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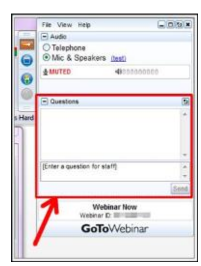

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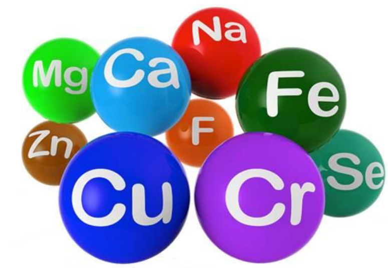

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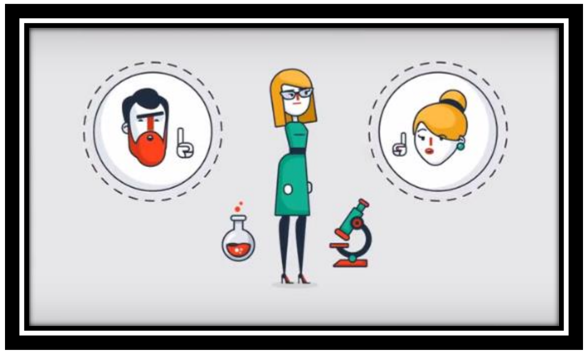

- Know your career options
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- How to estimate measurement variability
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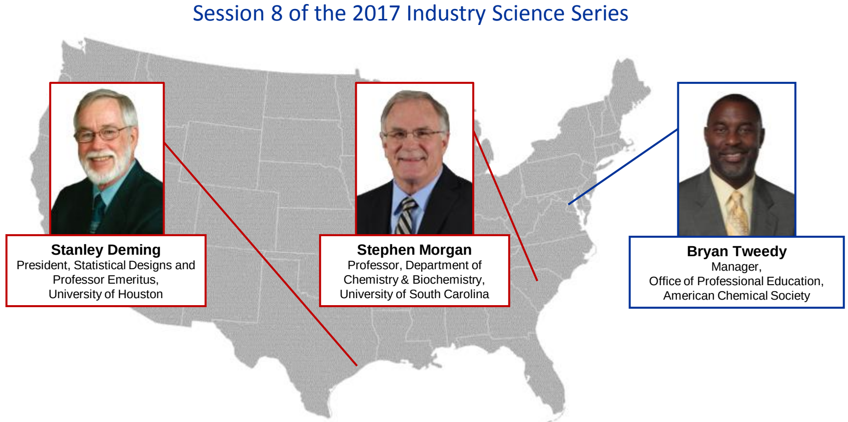

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Challenge Question #1: Gaussian Statistics

For a Gaussian distribution of data, how many standard deviations do you have to go on either side of the mean to include 95.00% of the data?

A. 0.67

B. 1.04

C. 1.96

D. 2.00

E. 2.54

F. None of the above.

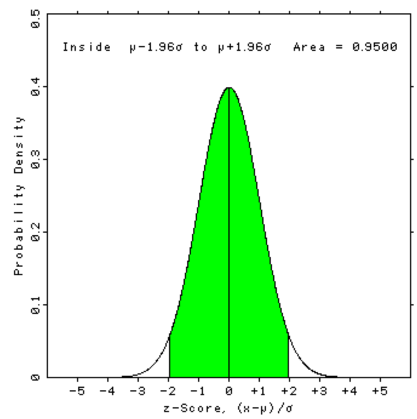
https://commons.wikimedia.org/wiki/File:Carl_Friedrich_Gauss.jpg

Statistical Analysis: Gaussian Areas and *z* values

When data are normally distributed, 95% of the values will lie <u>inside</u> the region centered at the true mean μ, and extending 1.96 standard deviations σ on either side of the true mean μ.

z values measure how many standard deviations you are away from the mean. If $z = 1.00$, you're 1.00 standard deviation above the mean. If $z = -1.96$, you're 1.96 standard deviations below the mean.

Thus, 95% of the values will lie <u>between</u> *z* values of -1.96 and +1.96.

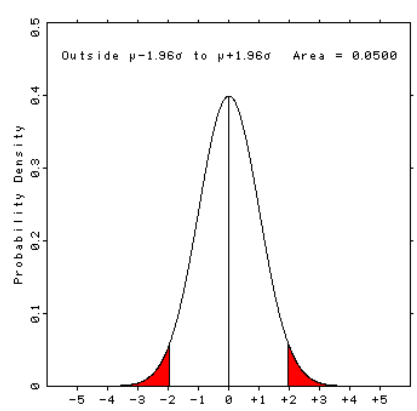


Statistical Analysis: Gaussian Areas

When data are normally distributed, only 5% of the values will lie <u>outside</u> the region centered at the true mean μ and extending 1.96 standard deviations σ on either side of the true mean μ.

An equivalent way of saying this is that only 5% of the values will lie <u>beyond</u> *z* values of -1.96 and +1.96.

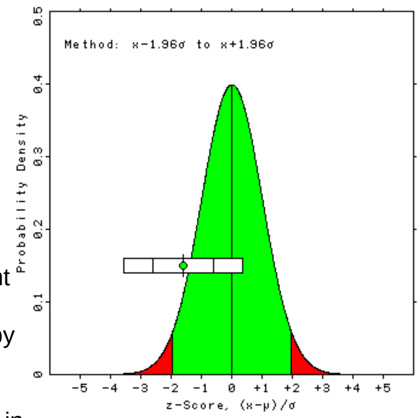
Half of the excluded area lies in the left tail; the other 2.5% of the area lies in the right tail.



Statistical Analysis: The Procedure Applied

Here is a procedure:

For a given data point, draw an interval extending plus and minus 1.96 standard deviations from the data point



Imagine that we select at random a data point from a distribution of data that is normally distributed. That data point might be shown by the single green dot in the figure at the right.

This procedure generates the interval shown in the figure.

Statistical Analysis: The Procedure Applied

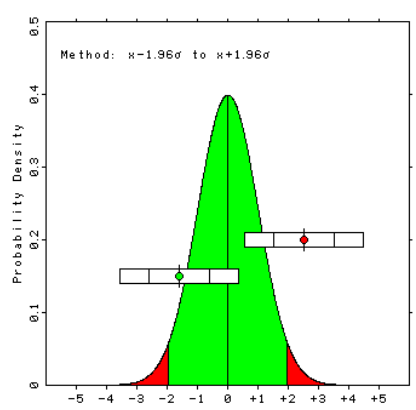
Imagine that we select at random a second data point from the same normal distribution.

That second data point and its interval might be shown by the upper red dot in the figure at the right.

In this example, the two intervals are different in an important way:

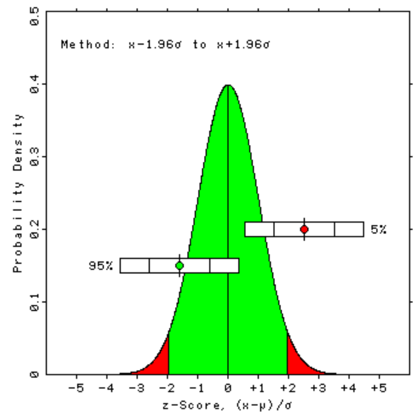
one interval includes μ

the other interval does not include μ



Statistical Analysis: The Procedure Applied

If we select at random a very large number of data points and apply the <u>procedure</u> to each of them, then we would expect that approximately 95% of the <u>intervals</u> would include μ, and approximately 5% of the <u>intervals</u> would not include μ.



Statistical Analysis: The Confidence Interval

These statements about the procedure apply to any data point taken from any Gaussian distribution, <u>whether we know the value of the true mean μ or not</u>. All we need to know is σ.

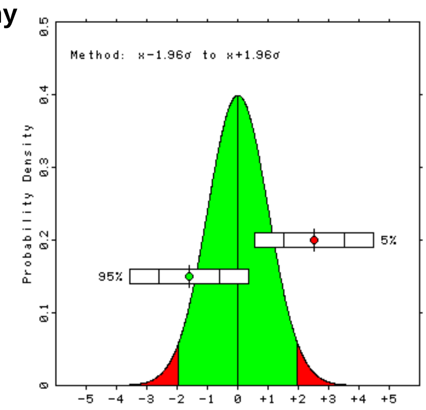
When we talk about confidence, we are expressing our confidence in the <u>procedure</u>.

The <u>two-sided or two-tailed confidence interval</u> (CI) for μ can be expressed as

$$(x - z_{\alpha/2}\sigma) \leq \mu \leq (x + z_{\alpha/2}\sigma)$$

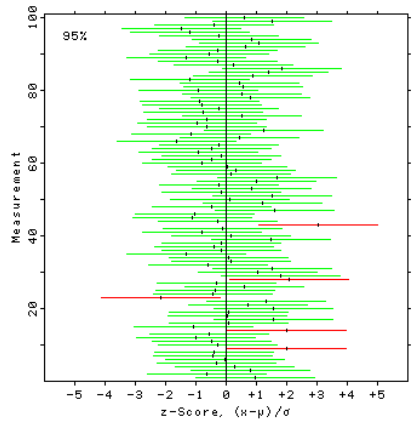
or

$$\text{CI for } \mu = x \pm z_{\alpha/2}\sigma$$



Statistical Analysis: 95% Confidence Intervals

The figure at the right shows the results of drawing at random 100 data points from a *z* distribution and applying the 95% confidence interval procedure.



As shown in the figure, the expected 95 out of 100 confidence intervals include μ, and the expected 5 out of 100 confidence intervals do not include μ.

(It is rare that a relatively small sample of 100 data points will give the exact expectation values. Figures in this module will show the exact expectation values. In real life, this won't always happen.)

Challenge Question #2: Confidence Intervals

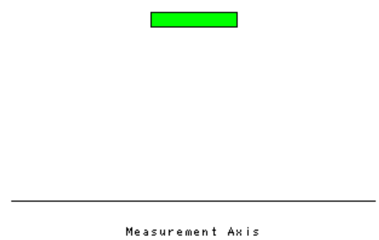
If you want more than 95% of your confidence intervals to include the true mean μ, then the *z* multiplier used to generate the confidence interval must be:

A. less than 1.54

B. greater than 1.96

Statistical Testing: Confidence Interval Details

In the figure at the right, the horizontal axis is a measurement axis. The vertical dimension has no meaning. The rectangular box represents a two-sided confidence interval for a population parameter (e.g., σ or μ).



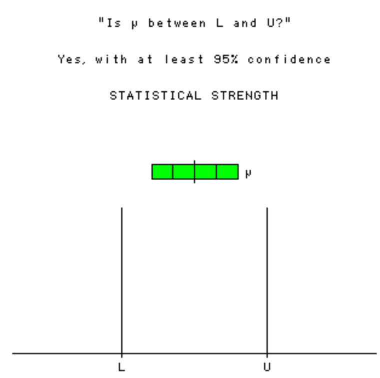
Statistical Testing: Testing For "Between"

Sometimes we want to know if a true mean μ is <u>between</u> two specified values — a lower specification L, and an upper specification U.

The statistical question then becomes, “Is μ between L and U?”

In this example, because the confidence interval for μ is both greater than L and less than U, we can state with at least 95% confidence that μ is probably between the values.

There is STATISTICAL STRENGTH in this statement.

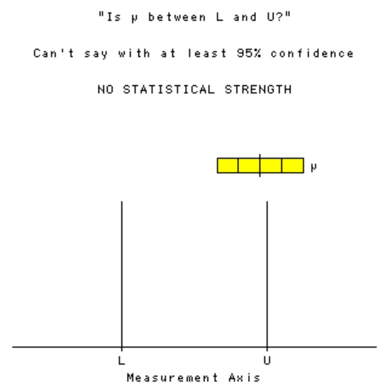


Statistical Testing: Testing For "Between"

In this example, the confidence interval for μ includes the upper specification U. The true mean μ might be below U, or it might be above U. If we ask the question, "Is the true mean μ between the values L and U?" then we must answer, "No, we can't say with at least 95% confidence that μ is between L and U."

In this case, we can't say much more.

There is NO STATISTICAL STRENGTH in this statement.



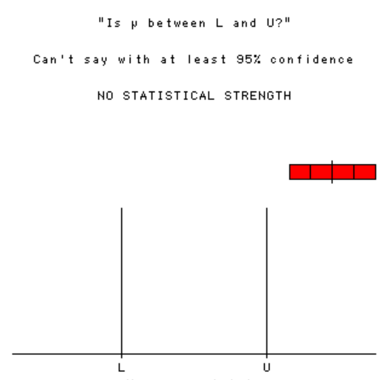
Statistical Testing: Testing For "Between"

For this example, again we must answer, "No, we can't say with at least 95% confidence that μ is between L and U."

There is NO STATISTICAL STRENGTH — for the question that was asked.

With this result we could say more. We can say something about the <u>opposite</u> of the sense of the question. We can be at least 95% confident that μ is <u>outside</u> the values.

But that isn't the question that was asked.



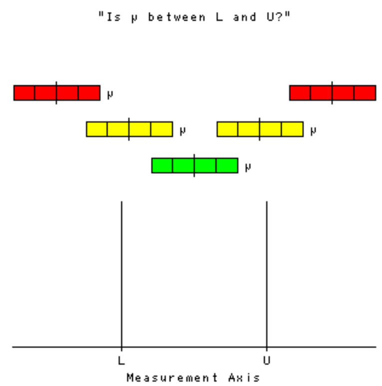
Statistical Testing: Testing For "Between"

To summarize: it is appropriate to use a <u>two-sided</u> confidence interval to see if μ is <u>between</u> L and U at some level of confidence. There are two possible outcomes:

1) We **can** say that μ is between L and U:
   μ > L and μ < U

2) We **can't** say that μ is between L and U

The second outcome does not necessarily mean that μ is outside the specifications.



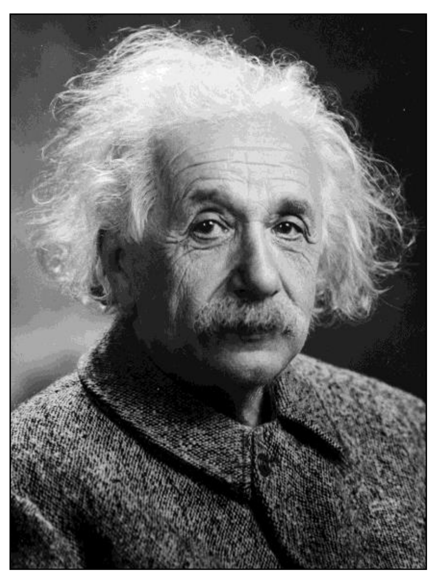
Challenge Question #3: An Uncertain World

A 95% confidence interval for the mean μ is calculated based on a set of eight replicate measurements. Which of the following statements is <u>not</u> true?

A. 95% of all future measurements will be within this interval.

B. The mean of the eight replicate measurements is inside the confidence interval.

C. The confidence interval might not contain μ.



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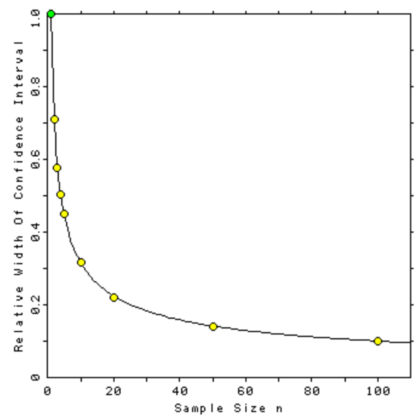
Experimental Design: Mathematical Description

The width of the confidence interval depends on the number of measurements that go into determining the mean. If the true standard deviation σ is known, then

$$\text{CI for } \mu = \bar{x} \pm z_{\alpha/2}\sigma_{\bar{x}} = \bar{x} \pm \frac{z_{\alpha/2}\sigma}{\sqrt{n}}$$

The width of the confidence interval decreases by a factor of 1/√*n*.



Experimental Design: Sample Size

A simple question that researchers frequently ask statisticians is,

"How big should my sample size be?"

And the researchers expect a simple answer ("Four!").

But statisticians always reply that there is no simple answer — it depends.

It depends on how small the desired standard deviation of the mean must be, and it depends on how large the standard deviation of the raw data is. And now you can figure out how big your sample size should be — you don't have to ask a statistician.

Hard Quiz #1: Sample Size

Problem: The percentage of toluene in 1000 chemical samples of gasoline is to be estimated by making multiple gas chromatographic measurements for each gasoline sample and using the statistical sample mean as an estimate of the toluene percentage. Previous experience has indicated that individual measurements produce a confidence interval that is 0.2% toluene wide.

How many measurements (n) must be taken to make the confidence interval less than or equal to 0.05% toluene?

"How big should my sample size be?"

Hard Quiz #1: Sample Size (Answer)

Answer: The sample size can be found from the relationship

$$\text{width for n} = (\text{width for n} = 1) / \sqrt{n}$$

$$0.05\ \%\ \text{toluene} = 0.2\ \%\ \text{toluene} / \sqrt{n}$$

$$\sqrt{n} = 0.2\ \%\ \text{toluene} / 0.05\ \%\ \text{toluene} = 4$$

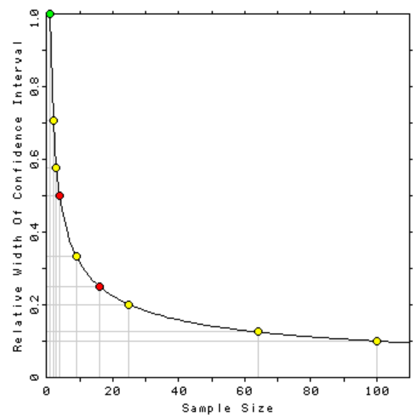
$$n = 16$$

Experimental Design: Budgetary Considerations

The 1/√*n* effect is like a "statistical sledgehammer" — it is a brute-force way of making the confidence interval of the mean as small as desired, simply by making *n* sufficiently large.

In the previous problem, there were 1000 gasoline samples to be analyzed, each involving 16 measurements, for a total of 16,000 gas chromatographic determinations. That can be expensive!

Is there a less expensive way to reduce the standard deviation of the mean? Yes!

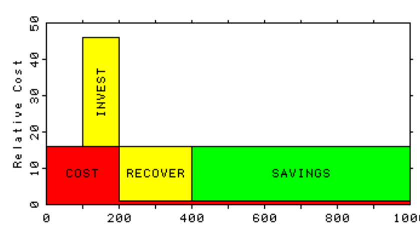


Improved Measurement: Budgetary Considerations

Instead of using the current measurement method with its inherent σ of 0.2% toluene, acquire a better measurement method with an inherent σ of 0.05% toluene. Then

$$\text{width for n} = (\text{width for n} = 1)/\sqrt{n}$$
$$0.05\ \%\ \text{toluene} = 0.05\ \%\ \text{toluene}/\sqrt{n}$$
$$\sqrt{n} = 0.05\ \%/0.05\ \% = 1$$
$$n = 1$$

Do not try to do with statistics what you can do cheaper with improved measurement



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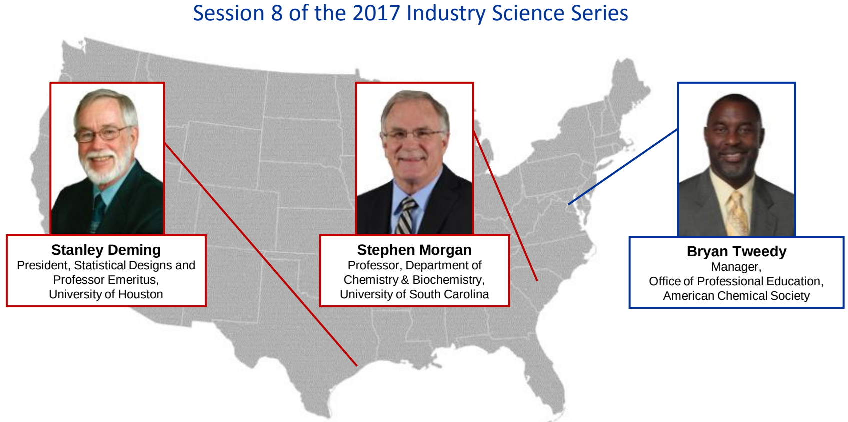

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Chemist Supervisor - Organic Unit
Tucson Water Quality Laboratory
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