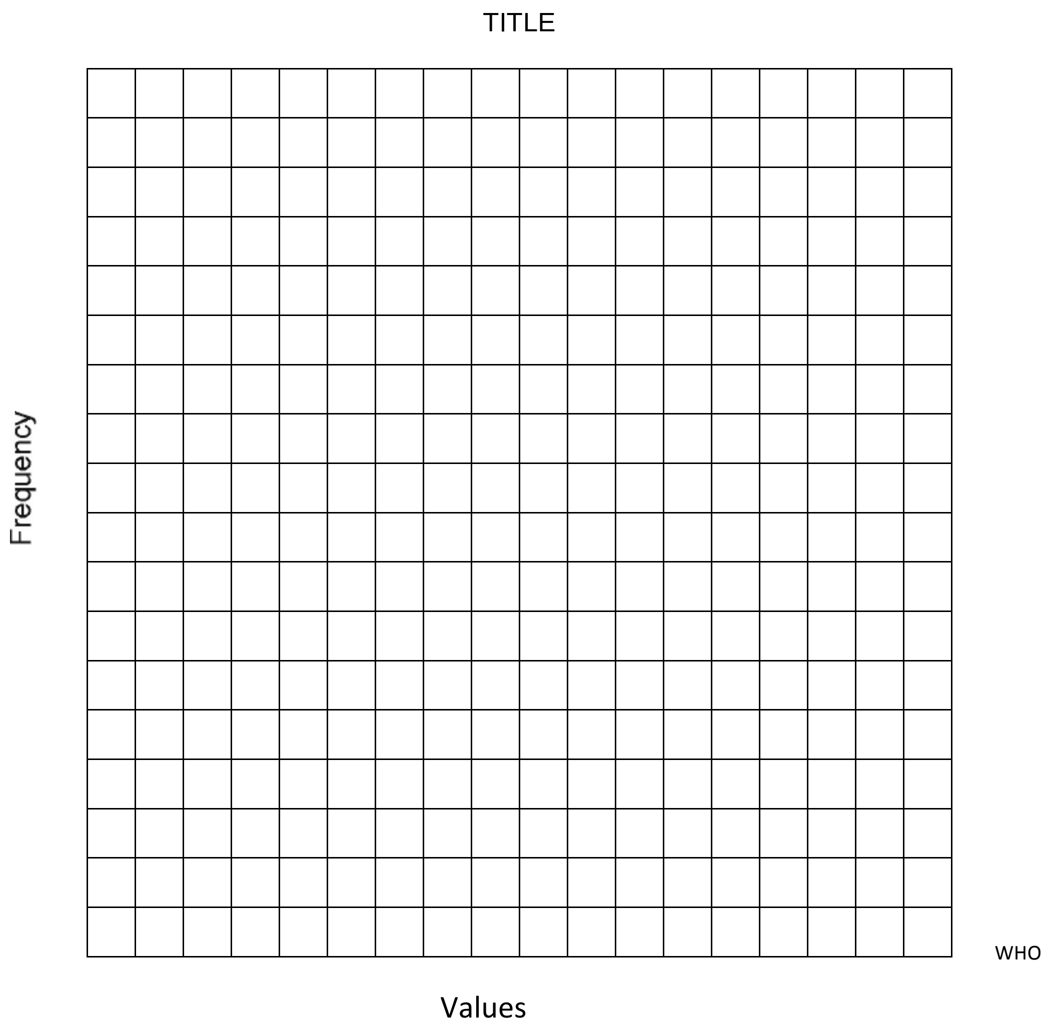
HISTOGRAM

FREQUENCY DISTRIBUTION WORKSHEET

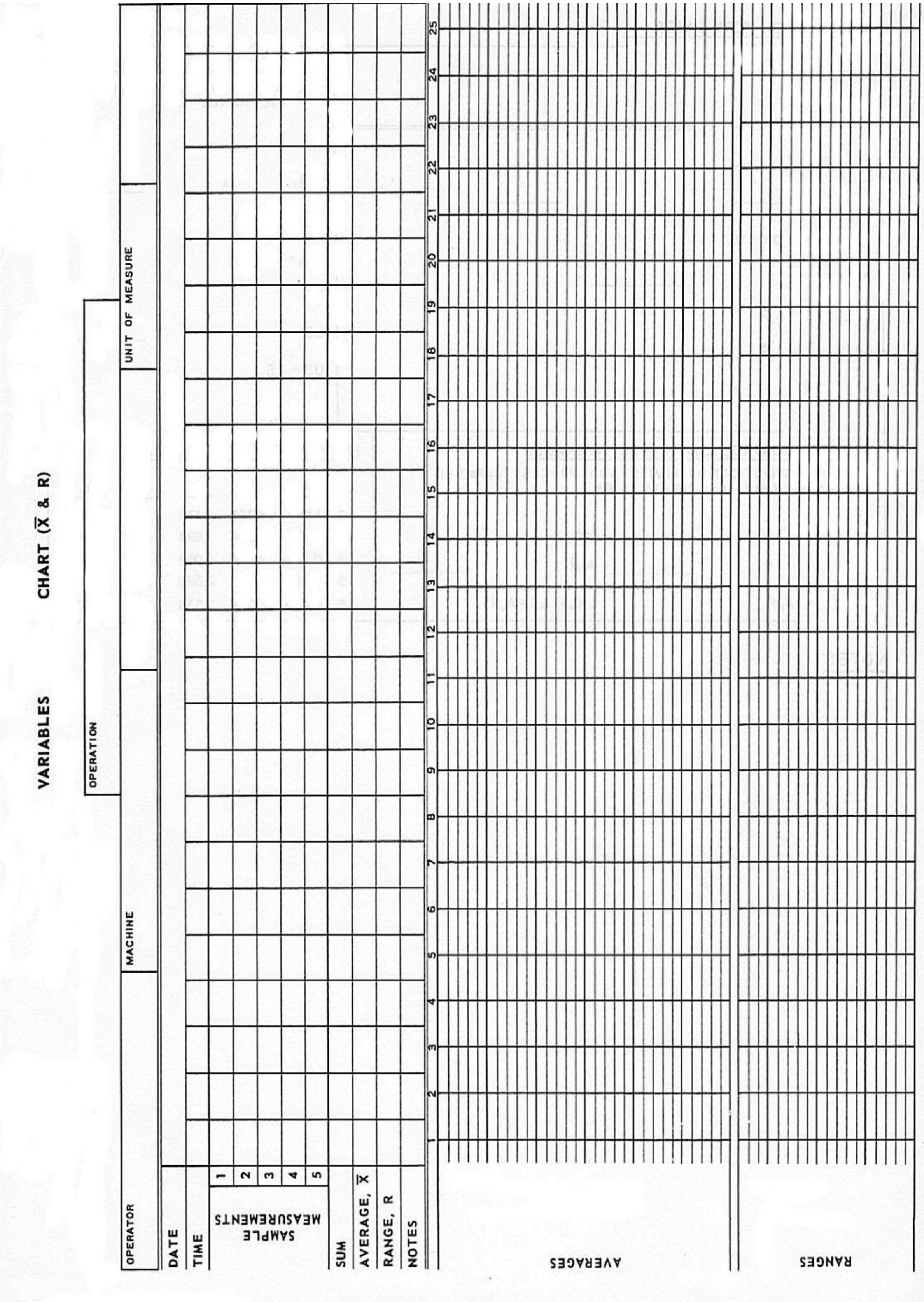
TECHNICIAN ______________________

TITLE ____ **DATE** _____________________________

MIDPOINT	INTERVAL	BOUNDARIES	TALLY	FREQUENCY

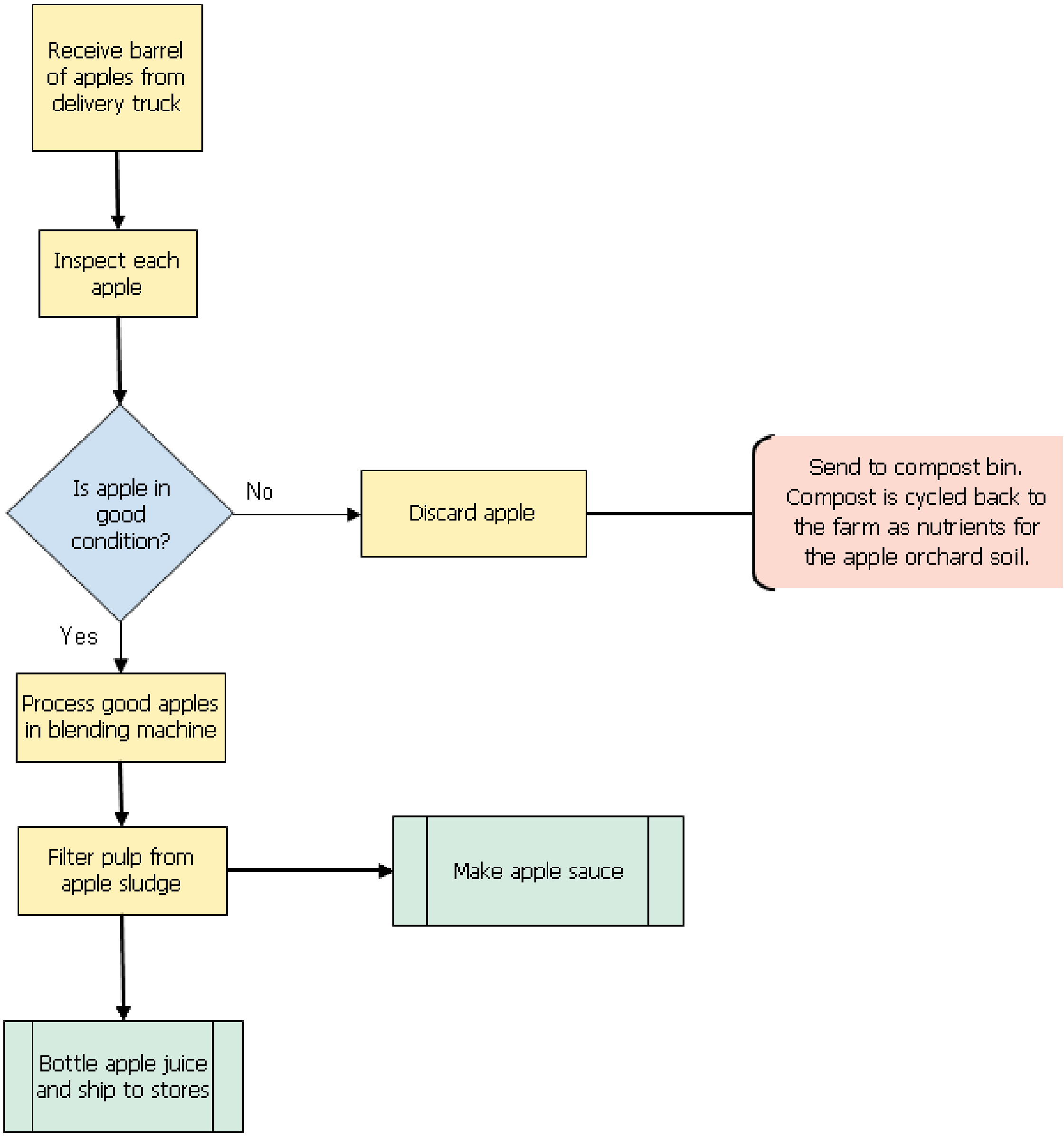


X-bar/R Chart


VARIABLES CHART (X̄ & R)
OPERATION
OPERATOR
MACHINE
UNIT OF MEASURE
DATE
TIME
SAMPLE MEASUREMENTS
1
2
3
4
5
SUM
AVERAGE, X̄
RANGE, R
NOTES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
AVERAGES
RANGES

Handout 4—Examples of Completed Forms

Sample Flowchart



The following website explains symbols used in flowcharts: http://www.rff.com/flowchart_shapes.htm

Sample Flowchart from Microsoft Corporation Excel Templates.

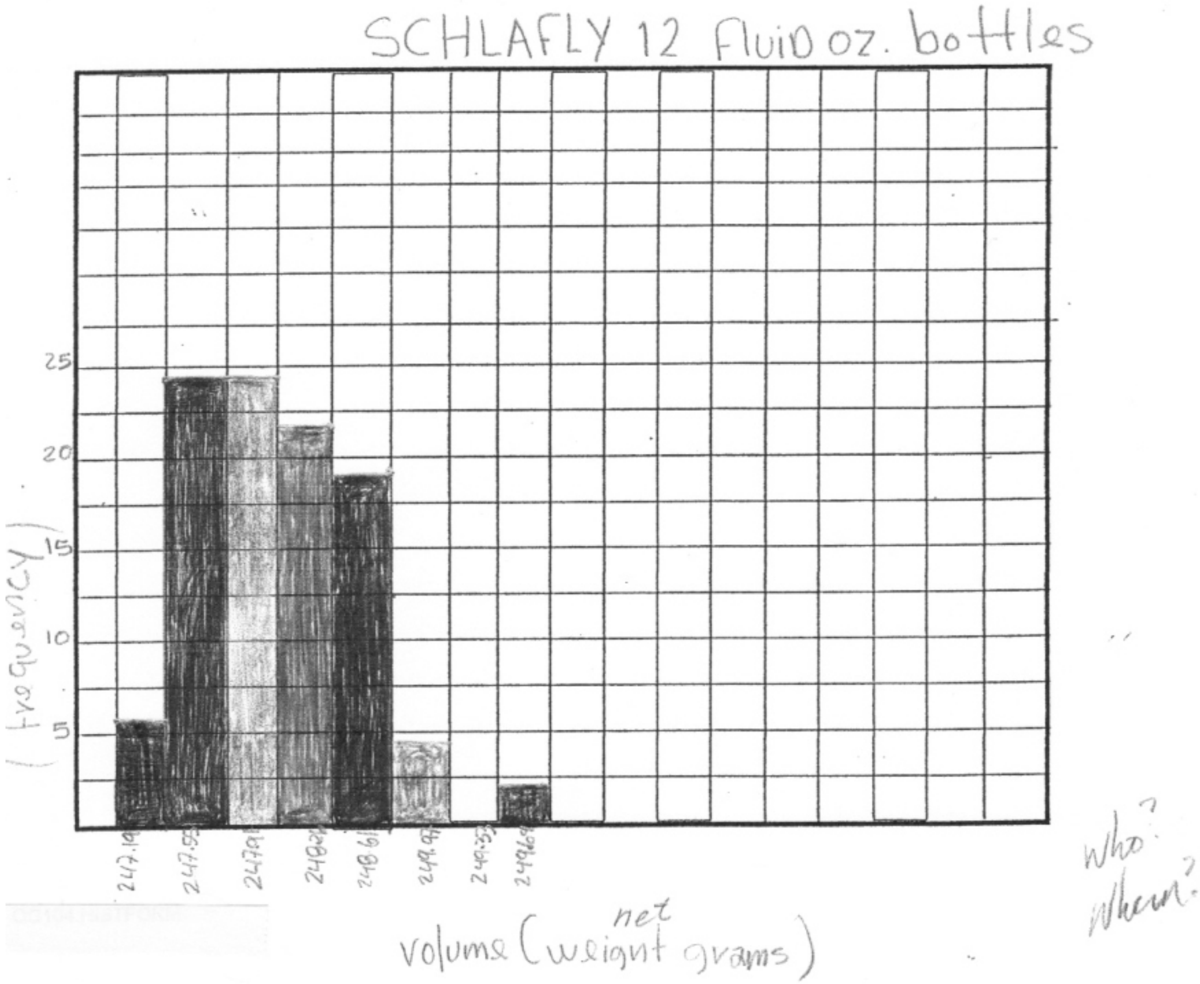
Sample Histogram

HISTOGRAM
FREQUENCY DISTRIBUTION WORK SHEET

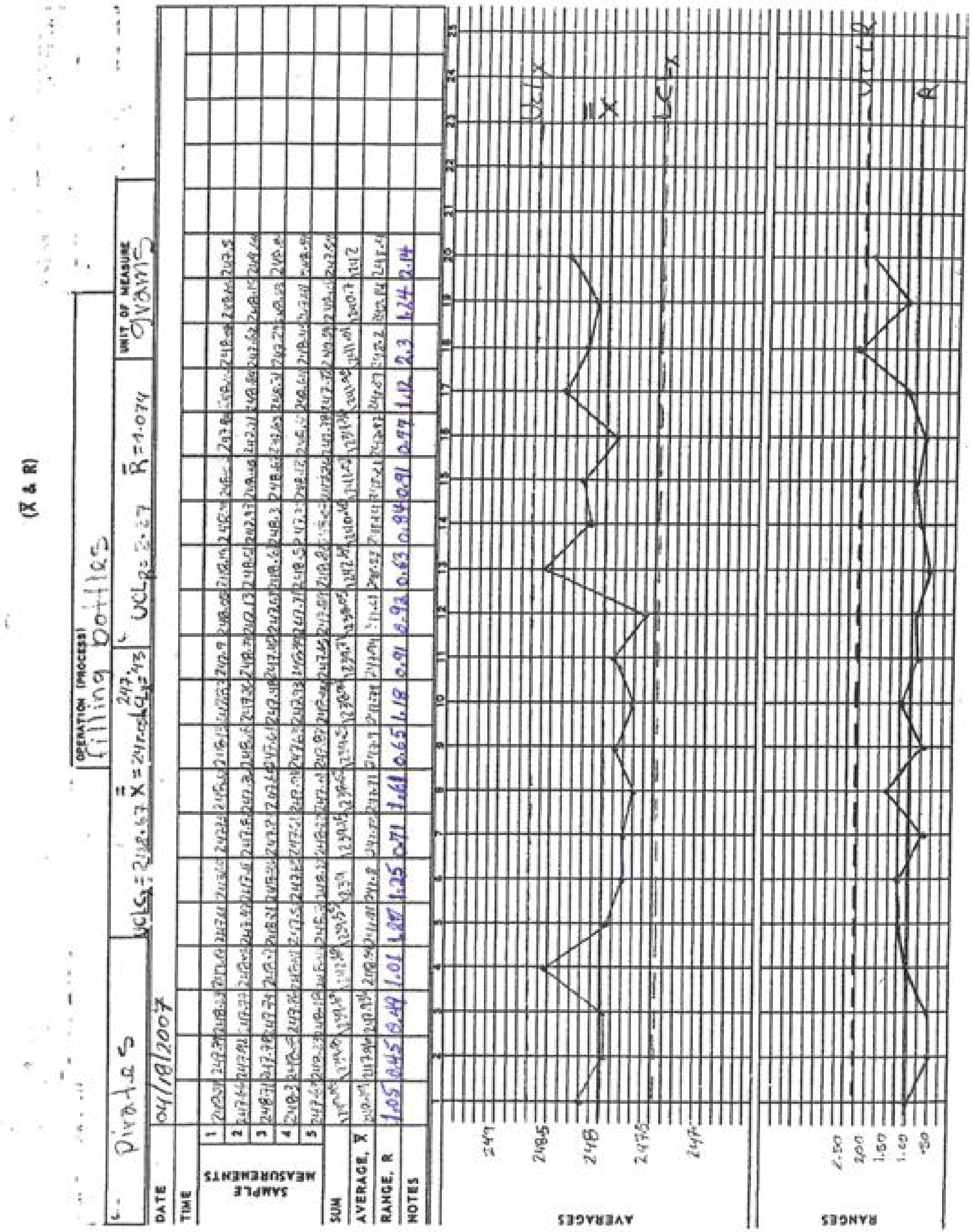
TITLE schlafly 12 fluid oz. glass bottles

By the pirates
Date 4/18/2007

Midpoint	Interval	Boundries	Tally	Tally check	Frequency
247.19	247.01–247.3[illegible]	247.005 - 247.355	卌-I		6
247.55	247.37–247.7[illegible]	247.355- 247.705	卌-卌-卌-卌-IIII		24
247.91	247.73–248.0[illegible]	247.705–248.055	卌-卌-卌-卌-IIII		24
248.26	248.08–248.42	248.055–248.405	卌-卌-卌-卌-II		22
248.61	248.43–248.78	248.405–248.755	卌-卌-卌-III		18
248.97	248.79–249.14	248.755–249.105	IIII		4
249.33	249.15–249.5[illegible]	249.105–249.455			
249.69	249.51–249.8[illegible]	249.455–249.805	II		2
					100



Sample X-Bar/R Chart



Handout 5—Quality Control

Statistical Process Control

Statistical quality control is the use of statistical methods for control of a product. Statistical process control (SPC) is the use of statistical methods for quality control of a process rather than a product. With this definition, it is clear that SPC applies to service or office jobs as well as manufacturing jobs.

The age-old way of concentrating quality control effort on inspection of finished items has been replaced with the more affordable, efficient, and effective SPC. SPC involves defining a number of processes throughout the manufacturing operation. Each process is treated as the producer of a finished product and the next step or process is treated as a customer. This approach is a prevention system because each internal customer identifies acceptable product for that process. Each step neither accepts a bad product nor passes a bad product on to the next customer/operation. This is designed to provide full customer satisfaction at each stage.

Once the process is defined, it is tested to determine its capability. Once the capability is determined, it can be compared with customer requirements. If the process is not capable or borderline, changes need to be made to bring it into a capable process. This is sometimes a very hard job, but at least we know what to expect from the process as defined.

Traditional Quality Control (QC) efforts centered on *detection* of poor quality on finished product have now been replaced by *prevention* of poor quality through a defined process. Continual improvement of the process results in better quality product, lower cost, and increased job security, leading to the survival of the business.

Total Quality Control is a discipline that uses a number of quantitative methods and tools to identify problems and suggest avenues for continuous improvement in fields such as manufacturing. Statistics is a science that deals with the collection, tabulation, analysis, interpretation, and presentation of quantitative data. There are two basic types of statistics; descriptive and inductive. Descriptive statistics is used to describe and analyze a subject or group. Inductive statistics is used to determine from a limited amount of data (sample) an important conclusion about a much larger amount of data (population). A complete body of data to be analyzed is called the population. In most cases we must be satisfied with taking a sample of the population.

Types of Sample Data

Sample data may be either attribute data or variable data.

Attribute data is not a measured value. It is classified as either conforming or not conforming. A common term is “go/no-go” when fixed gauges are used for measurement. An example of attribute data is the number of paper sheets rejected at the feeder of a printer. Attribute data can be classified by type of nonconformity as well as number of nonconforming. An example is the number of boxes rejected for poor or misaligned printing.

Variable data is data which has a measured value. Examples of variable data are the length, width, and caliper (thickness) of a corrugated sheet. For each of these there is a numerical value in inches or millimeters when measured. The data can be represented graphically as a distribution with the horizontal axis representing the variable and the vertical axis the number of occurrences.

How to Look at Data

A picture is worth a thousand words. Having a good picture of the data improves our ability to understand the information and thereby make better decisions.

Ungrouped data is not as valuable as grouped data.

For example:

UNGROUPED

Septi-Soft Concentration (grams):

141, 141, 143, 139, 141, 142, 140, 143
144, 140, 142, 142, 143, 144, 142, 142

GROUPED

Septi-Soft Concentration (grams):

Grams	Frequency
139	1
140	11
141	111
142	11111
143	111
144	11
145	
146	

The grouped data is the same data as the ungrouped data but has been arranged with the Septi-Soft Concentrate bottle weight in a vertical table and a frequency tally for each value. The arrangement in this frequency distribution gives a better picture of the data.

With a frequency distribution, we can look at the distribution characteristics of Central Tendency and Dispersion or Variability. These describe **location, spread and shape.**

Central Tendency

- Mean – average, X bar
- Mode – most frequent value
- Median – center value
- Average – For symmetrical distributions the average (or mean) provides a good description of the central tendency (or location) of the process. For very skewed distributions, the median is a much better indicator of location (or central tendency).

Dispersion or Variability

- Range – difference between maximum and minimum values
- Variance – statistical value for range
- Standard deviation – square root of variance. Denoted with the Greek symbol Sigma, (σ) the standard deviation provides an estimate of variation. In mathematical terms, it is the *second moment about the mean*. In simpler terms, you might say it is how far the observations vary from the mean.

Variation is a killer. Just because one item was okay or conformed to specification, we cannot assume that all product pieces will conform. The reason is that something is changing, and this change or variation is where we must focus our attention. The underlying cause for the difference in quality or reliability is variation.

There are two sources of variation:

Natural –inherent or common, i.e., it is process generated. This is the variation when the process is operating according to plan.

Unnatural –assignable or special, i.e., something slipped, there was not a change in the plan. In other words, unnatural variation is the variation that occurs when operation is not according to plan.

Both natural and unnatural variation can result from persons, machines, materials, methods, environments, and information.

Over many years, total quality practitioners gradually realized that a large number of quality related problems can be solved with seven basic quantitative tools, which then became known as the traditional "Seven Tools of Quality."

Seven Tools of Quality

Cause-and-effect diagram

Pareto chart

Check sheet

Control chart

Flowchart

Histogram

Scatter diagram

Creating Statistical Charts and Graphs

A chart or graph is a type of information graphic that represents tabular numeric data and/or functions. Charts are often used to make it easier to understand large quantities of data and the relationship between different parts of the data. They can usually be read more quickly than the raw data they represent. Used in a wide variety of fields, they can be created by hand on graph paper or by using a computer program. Certain types of charts are more useful for presenting a given data set than others. A histogram typically shows the quantity of points that fall within various numeric ranges. A bar graph uses bars to show frequencies or values for different categories. A **flowchart** is a schematic representation of a process. In statistical process control, the **control chart** is a tool used to determine whether a manufacturing or business process is in a state of statistical control or not. If the chart indicates that the process is currently under control then it can be used with confidence to predict the future performance of the process. If the chart indicates that the process being monitored is not in control, the pattern it reveals can help determine the source of variation to be eliminated and bring the process back into control. The X-bar/R chart is normally used for numerical data that is captured in subgroups in some logical manner. For example, three production parts measured every hour. A special cause such as a broken tool will then show up as an abnormal pattern of points on the chart.

A. Making a Flowchart

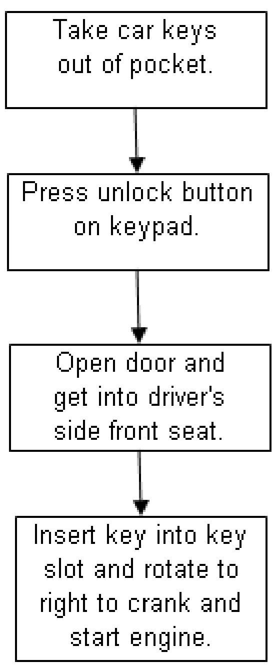
Before you try to solve a problem, you must define it. Before you try to control a process, you must understand it by determining the important elements or steps.

Flowcharts are helpful in bringing process control to both manufacturing and administrative processes. The easiest way to understand a process is to draw a picture of it—a flowchart. Flowcharts show process steps, material movement, and decision points.

Questions to ask yourself when creating a flowchart include:

- What is the first thing that happens?
- What is the next thing that happens?
- Where does the material/service come from?
- What happens if it is good?
- What happens if it is not good?
- What else must be done at this point?
- Where does the product/service go?
- What tests are performed?

If you are going to drive a car you might make a flowchart with these steps.



When making a flowchart for a project, identify all the steps. Think of the above questions. You cannot include too much detail.

B. Using a Check Sheet

The **check sheet** is a simple document that is used for collecting data in real time and at the location where the data is generated. The document is typically a blank form that is designed for quickly recording information, which can be either quantitative or qualitative. When the information is quantitative, the check sheet is sometimes called a tally sheet. A defining characteristic of a check sheet is that data is recorded by making marks ("checks") on it. Quality improvement is an information-intensive activity. We need clear, useful information about problems, including who, what, when, where.

Example of a Check Sheet

Paint Job Quality Control Check Sheet

Job: 629555 101 Bear Place Date 4/14/08
Inspector: Al Johnson

Problem	Frequency
Chip	𝍸 𝍸 |||
Bubble	|||
Run	𝍸 |
Scrape or scratch	
Inadequate coverage	𝍸 𝍸 𝍸 ||
Other	

What can you determine about the quality of paint job #629555 from this check sheet?

C. Making a Run Chart

A run chart is also known as a run-sequence plot. It is a graph that displays observed data in a time sequence.

The data usually represents the performance of a business or manufacturing process. Examples could include measurements of the liquid level of bottles filled in a bottling plant, the water temperature of a dishwasher each time it is run, or the color distribution in packages of M&M's.

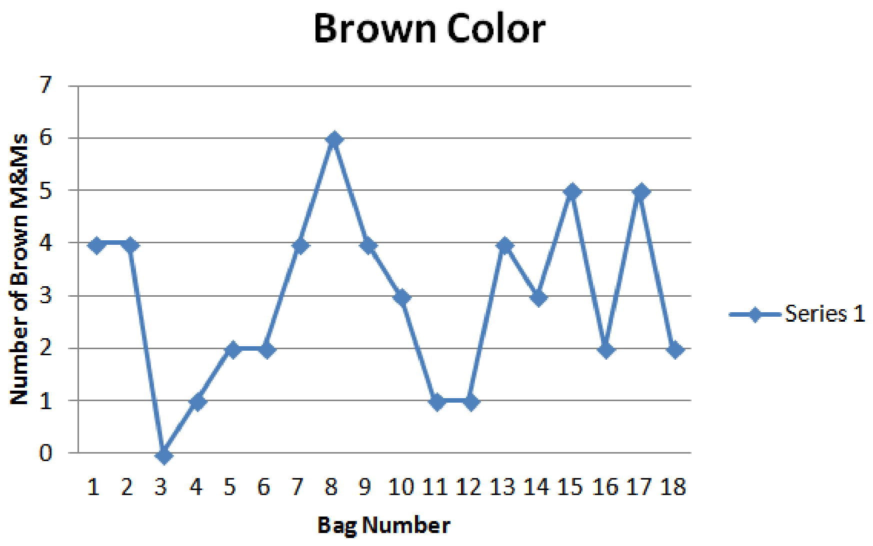
Time is generally represented on the horizontal (x) axis and the observed property on the vertical (y) axis.

Often, some measure of mean or median of the data is indicated by a horizontal reference line on the graph.

Run charts are analyzed to find anomalies in data. Long runs of data points above or below the mean or median line, or a long series of increases or decreases indicate factors that may be influencing variability. Run charts are simple to produce but only allow simple analysis.

Example of a Run Chart:

Shows the number of brown M&M's in 18 Fun Size bags.



Run charts can be done easily by recording the data in a spreadsheet in Microsoft Excel and using the program to prepare the graphs, as in the example above.

D. Histograms

What Is a Histogram?

A histogram is a special bar graph that shows how much a certain product or product characteristic *varies* when we measure samples.

- Products from the same production line will almost always vary slightly.
- Because of this variation, there will be a distribution of data points.
- A histogram is a graph made up of a series of bars that show this distribution.

Histograms display one characteristic at a time but represent many samples. A histogram should show:

- The highest and lowest values (the range).
- The average value (the mean, where the process is centered).
- The value which occurred most of the time (the mode)
- A comparison with the desired specifications.

Making a Histogram

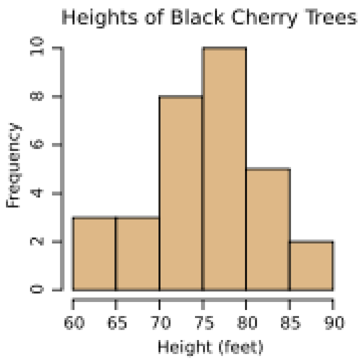
STEPS:

1. Make the table and collect the data.
   - Collect at least 50 data points.
   - Use a check sheet to record the data.
2. Find the largest and smallest values in the data table.
   - Circle the highest and the lowest and calculate the range. RANGE = Largest minus smallest
3. Determine how many columns or bars the histogram should have.
   - Pick the number of columns needed to get a good representation on the graph.
   - Use a minimum of five columns.
4. Make all the columns the same width.
5. Set the column boundaries.
   - Start from the lowest value.
6. Construct the Frequency Distribution Table.
   - Go through the data table and count how many times there was a value that fit into each column's boundaries.
7. Make the Histogram
   A. Draw the vertical and horizontal axis.
   B. On the horizontal axis use equally spaced marks to show each column's boundaries.
   C. For the vertical axis, look at the frequency distribution table and find the largest number of tally marks in a single column and make the vertical axis at least that high.
   D. Draw the bars. Make the height of each bar equal to the frequency for that interval.
8. Add a Legend
   - Who, What, Where, Date

Example Frequency Worksheet and Histogram

	Frequency	**Distribution**	**Worksheet**	
			Technician:	**Ed Jones**
Title: Heights of Black Cherry Trees			**Date: 04/08**	
Midpoint	**Interval**	**Boundaries**	**Tally**	**Frequency**
62.5	**60-64**	**59.45-64.45**	111	**3**
67.5	**65-69**	**64.45-69.45**	111	**3**
72.5	**70-74**	**69.45-74.45**	~~1111~~ 111	**8**
77.5	**75-79**	**74.45-79.45**	~~1111~~ ~~1111~~	**10**
82.5	**80-84**	**79.45-84.45**	~~1111~~	**5**
87.5	**85-89**	**84.45-89.45**	11	**2**

Histogram



E. Control Charts (Optional activities)

The goal of a process control system is to make economically sound decisions about actions affecting the process. The control chart is a vital part of any process control system. It is a graphic comparison of a measured characteristic against computed control limits. It plots variation over time. The primary use is to detect assignable causes of variation in a process. The purpose of any control chart is to help determine if variations in measurements are caused by small, normal variations that cannot be acted upon ("common causes") or by some larger "special cause" that can be acted upon or fixed. Control charts distinguish between common causes and special causes of variation through the use of control limits calculated from the laws of probability.

Two kinds of control charts—measurable vs. countable:

Variable — Contains data measured along a scale

Attribute — Contains data that is counted, such as the number of defects

Variable charts show process data in terms of both its range (piece-to-piece variability) and its location (process average). Control charts for variables are almost always prepared and analyzed in pairs—one chart for location and another for spread.

X-bar/R Control Chart (Averages and Range)

The most commonly used control chart pair is the X-bar and R chart. X-bar is the average of the values in small subgroups—a measure of location; R is the range of values within each subgroup (highest minus lowest)—a measure of spread. If rational subgroups—subgroups selected to makes each as homogeneous as possible—can be formed, the X-bar charts are generally preferred, since the control limits are easily calculated using values from the table of control chart constants.

- X-bar and R charts are the most commonly used control charts and the most powerful.
- X-bar is a continuous plot of subgroup averages.
- R is a continuous plot of subgroup ranges.

X-bar/MR Control Chart (Individual and Moving Range Charts)

Used when the subgroup size is one.

X-bar / Moving Range charts are generally used when:

1. The cost of the product or cost of testing is very expensive.
2. The sample is from a chemical process such as liquid in a vat.
3. The process has demonstrated a low variance and warrants reduced testing and the associated cost savings.
4. The 3 sigma (σ) limits are process capability limits so the process is generally monitored to 2 sigma limits.

Making an X-bar/R Chart

X-bar

First, perform the calculations for the X-bar or top part of the graph.

STEPS:

1. Collect the data. (Using at least 100 samples is best.)
2. Divide the data into subgroups of four or five data points each. The number of samples is represented by the letter *n* and the number of subgroups is represented by the letter *k*.
3. Record the data on the data sheet.
4. Find the sum or total of each subgroup.
5. Using the following formula, find the mean value or X-bar $\left(\overline{X}\right)$ for each subgroup. Find the sum of each subgroup and divide by the number of sample measurements.

$$\text{(X-bar) } \overline{X} = \frac{x_1 + x_2 + x_3 + ... + x_n}{n}$$

6. Find the overall mean, or X double bar $\left(\overline{\overline{X}}\right)$. Total the mean values of X-bar for each subgroup and divide by the number of subgroups (k).

$$\text{(X double bar) } \overline{\overline{X}} = \frac{\overline{X_1} + \overline{X_2} + \overline{X_3} + ... \overline{X_n}}{\text{k (\# of subgroups)}}$$

R bar

Now, perform the calculations for R bar, or the bottom part of the graph.

Using the following formula, find the range, R, for each subgroup.

7. Range = (largest value) – (smallest value)
8. Record the range for each subgroup.
9. Compute the average value of the range, R. Add R for all the groups and divide by the number of subgroups, k.

$$\overline{R} = \frac{R_1 + R_2 + R_3 + ...R_k}{k}$$

Compute the Control Limit Lines

Use the following formulas for X-bar and R Control Charts. The coefficients for calculating the control lines are A_2, D_4, and D_3, shown below in the Control Chart Constants.

CONTROL CHART CONSTANTS

NUMBER IN SUBGROUP	A_2	d_2	D_3	D_4
2	1.88	1.113	0	3.287
3	1.023	1.693	0	2.575
4	0.729	2.059	0	2.282
5	0.577	2.326	0	2.115
6	0.483	2.534	0	2.004
7	0.419	2.704	0.076	1.924
8	0.373	2.847	0.135	1.864
9	0.337	2.97	0.184	1.816
10	0.308	3.078	0.223	1.777

10. Find Upper Control Limit (UCL) for X-bar

$$UCL_{\overline{X}} = \overline{\overline{X}} + \left(A_2 \times \overline{R}\right)$$

11. Find Lower Control Limit (LCL) for X-bar

$$LCL_{\overline{X}} = \overline{\overline{X}} - \left(A_2 \times \overline{R}\right)$$

12. Plot the Upper Control Limit (UCL) and the Lower Control Limit (LCL) on the X-bar part of the chart.
13. Find UCL

$$UCL_R = D_4 \times \overline{R}$$

14. Find LCL

$$LCL_R = D_3 \times \overline{R}$$

15. Plot the Upper Control Limit (UCL) and the Lower Control Limit (LCL) on the R bar part of the chart.
16. Find the largest and smallest numbers that you will be plotting. Place numerical values on the lines on the Averages and Ranges part of the chart. Place numbers equidistant apart. Line values do not have to be the same for Averages and Ranges.
17. Draw X double bar ($\overline{\overline{X}}$) on the chart. This is your Central Line (CL).
18. Notice in the charts on example one and example two, the Central Line is already shown in bold black.

19. The chart you are given to fill out may already have the Central Line shown in bold black. If so, then just label the Central Line with its appropriate numerical value.
20. It is recommended that you that you use a blue or black line for the CL and a red line for the UCL and LCL. The central line is a solid line. The UCL and LCL are drawn as broken lines.
21. Draw $\overline{R}$ line on the chart.
22. Plot the Upper Control Limit (UCL) and the Lower Control Limit (LCL) on the R part of the chart.
23. Construct the control chart using the handout Control Chart for Averages and Range.
24. Make sure the control lines are drawn and labeled correctly with their appropriate numerical values. Use a blue or black line for the CL and a red line for the UCL and LCL. The central line is a solid line. Plot the X-bar and R values as solid lines. The UCL and LCL are drawn as broken lines or dashed lines.
25. Plot the measurements or points on the X-bar chart for X-bar graph just below each subgroup and connect the points.
26. Plot the range for each subgroup on the range chart.
27. Look for any out-of-control conditions.
28. If there are out of control conditions attempt to find an assignable (special) cause.
29. Revise control limits as needed.

Making an X-bar/MR chart

The steps are the same until you are calculating upper and lower control limits. For the upper and lower control limits you must calculate the value of sigma and calculate the limits using a plus three values of sigma for the upper limit and a minus three values of sigma for the lower limit. **Refer to example two.**

DEFINITIONS OF SYMBOLS USED

n = the number of samples in a subgroup

X = the measured value

$\overline{X}$ = Average of the values of X

$\overline{\overline{X}}$ = X double bar the average of X bar

k = number of subgroups

R = Range: the difference from the maximum sample to the minimum sample in the subgroup

$\overline{R}$ = Average of range

UCL = Upper control limit

LCL = Lower control limit

σ (sigma)= Standard deviation

Example One:

Control Chart for Averages and Ranges (Example for n=5)

Sample number								
1	**92**	**93**	**93**	**95**	**91**	**96**	**90**	**91**
2	**91**	**94**	**93**	**95**	**94**	**93**	**96**	**92**
3	**90**	**96**	**93**	**92**	**94**	**94**	**98**	**95**
4	**91**	**94**	**93**	**92**	**95**	**97**	**95**	**94**
5	**92**	**98**	**94**	**95**	**94**	**90**	**94**	**94**
sum	**456**	**475**	**466**	**469**	**468**	**470**	**473**	**466**
Average $\overline{X}$	**91.2**	**95**	**93.2**	**93.8**	**93.6**	**94**	**94.6**	**93.2**
Max	**92**	**98**	**94**	**95**	**95**	**97**	**98**	**95**
Min	**90**	**93**	**93**	**92**	**91**	**90**	**90**	**91**
Range R	**2**	**5**	**1**	**3**	**4**	**7**	**8**	**4**
Sub Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**

$$\overline{\overline{X}} = \frac{\text{sum of } \overline{X}}{k} = \frac{91.2 + 95 + 93.2 + 93.8 + 93.6 + 94 + 94.6 + 93.2}{8} = 93.575$$

$$\overline{R} = \frac{\text{sum of R}}{k} = \frac{2 + 5 + 1 + 3 + 4 + 7 + 8 + 4}{8} = 4.25$$

For a Subgroup of n=5

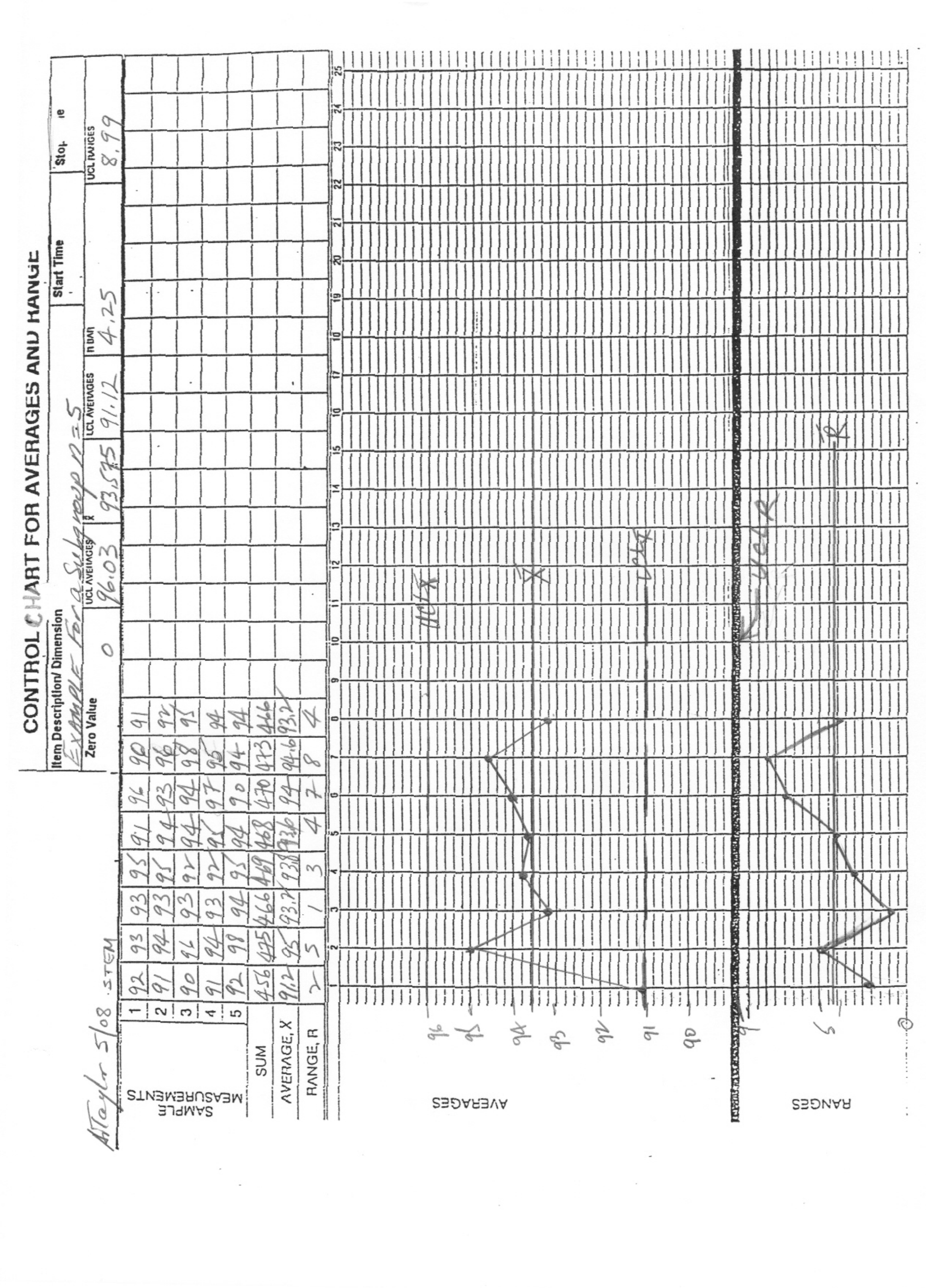
$$A_2 = 0.577, \quad D_3 = 0, \quad D_4 = 2.115$$

$$UCL_{\overline{X}} = \overline{\overline{X}} + \left(A_2 \times \overline{R}\right) = 93.575 + \left(0.577 \times 4.25\right) = 96.03$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - \left(A_2 \times \overline{R}\right) = 93.575 - \left(0.577 \times 4.25\right) = 91.12$$

$$UCL_R = D_4 \times \overline{R} = 2.115 \times 4.25 = 8.99$$

$$LCL_R = D_3 \times \overline{R} = 0 \times 4.25 = 0$$


CONTROL CHART FOR AVERAGES AND RANGE
Item Description/ Dimension
Example For a Subgroup n=5
Zero Value
UCL AVERAGES
96.03
93.575
LCL AVERAGES
91.12
4.25
Start Time
Stop Time
UCL RANGES
8.99
A Taylor 5/08
SAMPLE MEASUREMENTS
SUM
AVERAGE, X
RANGE, R
AVERAGES
RANGES

Example Two:
X-bar/MR Chart (Moving Range Chart)

For the X chart, n=1. Remember that n is the number of subgroups and for the R chart two values are involved (subgroup 1 minus subgroup 2, etc.), so from the table, $\mathbf{d_2}$ for n=2 is used.

Time	8:30	8:45	9:00	9:15	9:30
Sample 1	143	142	142	144	143
Sample 2					
Sample 3					
Sum					
Average					
Range		1	0	2	1
Sub Group	1	2	3	4	5

$$\overline{X} = \frac{143 + 142 + 142 + 144 + 143}{5} = 142.8$$

$$\overline{R} = \frac{1 + 0 + 2 + 1}{4} = 1.0$$

Look at Control Chart Constants (step 10) of this handout. For R based on a subgroup of 2:

$$d_2 = 1.128, \quad D_3 = 0, \quad D_4 = 3.267$$

For X based on individuals

$$\sigma = \frac{\overline{R}}{d_2} = \frac{1.0}{1.128} = 0.886$$

UCL and LCL for X bar

$$UCL_X = \overline{X} + 3\sigma$$

$$UCL_X = 142.8 + (3 \times 0.886) = 145.4$$

$$LCL_X = \overline{X} - 3\sigma$$

$$LCL_X = 142.8 - (3 \times 0.886) = 140.1$$

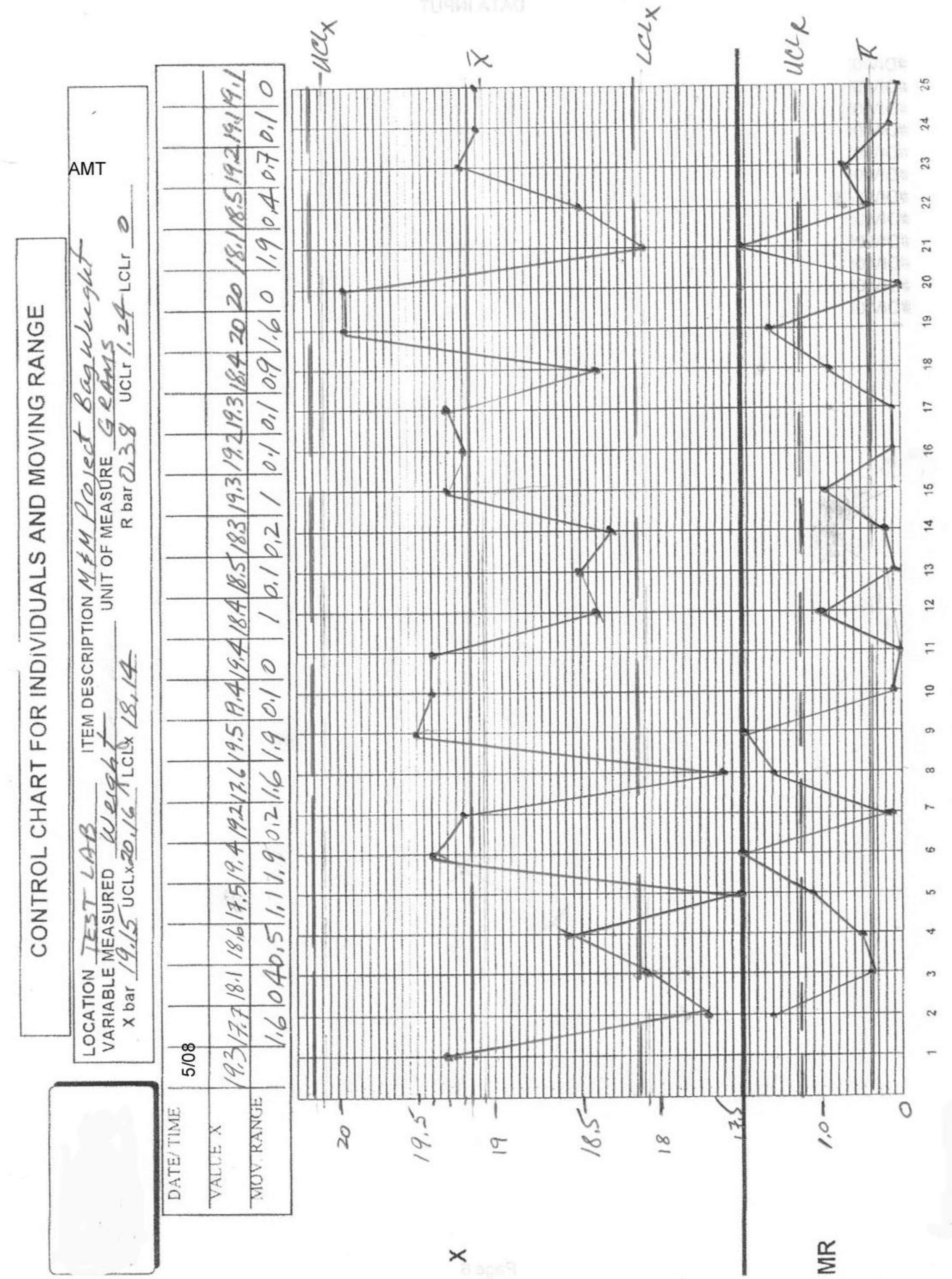
UCL and LCL for R bar

$$UCL_{MR} = D_4 \times \overline{R}$$

$$UCL_{MR} = 3.267 \times 1 = 3.267$$

$$LCL_{MR} = D_3 \times \overline{R}$$

$$LCL_{MR} = 0 \times 1.0 = 0$$


CONTROL CHART FOR INDIVIDUALS AND MOVING RANGE
AMT
LOCATION TEST LAB
ITEM DESCRIPTION M&M Project Bag Weight
VARIABLE MEASURED Weight
UNIT OF MEASURE GRAMS
X bar 19.15 UCLx 20.16 LCLx 18.14
R bar 0.38 UCLr 1.24 LCLr 0
DATE/TIME 5/08
VALUE X
MOV. RANGE
UCLx
LCLx
UCLR
X
MR

Assessment Tools/Strategies

This section includes specific strategies and instruments for assessing students' knowledge, skills, and attitudes related to problem-solving and decision-making skills.

RUBRICS

Rubrics are valuable assessment tools. Students should be provided with the rubric by which they will be assessed before an activity begins so they will understand the performance expectations. When time permits, students can contribute to the rubrics by brainstorming with the instructor about what a quality behavior or product looks like. For example, before assigning a team problem-solving project, ask students to describe how the ideal team would handle the assignment, how they would assign roles, divide the work, implement and monitor the process. Prompt students with specific components. Then have them describe a poor performance. These will be the descriptions of the characteristics for the highest and lowest ends of the Likert scale for each performance criteria. Instructors should add any required attributes to the rubric if the students do not come up with them on their own. Several rubrics related to problem-solving and decision-making skills have been provided as examples.

- The first three rubrics were developed to be used by the instructor or other observer in assessing a student. They each list characteristics or components of skill proficiency and include spaces where the instructor can insert additional attributes to tailor the rubric to a specific project or activity. These rubrics cover observation skills, problem-solving and decision-making, and the use of critical thinking skills.
- The fourth rubric is a self-evaluation tool for use by the student in examining their troubleshooting abilities. The students indicate the degree to which they think they are performing each attribute. They can periodically return to the rubric to reassess and determine if they are improving those skills.
- The final rubric on problem-solving is the most complex. The student is asked to reflect on their performance and provide examples of satisfactory or exemplary performance. Then the student meets with the instructor or peer observer and compares his/her reflections with their instructor's or peers' observations and formulates an action plan for improving attitudes, behaviors or skills. This type of rubric most resembles the type of assessment an employee might receive on the job. It is also the most time consuming. Ideally, this rubric would be used at least three times during a course:
    - At the beginning of the course, to get a baseline and to give students suggestions for specific actions they might take to improve their performance,
    - At the midpoint of the course, to check progress and refine the recommendations for improvement, and
    - At the end to assess the progress made over the duration of the course. Additional suggestions can be made for students' continued growth beyond the end of the course.

RUBRIC FOR ASSESSING OBSERVATION SKILLS

Outcome: Observation – Objectively observe people, situations, and circumstances. Identify and examine changes in conditions or behaviors to establish predictable patterns and relationships. Monitor and document situations according to established criteria, being alert to deviations, or discrepancies. Respond appropriately to anticipate needs, continue a process, or maintain a level of acceptability.

Demonstrates an awareness of situation being observed.	1 2 3 4 5
Identifies predictable trends.	1 2 3 4 5
Monitors multiple conditions.	1 2 3 4 5
Defines patterns and interrelationships.	1 2 3 4 5
Interprets results that lead to tentative conclusions.	1 2 3 4 5
Documents change and variations.	1 2 3 4 5
Identifies potential outcomes.	1 2 3 4 5
Connects multiple causes with effects to make meaning of the outcomes.	1 2 3 4 5

5	Always	Excellent
4	Most of the Time	Good
3	Sometimes	Adequate
2	Occasionally	Fair
1	Never	Poor or None

RUBRIC FOR ASSESSING PROBLEM-SOLVING AND DECISION-MAKING

Outcome: Problem-Solving and Decision-Making – Understand problem-solving and decision-making processes and apply these processes to personal and business situations. Identify root causes. Understand the factors that influence solving problems and making decisions and use this understanding in formulating and implementing action plans. Monitor action plans and make adjustments as needed.

Uses problem-solving and decision-making strategies that fit the given set of circumstances and variables.	1 2 3 4 5
Analyzes the source of the problem or reason for a decision by clarifying and validating root causes.	1 2 3 4 5
Applies problem-solving and decision-making strategies in both personal and business situations.	1 2 3 4 5
Takes into account the impact of significant factors in problem-solving and decision-making, such as economic, sociological, ethnic, political, legal, environmental, consumer, and interpersonal relationships.	1 2 3 4 5
Uses the processes of: identifying, clarifying, and validating the problem or reason for a decision; exploring options; considering consequences; clarifying values related to consequences; and formulating action plans to follow through on the reasoned-out conclusion of the process.	1 2 3 4 5
Analyzes the progress of action plans using the problem-solving and decision-making process of checking consequences, weighing values, and reconsidering possible options in order to reevaluate action plans.	1 2 3 4 5
Checks status of action plans by monitoring progress of self and others through keeping accurate records, asking pertinent questions of self and others, verifying evidence of progress, and reflecting on relevant consequences.	1 2 3 4 5
Modifies action plans on the basis of information gathered in the problem-solving and decision-making process.	1 2 3 4 5

5	Always	Excellent
4	Most of the Time	Good
3	Sometimes	Adequate
2	Occasionally	Fair
1	Never	Poor or None

RUBRIC FOR ASSESSING CRITICAL THINKING

Outcome: Critical Thinking – Demonstrate the use of strategic thinking, as well as the ability to analyze, synthesize and derive process-driven solutions to problems.

Demonstrate the ability to think strategically.	1 2 3 4 5
Use systematic approaches to problem-solving when appropriate.	1 2 3 4 5
Identify and obtain information needed to solve problems.	1 2 3 4 5
Evaluate information and formulate possible solutions.	1 2 3 4 5

5	Always	Excellent
4	Most of the Time	Good
3	Sometimes	Adequate
2	Occasionally	Fair
1	Never	Poor or None

RUBRIC FOR SELF-ASSESSMENT OF TROUBLESHOOTING TECHNIQUE

Component: Demonstrates proper troubleshooting technique.

Essential Attributes	I	II	III	IV
I identify problems and resolve them by applying appropriate problem-solving techniques.	Rarely, if ever	Occasionally	Usually	Consistently
I trace the source of any large disparity.	Rarely, if ever	Sometimes	Usually	Always
I use listening skills and assistive devices to assess signs and symptoms of malfunction.	Barely and rarely, if ever	Partially and occasionally	Generally and usually	Fully and consistently
I determine ongoing maintenance needs for equipment and machinery.	Never	Occasionally	Usually	Always
I conduct in-process inspections and use this information to adjust a process when necessary.	Never	Occasionally	Usually	Consistently
I coordinate activities with others to solve problems quickly during non-routine and/or upset conditions.	Barely	Partially	Mostly	Fully

RUBRICS FOR IMPROVING PROBLEM-SOLVING

Student Plan for Assessment and Improvement of Problem-Solving—Uses a logical methodology to solve problems and make decisions.

Performance Criteria		
Reflection Reflect on your actions during class or at a workplace and identify examples of when you:		**Personal Plan** Based on your examples and the feedback of your instructor or peers, describe the steps you might take to continue or improve your problem-solving skills.
Identified a problem to be solved.	*Example:* *Peer /supervisor review:* Do not agree … Strongly agree 1 2 3 4	*Steps:*
Consulted and/or worked with others as a team to solve the problem.	*Example:* *Peer /supervisor review:* Do not agree … Strongly agree 1 2 3 4	*Steps:*
Made a major decision independently.	*Example:* *Peer /supervisor review:* Do not agree … Strongly agree 1 2 3 4	*Steps:*

Performance Criteria		
Reflection Reflect on your actions during class or at a workplace and identify examples of when you:		**Personal Plan** Based on your examples and the feedback of your instructor or peers, describe the steps you might take to continue or improve your problem-solving skills.
Understood the problem and identified what was known and what needed to be learned.	*Example:* *Peer/supervisor review:* Do not agree — Strongly agree 1 2 3 4	*Steps:*
Developed a plan to solve the problem identifying the strategies that were to be used.	*Example:* *Peer/supervisor review:* Do not agree — Strongly agree 1 2 3 4	*Steps:*
Carried out the plan.	*Example:* *Peer/supervisor review:* Do not agree — Strongly agree 1 2 3 4	*Steps:*
Checked the results.	*Example:* *Peer/supervisor review:* Do not agree — Strongly agree 1 2 3 4	*Steps:*

Peer comments and suggestions:
Instructor comments:

Weblinks

http://www.stemtransitions.org/mn14/overview.php – This page includes an expanded version of the Tools for Preventing Problems Activity as well as two additional similar problems. There is a one time free registration to access materials from the site.

http://pred.boun.edu.tr/ps/index.htm – This web site highlights six different problem-solving strategies and gives additional problems such as the ones found in the Make a Plan Activity.

http://www.austintown.k12.oh.us/~aust_tr/PSS.htm – This is another website that supplies additional problem-solving strategies similar to those in Make a Plan Activity with additional problems.