This is a low-resolution printable version of the teacher-presentation information. The original PowerPoint slides are clearer and animated to assist the teacher in delivering quality content to the students.

Licensed users of the EST Foundations curriculum have access to:

- the original animated PowerPoint files
- accompanying handouts
- detailed homework assignments
- lesson plans including online reading and research assignments, and
- suggestions on integrating this project-based curriculum.

Topic 8 (ver 1.0) **Applied Product Testing**

Content of this module

- Bell work 8.1
- Discuss phases in experimentation project
- Discuss the basic experimentation principles
- Bell work 8.2
- Discuss useful statistics (frequency, mean, and range)
- Bell work 8.3
- Work in groups to develop an experimentation project plan
- Bell work 8.4
- Individually set up and conduct the experiments
- Bell work 8.5
- Finish experiments and report results

8.1 Experimentation Fundamentals

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Bell Work 8.1

- Why is "testing" listed as one of the steps in the design process?

Today's Agenda

- Discuss the phases in an experimentation project
- Discuss the basic principles of experimentation

Most important thing?

- Scientific experimentation is exactly the same as engineering experimentation in theory...but the objects of their focus can differ.
- Where scientists assess the correctness of a theory, engineers aim to assess the predictable characteristic of a product.
- The single most important fact to learn in this section is that **experimentation is more than just taking data**.
- Data-taking is only one of the many phases of an experimental program.

Real Word Experimentalists

- During your school career you will complete a lot of laboratory investigations that demonstrate known physical principles.
- For the most part, they are simply that..."demonstrations." Since the outcome is well known anyway, then why bother?
- Given the huge resource of computer assisted simulations and the universe of known scientific facts you might ask "why experiment, can't we just use our math?" (Granted, you are more likely to ask this question after taking 16 years of math like most Engineers do.)
- Practically speaking, even with our present analytical technical capabilities, most systems are well beyond our ability to completely represent them mathematically.
- Theoretically speaking, it is impossible to account for absolutely everything mathematically so there will always be assumptions involved...and the validity of assumptions should always be tested (in one way or another).

Experimental Approach

- So, the point is not to "demonstrate" something. The point is to conduct an investigation.
- It turns out that, the "Testing Phase" of our design project is actually a project in and of itself.
- Being a project, it has phases. These are the likely phases of the project:
  - Planning (identify the true question, related physical principles, relevant quantities to be measured, required accuracy, and the level of reporting that will be needed)
  - Design (define the test apparatus, test protocol and range of conditions to be tested)
  - Construction (apparatus is assembled and the instrumentation is calibrated)
  - Debugging (practice with the apparatus and polish the protocol until you are confident that the results will be valid)
  - Execution (continually check the condition of the apparatus while recording data)
  - Data Analysis (look for answers to the original question...spreadsheet software can be helpful)
  - Report (your question, approach, protocol, and your conclusions and their justification)

These are the phases described by Coleman and Steele, Experimentation and Uncertainty Analysis for Engineers, John Wiley & Sons, 1989.

Experimentation Principles

- There is no such thing as a perfect measurement.
  - All measuring devices have errors.
  - All people take measurements in a slightly different way.
  - The dimensions of your apparatus cannot be perfectly known.
  - The conditions of the environment cannot be completely controlled.
- The results of an experiment are only useful to an engineer if the experimental conditions reasonably represent the implementation conditions. "Reasonable" leaves a lot of room for personal judgement.

Experimentation Principles

- There are two types of errors in measurements that you should seek to reduce as much as possible:
  - **Bias error** occurs if your apparatus and instruments consistently influence the measurements in an undesirable way. An example would be if someone cut the first inch off of your ruler without you knowing it. Then all the measurements that you take would be one inch longer than the true values. Another example would be if there was unidentified friction in your apparatus when you were trying to measure force...the friction would effect each and every measurement consistently.
  - **Precision error** refers to the *random* variations in the measurement or the setup. An example would be if someone erased all the small divisions from your ruler. If a measurement didn't fall precisely on an inch mark, you would probably guess the measurement different every time (e.g., was it 1.25 inches or 1.33 inches?). Another example would be if you were taking GPS measurements. The signals from the satellite are distorted by disturbances in the ionosphere and this has subtle effects on the measurements.

8.2 Common Statistics

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Bell Work 8.2

- Using a ruler measure and record the length of each of the fingers on your left hand (borrow your neighbors hands only if absolutely necessary). Record each of your measurements to an accuracy of 1/8 of an inch. (We'll use these numbers later.)

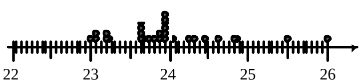
23 - 1/16
23 - 10/16
23 - 12/16
23 - 4/16
23 - 15/16
24 - 4/16
23 - 15/16
23 - 14/16
24 - 5/16
23 - 15/16
24 - 7/16
24 - 13/16
23 - 15/16
23 - 14/16
23 - 10/16
23 - 11/16
23 - 1/16
23 - 0/16
23 - 10/16
24 - 1/16
23 - 13/16
23 - 15/16
24 - 14/16
23 - 10/16
23 - 15/16
24 - 10/16
23 - 3/16
23 - 3/16
25 - 8/16
26 - 0/16

Today's Agenda

- Discuss useful statistics:
  - frequency distribution chart
  - Mean
  - Range

Tools to Analyze Data

- If you asked 30 students to measure the exact width of a table using only a 12-inch ruler you would probably get 30 different values.
- Let's say we did this experiment and asked students to measure the table to within 1/16 of an inch.
- We will graph each value as a dot on a scale.
- But, any time we run into a value that we have recorded already, we will put the new dot above the old dot.
- We would likely get a graph that looks like this:



What is the most likely value for the actual width of the table? Explain?

23 - 1/16
23 - 10/16
23 - 12/16
23 - 4/16
23 - 15/16
24 - 4/16
23 - 15/16
23 - 14/16
24 - 5/16
23 - 15/16
24 - 7/16
24 - 13/16
23 - 15/16
23 - 14/16
23 - 10/16
23 - 11/16
23 - 1/16
23 - 0/16
23 - 10/16
24 - 1/16
23 - 13/16
23 - 15/16
24 - 14/16
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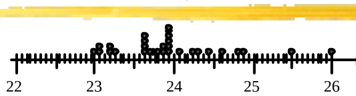
23 - 15/16
24 - 10/16
23 - 3/16
23 - 3/16
25 - 8/16
26 - 0/16

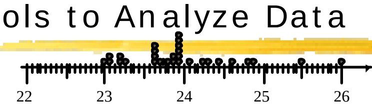
Tools to Analyze Data



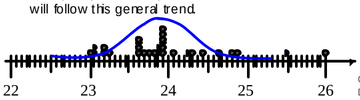
- The graph of the values is organized into what is called a "frequency distribution" chart or "histogram" or sometimes even "bar graph."
- Honestly, which format provides you with the best **overview** of the data? The histogram shown above, or the list of numbers on the right?
- To create a histogram, simply follow these steps:
  - Define the categories or intervals for the data (here every 1/16 inch)
  - Place each measurement in the correct category
  - Make the height of the bar in each category proportional to the number of measurements that fall into that category

23 - 1/16, 23 - 10/16, 23 - 12/16, 23 - 4/16, 23 - 15/16, 24 - 4/16, 23 - 15/16, 23 - 14/16, 24 - 5/16, 23 - 15/16, 24 - 7/16, 24 - 13/16, 23 - 15/16, 23 - 14/16, 23 - 10/16, 23 - 11/16, 23 - 1/16, 23 - 0/16, 23 - 10/16, 24 - 1/16, 23 - 13/16, 23 - 15/16, 24 - 14/16, 23 - 10/16, 23 - 15/16, 24 - 10/16, 23 - 3/16, 23 - 3/16, 25 - 8/16, 26 - 0/16

Tools to Analyze Data

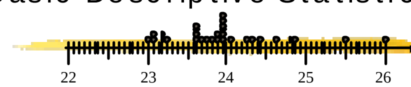


- Histogram Notes:
  - You'll need lots of measurements for the picture to look good
  - You spreadsheet software will have an automatic "frequency" function
  - Histograms quickly show us questionable data points (called "outliers") like the values at 25-1/2 and 26. Most likely there was some kind of mistake in those measurements so we'll just drop them so they don't mess up our calculations.
  - If the shape of the overall frequency distribution looks like the blue one below, then we call it a "normal frequency distribution." If you have done your job correctly and eliminated bias errors, then most data sets will follow this general trend.

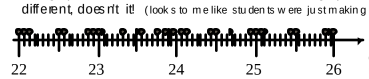


23 - 1/16, 23 - 10/16, 23 - 12/16, 23 - 4/16, 23 - 15/16, 24 - 4/16, 23 - 15/16, 23 - 14/16, 24 - 5/16, 23 - 15/16, 24 - 7/16, 24 - 13/16, 23 - 15/16, 23 - 14/16, 23 - 10/16, 23 - 11/16, 23 - 1/16, 23 - 0/16, 23 - 10/16, 24 - 1/16, 23 - 13/16, 23 - 15/16, 24 - 14/16, 23 - 10/16, 23 - 15/16, 24 - 10/16, 23 - 3/16, 23 - 3/16, 25 - 8/16, 26 - 0/16

Basic Descriptive Statistics



- Though the picture is helpful, it would be nice to have some concrete numbers that quickly summarize the data. Any single number that is calculated to describe a set of data is called a "descriptive statistic."
- We'll stick with the most commonly used ones:
  - Mean = (sum of all valid measurements) / (number of valid measurements). The Mean (what most non-statisticians call the "average") is your first best guess at what the actual value is.
    For our data (not including the two outliers) it is 23.83 (or just under 23 -14/16).
  - Isn't that pretty much what you would have guessed?
  - The Range is the difference between the highest value and the lowest value of the data. R = highest - lowest
  - The graph below has about the same Mean as the graph above, but it sure does look different, doesn't it! (looks to me like students were just making wild guesses)



More?...nah....well okay..

- If you want to know a little more about statistics try looking up "standard deviation" in the help file of your spreadsheet software...not only will it tell you a little about the meaning of the term, it will tell you how to calculate using the software (because it is not fun to calculate by hand).
- The standard deviation is an indicator of how far each data point is from the overall mean. It is a VERY common statistic to use.
- The formula for standard deviation is shown, below...but you probably should just leave it to the computer to calculate.

$$SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

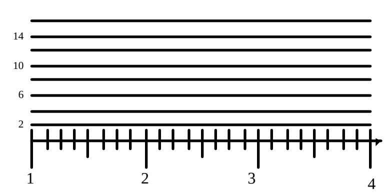
Like I said, just leave the calculations to the computer.

(In fact, let's just stick with Mean and Range...leave the rest to the professionals.)

How long are student fingers?

(Teacher: projecting this slide onto a whiteboard will facilitate this exercise)

- As a class create a frequency distribution of all the Bell work finger measurements on the scale below. How normal does the overall shape of the curve look? (If you see two humps instead of one do you have any guesses as to why?)



8.3 Planning an Experimentation Project

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Bell Work 8.3

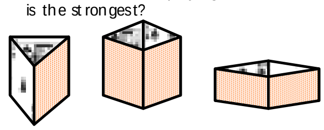
- What is the most important phase of an experimentation project? Why do you think so?

Today's Agenda

- Develop an experimentation plan for an example embodiment decision

Practice Your New Knowledge

- In small groups of 3-5 students, develop an experimentation plan to find out which column design (described below) is the strongest.
- Tomorrow, each individual will prepare their own testing apparatus according to the group's plan. Experiments will be conducted tomorrow and Friday.
- Your individual "report" will be due on Monday (sections should include: summary, background and problem description, plan, data collection method, data analysis, and conclusions)
- The Question: We have three embodiment ideas for a column made from playing cards and clear tape only. Which design is the strongest?



Assignment Constraints

- Only the designs that are shown are to be considered.
- Only one layer of tape can be used at the corners and the cards cannot be doubled (to make thick walls).
- You have to make any arrangements for your test apparatus and testing materials yourself (it would be smart if you plan to use whatever is generally available in the classroom).
- Things to consider:
  - How many tests will you run? What influences your decision?
  - How will you test the strength? Where will you get the forces?
  - What measurements will you take? What accuracy do you need and what accuracy will you get?
  - What uncertainties exist in the testing apparatus and your test procedure? How can you eliminate the uncertainties?
- Your group should design the data collection sheet today for use tomorrow!

Teacher HINTs

- The word "strongest" leaves room for creative interpretation. The word "column" implies a compressive load, but no matter what the interpretation, the students should mention why they made that interpretation in their report.
- A stack of consistent text books would make a pretty good source for force. It doesn't matter what the precise weight of each book is…It is simply important that each one represents a consistent "unit" of weight.
- The conditions of the test will make a big difference. Testing the Card-columns on a smooth hard surface versus on the carpet will likely yield different results.
- The four sided columns will not naturally maintain a square position, the student plans should incorporate this concern in their "apparatus." Or maybe that is part of the test results? They should make the call…but should be aware of the decision.

8.4 Executing an Experimentation Plan

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Bell Work 8.4

- Without leaving your chair do what preparations you can to get ready to perform your experiment. Mentally review the testing process that you will go through.

Today's Agenda

It is important that you adhere to the plan that your small group made because your results will be compared to the others' in your group

- Individually assemble the test apparatus, assemble test specimens and perform your experiment exactly as designed by your small group
- The teacher must monitor at least some of your tests and initial your data sheet
- When you are done, you can begin writing your report that is due Monday
- We will continue testing and writing tomorrow (if you finish both before tomorrow, then you'll have a special assignment to do in class)

Your individual "report" will be due on Monday (sections should include: summary, background and problem description, plan, data collection method, data analysis, and conclusions)

8.5 Reporting Results

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Bell Work 8.5

- In your journal, develop an outline for your experimentation report.

Today's Agenda

- Continue performing your experiment and writing your individual report that is due on Monday
- If you finish both then...