

The χ^2 Test

Use this test when:

The measurements relate to the number of individuals in particular categories;
The observed number can be compared with an expected number which is calculated from a theory.

The χ^2 test is a statistical test to compare observed results with theoretical expected results. The calculation generates a χ^2 value; the higher the value of χ^2 , the greater the difference between the observed and the expected results.

1. State the null hypothesis

This is a negative statement, basically saying that there is no statistical difference between the observed and the expected results.

Eg there is no difference between the observed results and the expected results.

2. Calculate the expected value

This may be the mean of the expected values.

Or when studying inheritance, you add up the expected values and apply a ratio.

3. Calculate χ^2

The formula is:
$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

o = observed value

e = expected value

Σ = the sum of

4. You will also need to know the degrees of freedom.

- This is calculated using the formula (n-1)
- where n = the number of sets of results.

5. Compare the χ^2 value against a table of critical values.

- Refer to the degrees of freedom,
- Look up the critical number at the $p = 0.05$ level

6. Make a conclusion:

- Biologists need to feel confidence in their results in order to say that a difference occurred due to a biological reason.
- They will only accept this if they have greater than 95% confidence.
- If they have less than 95% confidence, they are only willing to say that the difference between the results occurred due to chance alone.
- If the number exceeds the critical number at the 0.05 level then, as a biologist, you can reject the null hypothesis.
- If the χ^2 value is less than the critical number then you can accept the null hypothesis.
- Eg the calculated value is greater than the critical value so the null hypothesis is rejected and there is a significant difference between the observed and expected results at the 5% level of probability.

Chi-squared test example



Naked mole rats are a burrowing **rodent** native to parts of East Africa. They have a complex social structure in which only one female (the queen) and one to three males reproduce, while the rest of the members of the colony function as workers. Mammal ecologists suspected that they had an unusual male to female ratio. They counted the numbers of each sex in one colony.

| Sex | Number of animals |
|--------|-------------------|
| Female | 52 |
| Male | 34 |

State the Null hypothesis

Calculate the expected results

Calculate the chi-squared value

| Sex | Observed | Expected | O - E | (O - E) ² | (O - E) ² /E |
|--------|----------|----------|-------|----------------------|-------------------------|
| Female | 52 | | | | |
| Male | 34 | | | | |
| TOTAL | | | | | |

$$\chi^2 =$$

What are the degrees of freedom?

$$DF =$$

Compare the calculated value with the critical value

| Degrees of freedom | Significance level | | |
|--------------------|--------------------|------|------|
| | 5% | 2% | 1% |
| 1 | 3.84 | 5.41 | 6.64 |
| 2 | 5.99 | 7.82 | 9.21 |

Make a conclusion

Chi-squared test example answer sheet



Naked mole rats are a burrowing **rodent** native to parts of East Africa. They have a complex social structure in which only one female (the queen) and one to three males reproduce, while the rest of the members of the colony function as workers. Mammal ecologists suspected that they had an unusual male to female ratio. They counted the numbers of each sex in one colony.

| Sex | Number of animals |
|--------|-------------------|
| Female | 52 |
| Male | 34 |

State the Null hypothesis

There is no difference in the numbers of male and female naked mole rats

Calculate the expected results

Expected results = $\frac{52 + 34}{2} = \frac{86}{2} = 43$

$$\frac{52 + 34}{2} = \frac{86}{2} = 43$$

Calculate the chi-squared value

| Sex | Observed | Expected | O - E | (O - E) ² | (O - E) ² /E |
|--------|----------|----------|-------|----------------------|-------------------------|
| Female | 52 | 43 | 9 | 81 | 1.88 |
| Male | 34 | 43 | -9 | 81 | 1.88 |
| TOTAL | | | | | 3.76 |

$$\chi^2 = 3.76$$

What are the degrees of freedom?

$$DF = n - 1 = 2 - 1 = 1$$

Compare the calculated value with the critical value

| Degrees of freedom | Significance level | | |
|--------------------|--------------------|------|------|
| | 5% | 2% | 1% |
| 1 | 3.84 | 5.41 | 6.64 |
| 2 | 5.99 | 7.82 | 9.21 |

The critical value of Chi-squared at 5% significance and 1 degree of freedom is 3.84

Our calculated value is 3.76

The calculated value is smaller than the critical value at the 5% level of probability.

Make a conclusion

We cannot reject the null hypothesis, so there is not a significant difference between the observed and expected results at the 5% level of probability.

In doing this we are saying that the naked mole rates do not have a significantly larger female population in comparison with the male population.

Chi-squared test example



You have been wandering about on a seashore and you have noticed that a small snail (the flat periwinkle) seems to live only on seaweeds of various kinds. You decide to investigate whether the animals prefer certain kinds of seaweed by counting numbers of animals on different species. You end up with the following data:

| TYPE OF SEAWEED | Number of animals on each kind of seaweed |
|-----------------|---|
| serrated wrack | 45 |
| bladder wrack | 38 |
| egg wrack | 10 |
| spiral wrack | 5 |
| other algae | 2 |
| TOTAL | 100 |

State the Null hypothesis

Calculate the expected results

Calculate the chi-squared value

| Seaweed | Observed | Expected | O - E | (O - E) ² | (O - E) ² /E |
|----------------|----------|----------|-------|----------------------|-------------------------|
| serrated wrack | 45 | | | | |
| bladder wrack | 38 | | | | |
| egg wrack | 10 | | | | |
| spiral wrack | 5 | | | | |
| other algae | 2 | | | | |
| TOTAL | | | | | |

$$\chi^2 =$$

What are the degrees of freedom?

Compare the calculated value with the critical value

| Degrees of freedom | Significance level | | |
|--------------------|--------------------|-------|-------|
| | 5% | 2% | 1% |
| 1 | 3.84 | 5.41 | 6.64 |
| 2 | 5.99 | 7.82 | 9.21 |
| 3 | 7.82 | 9.84 | 11.34 |
| 4 | 9.48 | 11.66 | 13.27 |

Make a conclusion

Chi-squared test example answer sheet



You have been wandering about on a seashore and you have noticed that a small snail (the flat periwinkle) seems to live only on seaweeds of various kinds. You decide to investigate whether the animals prefer certain kinds of seaweed by counting numbers of animals on different species. You end up with the following data:

| TYPE OF SEAWEED | Number of periwinkles on each kind of seaweed |
|-----------------|---|
| serrated wrack | 45 |
| bladder wrack | 38 |
| egg wrack | 10 |
| spiral wrack | 5 |
| other algae | 2 |
| TOTAL | 100 |

State the Null hypothesis

There is no difference in the numbers of flat periwinkles found on the different seaweeds.

Calculate the expected results

Expected results = $\frac{45 + 38 + 10 + 5 + 2}{5} = \frac{100}{5} = 20$

5

5

Calculate the chi-squared value

| Seaweed | Observed | Expected | O - E | (O - E) ² | (O - E) ² /E |
|----------------|----------|----------|-------|----------------------|-------------------------|
| serrated wrack | 45 | 20 | 25 | 625 | 31.3 |
| bladder wrack | 38 | 20 | 18 | 324 | 16.2 |
| egg wrack | 10 | 20 | -10 | 100 | 5 |
| spiral wrack | 5 | 20 | -15 | 225 | 11.3 |
| other algae | 2 | 20 | -18 | 324 | 16.2 |
| TOTAL | | | | | 79.9 |

$$\chi^2 = 79.9$$

What are the degrees of freedom?

$$DF = n - 1 = 5 - 1 = 4$$

Compare the calculated value with the critical value

| Degrees of freedom | Significance level | | |
|--------------------|--------------------|-------|-------|
| | 5% | 2% | 1% |
| 1 | 3.84 | 5.41 | 6.64 |
| 2 | 5.99 | 7.82 | 9.21 |
| 3 | 7.82 | 9.84 | 11.34 |
| 4 | 9.48 | 11.66 | 13.27 |

The critical value of Chi-squared at 5% level of probability and 4 degrees of freedom is 9.48.

Our calculated value is 79.9

The calculated value is bigger than the critical value at the 5% level of probability.

Make a conclusion

We must reject the null hypothesis, so there is a significant difference between the observed and expected results at the 5% level of probability.

In doing this we are saying that the snails are not homogeneously scattered about the various sorts of seaweed but seem to prefer living on certain species.

Spearman rank correlation

When to use it

Spearman rank correlation is used when you have two sets of measurement variables and you want to see whether as one variable increases, the other variable tends to increase or decrease.

There must be between 7 and 30 pairs of measurements

Example: Human body weight and blood pressure.

1. State the Null hypothesis

There is no association between the body weight of the humans tested and their blood pressure.

2. Convert the data into ranks

- Spearman rank correlation works by converting each variable to ranks.
- The lightest person would get a rank of 1, second-lightest a rank of 2, etc.
- The lowest blood pressure would get a rank of 1, second lowest a rank of 2, etc.
- When two or more observations are equal, the average rank is used.
- For example, if two observations are tied for the second-highest rank, they would get a rank of 2.5 (the average of 2 and 3).
- Record these ranks in a table keeping each the pairs of data on the same row.

3. Calculate the correlation coefficient

- For each pair of data calculate the difference between the rank values.
- Calculate the square of this difference for each pair.
- Find the sum of the squares of the difference: $\sum D^2$
- Now calculate the value of the Spearman rank correlation, r_s , from the equation:

$$r_s = 1 - \left(\frac{6\sum d^2}{n(n^2 - 1)} \right)$$

where n = the number of pairs of items in the sample

4. Look up and interpret the value of r_s

- The value of r_s will always be between 0 and either +1 or -1.
- A positive value indicates a positive association between the variable concerned.
- A negative value shows a negative association.
- A number near 0 shows little / no association.
- Compare the r_s against the critical values at $P = 0.05$ for the number of paired variables studied.

5. Make a conclusion

- If the number exceeds the critical number at the 0.05 level then, as a biologist, you can reject the null hypothesis.
- Eg. The calculated value is greater than the critical value, so the null hypothesis is rejected and there is a significant correlation between the body weight of the humans tested and their blood pressure at the 5% level of probability.

Spearman's Rank Correlation Coefficient Example



Great tits are small birds. In a study of growth in great tits, the relationship between the mass of the eggs and the mass of the young bird on hatching was investigated.

Their results are recorded in the table below.

1. State a suitable null hypothesis:

2. Complete the following table:

| Pair number | Egg mass / g | Rank | Chick mass / g | Rank | Difference in rank (D) | D ² |
|-------------|--------------|------|----------------|------|------------------------|----------------|
| 1 | 1.37 | | 0.99 | | | |
| 2 | 1.49 | | 0.99 | | | |
| 3 | 1.56 | | 1.18 | | | |
| 4 | 1.70 | | 1.16 | | | |
| 5 | 1.72 | | 1.17 | | | |
| 6 | 1.79 | | 1.27 | | | |
| 7 | 1.93 | | 1.75 | | | |
| | | | | | | $\sum D^2 =$ |

3. Calculate the correlation coefficient:

4. Look up the critical value for r_s :

5. Make a conclusion:

Spearman's Rank Correlation Coefficient Example Answer Sheet



Great tits are small birds. In a study of growth in great tits, the relationship between the mass of the eggs and the mass of the young bird on hatching was investigated.

Their results are recorded in the table below.

1. State a suitable null hypothesis:

There is no association between the mass of the eggs and the mass of the chicks which hatch from them

2. Complete the following table:

| Pair number | Egg mass / g | Rank | Chick mass / g | Rank | Difference in rank (D) | D ² |
|-------------|--------------|------|----------------|------|------------------------|------------------|
| 1 | 1.37 | 1 | 0.99 | 1.5 | 0.5 | 0.25 |
| 2 | 1.49 | 2 | 0.99 | 1.5 | 0.5 | 0.25 |
| 3 | 1.56 | 3 | 1.18 | 5 | 2 | 4 |
| 4 | 1.70 | 4 | 1.16 | 3 | 1 | 1 |
| 5 | 1.72 | 5 | 1.17 | 4 | 1 | 1 |
| 6 | 1.79 | 6 | 1.27 | 6 | 0 | 0 |
| 7 | 1.93 | 7 | 1.75 | 7 | 0 | 0 |
| | | | | | | $\sum D^2 = 6.5$ |

3. Calculate the correlation coefficient:

$$r_s = 1 - \left(\frac{6\sum d^2}{n(n^2 - 1)} \right)$$

$$= 1 - \frac{6 \times 6.5}{7^3 - 7}$$

$$= 1 - \frac{39}{336}$$

$$= 1 - 0.116 = 0.884$$

$$= 0.884$$

4. Look up the critical value for r_s :

Critical value = 0.79

5. Make a conclusion:

The correlation coefficient exceeds the critical value, so we can reject the null hypothesis and say that there is a significant correlation between the mass of an egg and the mass of the chick which hatched from it at the 5% level of probability.



Spearman's Rank Correlation Coefficient Example

Males of the magnificent frigatebird (*Fregata magnificens*) have a large red throat pouch. They visually display this pouch and use it to make a drumming sound when seeking mates. Madsen et al. (2004) wanted to know whether females, who presumably choose mates based on their pouch size, could use the pitch of the drumming sound as an indicator of pouch size. The authors estimated the volume of the pouch and the fundamental frequency of the drumming sound in 18 males.

Their results are recorded in the table below.

1. State a suitable null hypothesis:

2. Complete the following table:

| Pair number | Volume/ cm ³ | Rank | Frequency/ Hz | Rank | Difference in rank (D) | D ² |
|-------------|----------------------------|------|------------------|------|---------------------------|----------------|
| 1 | 1760 | | 529 | | | |
| 2 | 2040 | | 566 | | | |
| 3 | 2440 | | 473 | | | |
| 4 | 2550 | | 461 | | | |
| 5 | 2730 | | 465 | | | |
| 6 | 2740 | | 532 | | | |
| 7 | 3010 | | 484 | | | |
| 8 | 3080 | | 527 | | | |
| 9 | 3370 | | 488 | | | |
| 10 | 3740 | | 485 | | | |
| 11 | 4910 | | 478 | | | |
| 12 | 5090 | | 434 | | | |
| 13 | 5090 | | 468 | | | |
| 14 | 5380 | | 449 | | | |
| 15 | 5850 | | 425 | | | |
| 16 | 6730 | | 389 | | | |
| 17 | 6990 | | 421 | | | |
| 18 | 7960 | | 416 | | | |
| | | | | | | $\sum D^2 =$ |

3. Calculate the correlation coefficient:

4. Look up the critical value for r_s :

5. Make a conclusion:



Spearman's Rank Correlation Coefficient Example Answer Sheet

Males of the magnificent frigatebird (*Fregata magnificens*) have a large red throat pouch. They visually display this pouch and use it to make a drumming sound when seeking mates. Madsen et al. (2004) wanted to know whether females, who presumably choose mates based on their pouch size, could use the pitch of the drumming sound as an indicator of pouch size. The authors estimated the volume of the pouch and the fundamental frequency of the drumming sound in 18 males.

Their results are recorded in the table below.

1. State a suitable null hypothesis:

There is no association between the volume of the throat pouch and the pitch of the drumming sound.

2. Complete the following table:

| Pair number | Volume/ cm ³ | Rank | Frequency/ Hz | Rank | Difference in rank (D) | D ² |
|-------------|----------------------------|------|------------------|------|---------------------------|------------------------|
| 1 | 1760 | 1 | 529 | 16 | 15 | 225 |
| 2 | 2040 | 2 | 566 | 18 | 16 | 256 |
| 3 | 2440 | 3 | 473 | 10 | 7 | 49 |
| 4 | 2550 | 4 | 461 | 7 | 3 | 9 |
| 5 | 2730 | 5 | 465 | 8 | 3 | 9 |
| 6 | 2740 | 6 | 532 | 17 | 11 | 121 |
| 7 | 3010 | 7 | 484 | 12 | 5 | 25 |
| 8 | 3080 | 8 | 527 | 15 | 7 | 49 |
| 9 | 3370 | 9 | 488 | 14 | 5 | 25 |
| 10 | 3740 | 10 | 485 | 13 | 3 | 9 |
| 11 | 4910 | 11 | 478 | 11 | 0 | 0 |
| 12 | 5090 | 12.5 | 434 | 5 | 7.5 | 56.25 |
| 13 | 5090 | 12.5 | 468 | 9 | 3.5 | 12.25 |
| 14 | 5380 | 14 | 449 | 6 | 8 | 64 |
| 15 | 5850 | 15 | 425 | 4 | 11 | 121 |
| 16 | 6730 | 16 | 389 | 1 | 15 | 225 |
| 17 | 6990 | 17 | 421 | 3 | 14 | 196 |
| 18 | 7960 | 18 | 416 | 2 | 16 | 256 |
| | | | | | | $\sum D^2 =$ 1707.5 |

3. Calculate the correlation coefficient:

$$r_s = 1 - \left(\frac{6 \sum d^2}{n(n^2 - 1)} \right)$$

$$= 1 - \frac{6 \times 1707.5}{5814}$$

$$= -0.760$$

4. Look up the critical value for r_s :

Critical value = - 0.48

5. Make a conclusion:

The correlation coefficient exceeds the critical value, so we can reject the null hypothesis and say that there is a significant **negative** correlation between the volume of the throat pouch and the pitch of the drumming sound at the 5% level of probability.

Standard Error and 95% confidence limits

Use this test when:

- You wish to find out if there is a significant difference between two means;
- The data are normally distributed; when plotted as a graph it forms a bell shaped curve.
- The sizes of the samples are at least 30.
- **Example:** Measuring a continuous variable such as height of males and females in a population.
- The measured values always show a range from a minimum to a maximum value.
- The size of the range is determined by such factors as:
 - Precision of the measuring instrument
 - Individual variability among the objects being measured.
- Biologists like to be confident that the data they achieve is within acceptable limits of variance from the mean.

Null hypothesis

- A negative statement that you are looking to disprove.
- Eg. There is no difference between the heights of the males and females in the population

Mean

- Use your calculator to calculate the mean of each set of data

Standard Deviation

- This quantifies the spread of the data around the mean.
- The larger the standard deviation, the greater the spread of data around the mean.
- Use your calculator to calculate the standard deviation for the two sets of data.

Standard Error of the Mean

- Used to provide confidence limits around the mean.
- Providing no other factors other than chance influence the results, the means of future sets of data should fall within these.
- Standard error of the mean is calculated using the equation

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$

- Where S is the standard deviation
- n is the number of measurements

95% Confidence Limits

- Biologists like to be 95% confident that the mean of any data achieved only varies from the mean of previously recorded data by chance alone.
- This range is roughly between -2 and +2 times the standard error.
- (Accurately it is 1.96 times)
- The probability (p) that the mean value lies outside those limits is less than 1 in 20 (p = <0.05).
- Multiply the standard error by 2 then add this to and subtract it from the mean.
- Do this for both sets of data.
- If the 95% confidence limits do not overlap there is a 95% chance that the two means are different.
- You can reject the null hypothesis and say:
 - There is a significant difference between the means of the two samples at the 5% level of probability

Standard Error Example



A student investigated the variation in the length of mussel shells on two locations on a rocky shore.

Null hypothesis:

| Shell length: group A / mm, x_1 | Shell length: group B / mm, x_2 |
|--------------------------------------|--------------------------------------|
| 46 | 23 |
| 50 | 28 |
| 45 | 41 |
| 45 | 31 |
| 63 | 26 |
| 57 | 33 |
| 65 | 35 |
| 73 | 21 |
| 55 | 38 |
| 79 | 30 |
| 62 | 36 |
| 59 | 38 |
| 71 | 45 |
| 68 | 28 |
| 77 | 42 |
| Mean (\bar{x}) = | Mean (\bar{x}) = |

Calculate the 2 Standard deviations:

$S_1 =$

$S_2 =$

Calculate the 2 standard errors:

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$

Group A SE =

Group B SE =

Calculate the confidence limits for the 2 groups:

$$\text{Confidence limits} = \bar{X} \pm (\text{SE} \times 2)$$

Group A:

Group B:

Make a conclusion:

What does this tell you about the 2 sets of muscles and their environment?

What factors may encourage this in their environment?

Standard Error Example Answer Sheet

A student investigated the variation in the length of mussel shells on two locations on a rocky shore.

Null hypothesis: there is no difference between the shell lengths of the mussels found at the two locations



| Shell length: group A / mm, x_1 | Shell length: group B / mm, x_2 |
|--------------------------------------|--------------------------------------|
| 46 | 23 |
| 50 | 28 |
| 45 | 41 |
| 45 | 31 |
| 63 | 26 |
| 57 | 33 |
| 65 | 35 |
| 73 | 21 |
| 55 | 38 |
| 79 | 30 |
| 62 | 36 |
| 59 | 38 |
| 71 | 45 |
| 68 | 28 |
| 77 | 42 |
| Mean (\bar{x}) = 61 | Mean (\bar{x}) = 33 |

Calculate the 2 Standard deviations:

$$S_1 = 10.97$$

$$S_2 = 6.87$$

Calculate the 2 standard errors:

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$

Group A SE = 2.84

Group B SE = 1.8

Calculate the confidence limits for the 2 groups:

Confidence limits = $\bar{X} \pm (SE \times 2)$

Group A: 61 ± 5.68

Group B: 33 ± 3.6

Make a conclusion:

- There is no overlap between the two 95% confidence limits so we can reject the null hypothesis.
- There is a significant difference between the means of the two samples at the 5% level of probability.

What does this tell you about the 2 sets of mussels and their environment?

- Group A therefore had the greatest standard deviation.
- The shell length of the mussels in-group A had a greater variation about their mean.
- This means that the environment they live in supported a greater range of mussel sizes.
- Additionally, their average shell length was a lot bigger.
- Therefore, these mussels probably lived longer on average.

What factors may encourage this in their environment?

- Greater variety of niches.
- More favourable terrain.
- Less wave action.
- More sheltered.
- More food.
- Less predators.

Standard Error Example



An investigation was made of the effect of the distance apart that parsnip seeds were planted on the number of seeds that germinated. Sets of 30 parsnip seeds were grown in trays. The seeds in a set were either touching each other or placed 2cm apart. The numbers of seeds in each set that had germinated after 10 days were recorded in the table below.

1. State a suitable null hypothesis:

| Number of seeds that had germinated after 10 days | | | |
|---|----|------------------------|----|
| Seeds touching each other | | Seeds placed 2cm apart | |
| 8 | 9 | 14 | 14 |
| 9 | 8 | 16 | 13 |
| 9 | 6 | 16 | 13 |
| 5 | 12 | 12 | 11 |
| 5 | 9 | 15 | 15 |
| 11 | 11 | 16 | 14 |
| 13 | 7 | 10 | 8 |
| 9 | 8 | 12 | 13 |
| 12 | 12 | 13 | 14 |
| 11 | 10 | 16 | 19 |
| 8 | 9 | 12 | 11 |
| 10 | 9 | 10 | 12 |
| 7 | 11 | 15 | 17 |
| 9 | 6 | 11 | 9 |
| 9 | 8 | 15 | 17 |
| Mean (\bar{x})= | | Mean (\bar{x}) = | |

2. Use your calculator to work out the 2 Standard deviations:

| | Seeds touching each other | Seeds placed 2cm apart |
|--------------------|---------------------------|------------------------|
| Mean | | |
| Standard deviation | | |

3. Calculate the 2 standard errors:

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$

| | Seeds touching each other | Seeds placed 2cm apart |
|----------------|---------------------------|------------------------|
| Standard error | | |

Calculate the confidence limits for the 2 groups:

$$\text{Confidence limits} = \bar{X} \pm (SE \times 2)$$

| | Seeds touching each other | Seeds placed 2cm apart |
|-------------------|---------------------------|------------------------|
| Confidence limits | | |

Make a conclusion:

Standard Error Example



An investigation was made of the effect of the distance apart that parsnip seeds were planted on the number of seeds that germinated. Sets of 30 parsnip seeds were grown in trays. The seeds in a set were either touching each other or placed 2cm apart. The numbers of seeds in each set that had germinated after 10 days were recorded in the table below.

1. State a suitable null hypothesis:

There is no difference between the number of seeds which germinated when they were touching and when they were placed 2 cm apart.

| Number of seeds that had germinated after 10 days | | | |
|---|----|----------------------------|----|
| Seeds touching each other | | Seeds placed 2cm apart | |
| 8 | 9 | 14 | 14 |
| 9 | 8 | 16 | 13 |
| 9 | 6 | 16 | 13 |
| 5 | 12 | 12 | 11 |
| 5 | 9 | 15 | 15 |
| 11 | 11 | 16 | 14 |
| 13 | 7 | 10 | 8 |
| 9 | 8 | 12 | 13 |
| 12 | 12 | 13 | 14 |
| 11 | 10 | 16 | 19 |
| 8 | 9 | 12 | 11 |
| 10 | 9 | 10 | 12 |
| 7 | 11 | 15 | 17 |
| 9 | 6 | 11 | 9 |
| 9 | 8 | 15 | 17 |
| Mean (\bar{x})= 9.00 | | Mean (\bar{x}) = 13.43 | |

2. Use your calculator to work out the 2 Standard deviations:

| | Seeds touching each other | Seeds placed 2cm apart |
|--------------------|---------------------------|------------------------|
| Mean | 9.00 | 13.43 |
| Standard deviation | 2.03 | 2.54 |

3. Calculate the 2 standard errors:

$$S_{\bar{x}} = \frac{S}{\sqrt{n}}$$

| | Seeds touching each other | Seeds placed 2cm apart |
|----------------|---------------------------|------------------------|
| Standard error | 0.37 | 0.46 |

Calculate the confidence limits for the 2 groups:

$$\text{Confidence limits} = \bar{X} \pm (\text{SE} \times 2)$$

| | Seeds touching each other | Seeds placed 2cm apart |
|-------------------|---------------------------|------------------------|
| Confidence limits | 8.26 – 9.74 | 12.51 – 14.35 |

Make a conclusion:

There is no overlap between the two 95% confidence limits so we reject the null hypothesis at the 5% level of probability and say that there is a significant difference between the number of seeds which germinated when they were touching and when they were placed 2cm apart.