# Teacher Delivery Guide Statistics: Bivariate data

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| **Y422 STATISTICS MAJOR: BIVARIATE DATA (a)****Y432 STATISTICS MINOR: BIVARIATE DATA****Y412 STATISTICS a: BIVARIATE DATA** |
| There are two kinds of bivariate data considered in A Level Mathematics and Further Mathematics and it is important to distinguish between them when considering correlation and regression. This note explains the reason for the distinction; learners will only be assessed on what appears under a specification reference below.Case A: Only **one of the variables** may be considered as **a random variable**. Often this occurs when one of the variables, the independent variable, is controlled by an experimenter and the other, the dependent variable, is measured. An example of this would be (weight, extension) in an investigation of Hooke’s law for a spring. In this case, certain fixed weights are used; this variable is *not* a random variable, any errors in measuring the weights are negligible. The extension *is* a random variable. There will be deviations from the ‘true’ value that a perfect experimenter would observe from a perfect spring as well as errors in the measurement. This case is referred to as **‘random on non-random’**. The points on the scatter diagram are restricted to lie on certain vertical lines corresponding to the values of the controlled variable.Case B: The **two variables may both** be considered as **random variables**. An example of this would be (height, weight) for a sample from a population of individuals. For any given value of height there is a distribution of weights; for any given value of weight there is a distribution of heights. That is, there is no ‘true’ weight for a given height or ‘true’ height for a given weight. This case is referred to as **‘random on random’**. The scatter diagram appears as a ‘data cloud’.If a linear relationship between the variables is to be investigated and modelled using correlation and regression techniques then the two cases must be treated differently.  |

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| If it is desired to test the significance of Pearson’s product moment correlation coefficient then, as with all parametric hypothesis tests, probability calculations have to be performed to calculate the *p*-value or the critical region. These calculations rely on certain assumptions about the underlying distribution – **these assumptions can never be met in the ‘random on non-random case’** – because one of the variables does not have a probability distribution – so **such a test is never valid in this case**. In fact the pmcc is not used in this case. In the ‘random on random’ case the distributional assumptions **may** be met – see the specification below for details.If it is desired to calculate the equation of a line of best fit then the least-squares method is often used in both cases. However its interpretation is different in the two cases. In the example of the random on non-random case, (weight, extension), the line of regression is modelling the ‘true’ value of the extension for a given weight – the value that a perfect experimenter would observe from a perfect spring. In the example of the **random on random case**, (height, weight), the two **lines of regression are modelling the mean value of the distribution of weights for a given height and the mean value of the distribution of heights for a given weight**. |

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Scatter diagrams | b1 | Understand what bivariate data are and know the conventions for choice of axis for variables in a scatter diagram. | In the random on non-random case the independent variable is often one which the experimenter controls; the dependent variable is the one which is measured. The independent variable is usually plotted on the horizontal axis.In the random on random case (where both variables are measured), it may be that one is more naturally seen as a function of the other; this determines which variable is plotted on which axis. |  |  |
| b2 | Be able to use and interpret a scatter diagram. | To look for outliers (by eye). To gain insight into the situation, for example to decide whether a test for correlation or association might be appropriate.Learners may be asked to add to a given scatter diagram in order to interpret a new situation. |  |  |
| b3 | Interpret a scatter diagram produced by software. | Including where the software draws a trendline and gives a value for pmcc or (pmcc)².  |  |  |

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Pearson’s product moment correlation coefficient (pmcc) | b4 | Be able to calculate the pmcc from raw data or summary statistics. | The use of a calculator is expected for calculation from raw data. Summary statistics formulae will be given. | Sample value *r.* |  |
|  b5 | Know when it is appropriate to carry out a hypothesis test using Pearson’s product moment correlation coefficient. | The data must be random on random i.e. both variables must be random. There must be a modelling assumption that the data are drawn from a bivariate Normal distribution. This may be recognised on a scatter diagram by an approximately elliptical distribution of points. Learners will not be required to know the formal meaning of bivariate Normality but will be expected to know that where one or both of the distributions is skewed, bimodal, etc., the procedure is likely to be inappropriate.The test is for correlation, a linear relationship, so a scatter diagram is helpful to check that the data cloud does not indicate a non-linear relationship.  |  |  |

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Pearson’s product moment correlation coefficient (pmcc)(cont) | b6 | Be able to carry out hypothesis tests using the pmcc and tables of critical values or the *p*-value from software. | Only ‘H0: No correlation in the population’ will be tested. Both one-sided and two-sided alternative hypotheses will be tested.Learners should state whether there is sufficient evidence or not to reject H0 and then give a non-assertive conclusion in context e.g. ‘There is sufficient evidence to suggest that there is positive correlation between … and …’ | Null hypothesis, alternative hypothesisH0, H1 |  |
| b7 | Use the pmcc as an effect size1. | Sensible informal comments about effect size are expected, either alongside or instead of a hypothesis test.  |  | Any formal rules for judging effect size will be given. |
| 1**Note on effect size for correlation**For a large set of random on random bivariate data a small non-zero value of the pmcc is likely to lead to a rejection of the null hypothesis of no correlation in the population; the test is uninformative. In some contexts it is more important to consider the size of the correlation rather than test whether the population correlation is non-zero. The phrase ‘effect size’ is sometimes used in this context for the value of the pmcc. In social sciences, Cohen’s guideline is often used: small effect size 0.1; medium effect size 0.3, large effect size 0.5. Learners are not expected to know this rule; this or any other formal rule will be given if necessary. Effect sizes for other situations, e.g. for the difference of two means, are beyond the scope of this specification. |

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Spearman’s rank correlation coefficient | b8 | Be able to calculate Spearman's rank correlation coefficient from raw data or summary statistics. | Use of a calculator on the ranked data is expected.  | Sample value . | Tied ranks. |
| b9 | Be able to carry out hypothesis tests using Spearman's rank correlation coefficient and tables of critical values or the output from software. | Hypothesis tests using Spearman’s rank correlation coefficient require no modelling assumptions about the underlying distribution.Only ‘H0: No association in the population’ will be tested.Both one-sided and two-sided alternative hypotheses will be tested.Learners should state whether there is sufficient evidence or not to reject H0 and then give a non-assertive conclusion in context e.g. ‘There is insufficient evidence to suggest that there is an association between … and …’ |  |  |
| Comparison of tests | b10 | Decide whether a test based on *r* or *rs* may be more appropriate, or whether neither is appropriate. | Considerations include the appearance of the scatter diagram, the likely validity of underlying assumptions, whether association or correlation is to be tested for.Spearman’s test is not appropriate if the scatter diagram shows no evidence of a monotonic relationship i.e. one variable tends to increase (or decrease) as the other increases.Understanding that ranking data loses information, which may affect the outcome of a test. |  |  |

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Regression line for a random variable on a non-random variable | b11 | Be able to calculate the equation of the least squares regression line using raw data or summary statistics. | The goodness of fit of a regression line may be judged by looking at the scatter diagram. In this case examination questions will be confined to cases in which a random variable,  and a non-random variable, , are modelled by a relationship in which the ‘true’ value of is a linear function of .Only the use of a calculator is only expected for calculation from raw data. Summary statistics formulae will be given. |  | Derivation of the least squares regression line. |
| b12 | Be able to use the regression line as a model to estimate values and know when it is appropriate to do so.Know the meaning of the term residual and be able to calculate and interpret residuals. | residual = observed value – value from regression lineInformal checking of a model by looking at residuals. | Interpolation extrapolation. |  |
| Regression lines for a random variable on a random variable | b13 | Be able to calculate the equation of the two least squares regression lines,  on  and on *,* using raw data or summary statistics.Be able to use either regression line to estimate the expected value of one variable for a given value of the other and know when it is appropriate to do so. | In the  on  case, the least squares regression line estimates , that is the expected value of  for a given value of .Conversely for the on  case.Only the use of a calculator is only expected for calculation from raw data. |  | Derivation of the least squares regression lines. |
| b14 | Check how well the model fits the data. | Informal checking only of a model by visual inspection of a scatter diagram or consideration of (pmcc) 2. |  | Residuals in this case. |
| b15 | Know the relationship between the two regression lines and when to use one rather than the other.Be able to use the correct regression line to estimate the expected value of one variable for a given value of the other and know when it is appropriate to do so. | Both lines pass through . Choice of line to use depends on which variable is to be estimated. | Interpolation extrapolation. |  |

# Thinking Conceptually

### General approaches

Before students begin A Level work on the bivariate data section it would be beneficial if they had a firm understanding of the basics of scatter diagrams and types of correlation. It would also be helpful if learners understood the types of data that may be correlated, for example, height and weight but not height and favourite TV show. This should be a core component of the initial approach.

It is useful to make links with other subject areas and learners may have experience of using correlation and different tests to make inferences in their other A Level subjects. Some learners may have experience of using linear regression to make inferences in their other classes.

It is important to emphasise that learners are using sample evidence to try to make an inference for the population. They need experience of lots of different examples to ensure that they understand the language needed to make conclusions based on their calculations. Experience of using technology to make the calculations is encouraged and can aid understanding.

Students should understand that the Spearman rank correlation coefficient is the Pearson correlation coefficient calculated for the ranks and should be able to use their calculators to get either correlation coefficient from a small set of data as well as using formulae for larger data sets. It will be helpful for students to verify that the formula  gives the same result as using calculator functions on ranks when there are no tied ranks.

Further maths students would benefit from collecting their own data so that they could use real life examples, in which they have an interest, to make conclusions.

Linear regression is generally used to predict a dependent variable given an independent variable, via a straight line. Learners should understand that in general the independent variable is plotted on the x-axis and the dependent variable is plotted on the y-axis.

Learners should understand that the equation of the line represents the relationship between the dependent and independent variables.

### Common misconceptions

There are a number of misconceptions that learners may hold, or develop, regarding correlation and care should be taken to avoid these becoming ingrained.

One source of confusion for learners may be in the difference between correlation and causation. It is important that learners are clear on the difference. They often confuse an association with causality and believe that evidence of correlation always results from a causal relationship. This should be discussed with examples and counter examples to ensure clarity.

It would be useful to spend some time with examples of correlation where the effect of an outlier can be seen. Learners often misunderstand the effect of an outlier on data sets, particularly when the data set is large. This would highlight misconceptions held and allow for discussion of the effect of outliers.

Learners often assume a Pearson’s value of zero implies there is no relationship between the variables, whereas it actually means there is no linear relationship. It is important to ensure they understand the difference. It is often useful to check to see if a relationship exists by completing a scatter diagram, and learners should be encouraged to complete this step first before they make a general comment on the relationship.

One source of confusion for learners may be the difference between the independent and dependent variable; this needs to be clear as learners should distinguish between the y on x regression line and the x on y regression line.

Learners should have experience of data sets with similar “r” values but different scatter diagrams to understand the influence of outliers.

It is also helpful for students to calculate both Pearson and Spearman correlation coefficients for small sets of data and to think about why one value might be higher than the other. They should also consider whether one might be more appropriate than the other when conducting a hypothesis test.

It would be valuable to spend time with examples of linear regression lines and use them for prediction purposes. This would highlight misconceptions held and allow for discussion of the effect of outliers and the extent of the usefulness of the predictive model (it may not be suitable outside the bounds of the data used to create the model).

Students often stop their work once they have obtained calculated values and this is usually inadequate. Their results should be accessible to a general audience and often need to be given in words which convey the context as clearly as possible. Teachers should also encourage learners to check the reasonableness of their results otherwise errors are often missed. In general, the context should remain at the centre of their learning.

Learners often confuse their calculated answer with the final result and need to refer back to the initial context to give their work meaning. Students should be able to use appropriate calculator functions efficiently and correctly. Teachers should encourage learners to check the reasonableness of their results within the context so that errors are avoided. In general students should be encouraged to pay close attention to the context of the data and keep it central in their work.

### Conceptual links to other areas of the specification

Correlation has links with both variance and hypothesis tests, and the resources section contains some materials which explore these aspects. The calculations in this section also link into linear regression formulae and the ideas involved have some overlap. Other statistical work using averages and the standard deviation link with correlation and bivariate data.

Teachers should ensure that time is spent on longer questions so that learners have the opportunity to extract the data they need and ignore extraneous information. It is strongly suggested that teachers provide as many real life uses of correlation from other topic areas and different real world examples to emphasise the relevance of this area of mathematics.

Linear regression links with correlation studies if there is established evidence of a strong relationship. It is used in the sciences to help describe these relationships and make future predictions. It is related to straight line graphs; ideas of deviations and the concept of using squares to focus on the size of differences rather than their sign.

They should be encouraged to have a clear understanding of the use of calculators and other technology to find the coefficients within linear regression.

The use of the formulae is expected for summary data and it can aid understanding of the concepts for students to see how the formulae relate to raw data, starting from a small number of points in a scatter diagram. The use of technology may help learners to understand the concepts covered without getting confused with the calculations.

It is strongly suggested that teachers provide opportunities to use as many real life examples of linear regression from other topic areas and different real world scenarios to emphasise the relevance of this area of mathematics to learners.

# Thinking Contextually

Learners need to see the relevance of their studies to real life events; they often struggle to understand the concepts in mathematics unless they can see the relevance.

The very nature of correlation and linear regression is contextual as it is based on real data that may be given or collected and many different areas can be used to enhance learners’ understanding. These can be as basic as collecting data within the classroom, for example, height and foot length to much more complex examples comparing GDP to other social statistics for different countries. This can be a very useful way of checking full understanding of the concepts encountered in correlation.

Learners will be more successful if they can see how the concepts can be used outside of the classroom. If scenarios are chosen that are meaningful it will help to maintain their interest and motivation. This will also help learners to focus on the mathematics and lead to independent thinking and greater retention of the skills.

# Resources

| **Title** | **Organisation** | **Description** | **Ref** |
| --- | --- | --- | --- |
| [Correlational study](http://mei.org.uk/IMPS) | MEI | An introduction to hypothesis testing using Pearson’s product moment correlation coefficient in a context related to psychology. | b4, b5, b6, b7 |
| [Hydraulic radius](http://mei.org.uk/IMPS) | MEI | An introduction to hypothesis testing using Spearman’s rank correlation in a geography context.  | b8, b9, b10 |
| [Meaning of Covariance](http://www.statisticshowto.com/covariance/) | Statistics How To | Quick to read in accessible terms. Also deals with the problem of the interpretation of covariance and why the correlation coefficient is preferable. | b4 |
| [Stretch for Correlation Coefficient and Covariance](https://www.youtube.com/watch?v=IujCYxtpszU) | Harvard University | Professor Joe Blitzstein from the Department of Statistics explores covariance and correlation. Provides greater depth and is 50 minutes long. Could be used as a stretch resource or may be useful just for teachers.  | b4 |
| [Derivation of Pearson’s coefficient](http://mathworld.wolfram.com/CorrelationCoefficient.html) | Wolfram Math World | Stretch material to further grasp the maths underlying correlation. | b4 |
| [Chance of That](http://nrich.maths.org/7287) | Nrich | This is an open ended investigation for learners to work with correlation. There is a “getting started” link which may help some learners to move forward. This could be used as a starter or plenary activity to investigate correlation. | b4 |
| [Pearson](http://www.ucl.ac.uk/statistics/department/pearson) | UCL | Starter resource from UCL which gives background on the statistician Karl Pearson. | b4 |
| [PPMC Whole Lesson](https://www.tes.com/teaching-resource/product-moment-correlation-coefficient-pmcc-a-level-statistics-complete-lesson-11163343) | TES / we teach maths | This resource is a complete lesson with a full worked calculation of the correlation coefficient. There are worksheets and a final assessment question. Time is spent understanding the formula as well as key points such as referring back to the original question. | b4 and b5 |
| [Product Moment Correlation Coefficient](https://www.examsolutions.net/tutorials/product-moment-correlation-coefficient-pmcc/?level=A-Level&board=MEI&module=S2&topic=1844) | Exam Solutions | In this video, product moment correlation coefficient is introduced along with notation used. There is a full example of how to calculate the coefficient. This could be used as a flipped learning lesson or as a revision exercise.  | b4 and b5 |
| [Product Moment Correlation Coefficient 2) Coding PMCC Past paper exam question](https://www.youtube.com/watch?v=Lr1Il2xcGws) | UkMathsteacher | An exam question with a nice example of coding the data. This would be useful for learners who may need further examples. | b4 and b5 |
| [Ten Point PMCC](http://www.s253053503.websitehome.co.uk/msv/msv-17.html) | MSV | Find ten points on a scatter diagram that have a PMCC of exactly 0.99. | b4 and b5 |
| [Hypothesis testing with Pearson’s r](http://statisticslectures.com/topics/hypothesispearsonr/) | Statistics Lectures | This is a full lesson (including a video of the lecture, if needed) covering the procedure for hypothesis testing with Pearson’s. There is a full worked example with calculations. This could be used as a revision exercise.  | b4, b5 and b6 |
| [Spearman](https://www.youtube.com/watch?v=-AiUx3ak3rE) | Waterloo University | Short video of 3 minutes about the work of Charles Spearman. Could be used within a starter. | b8 |
| [Statistical Skills example sheet: Spearman’s rank](http://www.moorsforthefuture.org.uk/sites/default/files/documents/Statistical%20Skills%20example%20sheet%20Spearmans%20Rank.pdf) | Moor Life Learning | A worksheet giving an example of Spearman’s rank. This is a Biology example, but is useful for learners to see the cross over between subject areas. There is then opportunity to complete an example calculating Spearman’s rank and the hypothesis test.  | b8 and b9 |
| [Ocean Acidification; Spearman’s Rank](https://www.rgs.org/NR/rdonlyres/B548073B-18DD-426F-B28A-366255201D63/0/OASpearmansRankexamplePDF.pdf) | Royal Geographical Society | A nice example of hypothesis testing using Spearman’s rank in a geographical context. This is a full worked example that allows learners to see the relevance of this test in different contexts. | b8 and b9 |
| [Spearman’s Rank Correlation](https://www.tes.com/teaching-resource/spearman-s-rank-correlation-6368164) | Criggelations | A basic introduction to Spearman’s rank and how to calculate it. It also shows an example and link to Pearson’s. PowerPoint. | b8, b9 and b10 |
| [A comparison of the Pearson and Spearman’s correlation methods](http://support.minitab.com/en-us/minitab-express/1/help-and-how-to/modeling-statistics/regression/supporting-topics/basics/a-comparison-of-the-pearson-and-spearman-correlation-methods/)  | Minitab Express Support | This gives an overview of the differences between the two coefficients with graphs to demonstrate these. | b10 |
| [Pearson Vs Spearman](http://www.johnmyleswhite.com/notebook/2009/02/17/pearson-vs-spearman-correlation-coefficients/) | John Myles WhiteFacebook, MIT, Princeton | A blog explaining the difference between the two coefficients and their uses. This could be used as a start point for further discussion.  | b10 |
| [Independent and dependent variables](https://www.youtube.com/watch?v=HjVoml2EJwM) | Mrmathblog | This resource shows examples of dependent and independent variables in different contexts and explains why they are named in this way. This would be a useful starter exercise.  | b11 |
| Independent and dependent variables | Sciencebuddies | General illustrations of independent and dependent variables. | b11 |
| [Independent and Dependent Variables](http://digitalcommons.pace.edu/cgi/viewcontent.cgi?article=1003&context=middle_math) | Pace University | Could be a helpful resource for project work. Lots of examples of independent and dependent variables. | b11 |
| [Independent and dependent variables in an example](http://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_correlation-regression/bs704_correlation-regression_print.html) | Boston University School of Public Health | Scroll down to ‘Simple Linear Regression’ to find a clear, helpful and real life example to illustrate independent and dependent variables. | b11 |
| [Interpolation, Extrapolation & Predictions](https://www.youtube.com/watch?v=IwAHeJY-INc) | Maths Resource | 5 minute video which discusses limitations of predictions. Good plenary. | b11, b12, b13, b14 and b15 |
| [Linear Regression](https://education.ti.com/en/activity/detail?id=4AD06F1E88154F1BB70462773C56F3EB)  | Texas Instruments | Learners generate scatter plot from a set of data. They then use an existing set of data to generate a scatter plot and then use the data analysis to find the linear regression equation and the r value. This is a lesson based on using the graphical calculator to perform these calculations. Full notes are provided for teachers and students. | b11, b12, b13, b14 and b15 |
| [Activities for linear regression](http://courses.ncssm.edu/math/Stat_inst01/PDFS/helilinear.pdf) | North Carolina School of Science and Mathematics (NCSSM) | This is a full selection of activities where learners design an experiment, collect data and fit a linear regression model. A useful exercise which allows learners to collect and interpret real data. | b11, b12, b13, b14 and b15 |
| [Regression line illustrated within examples](https://newonlinecourses.science.psu.edu/stat200/lesson/12/12.3) | Penn State University | Good summary of the regression line with accurate diagrams which correctly illustrate the regression line falling within the boundaries of the original data. | b11, b12, b13, b14 and b15 |
| [Interpreting the regression line constants, explanatory and response variables](https://www.examsolutions.net/tutorials/interpreting-regression-line-constants-explanatory-response-variables/?level=Statistics&board&module=statistics&topic=1846) | Exam Solutions | In this video, examples of how to interpret the values of a and b in the regression line in the context of the problem. The dependent and independent variables are also covered. This could be used as a flipped learning lesson or as a revision exercise. | b11, b12, b13, b14 and b15 |
| [Automobile year vs Mile age](http://illuminations.nctm.org/Lesson.aspx?id=1476) | National Council for Teachers of Mathematics (NCTM) | Learners plot data and find the regression line. They can then interpret the line and use it for predictive purposes. This resource has some useful probing questions attached to aid learners’ thinking. | b11, b12, b13, b14 and b15 |
| [Probability & Statistics Modular Learning Exercises](https://www.actuarialfoundation.org/portfolio/probability-statistics-modular-learning-exercises/) | The actuarial Foundation | Learners take on the role of an actuary as they help an insurance company estimate the risk of storm activity and calculate potentially costly damages. There are 4 modules covering aspects of Maths and Further Maths. Module 4 focuses specifically on correlation and regression and this begins on page 27. The tasks use both graphical calculators and Microsoft Excel.  | b11, b12, b13, b14 and b15 |
| [Regression](https://www.examsolutions.net/tutorials/regression/?level=Statistics&module=statistics&topic=1846) | Exam Solutions | In this video, linear regression is introduced along with notation used. There is a full example of how to calculate the regression line of y on x.This could be used as a flipped learning lesson or as a revision exercise. | b11, b12, b13, b14 and b15 |
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| [Predictions](http://www.statisticshowto.com/probability-and-statistics/regression-analysis/) | Statistics How To | General notes and examples about using the regression line for predictions. | b11, b12, b13, b14 and b15 |
| [Lecture on Predictions](https://www.youtube.com/watch?v=vwIXNPC5J58) | Carnegie Mellon University | Video lecture with good example, look from 15 minutes into the lecture until 25 minutes. Could be a plenary clip to round off a class where students have been finding regression lines. | b11, b12, b13, b14 and b15 |

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