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Examiners' report

FURTHER MATHEMATICS B (MEI)

H645

For first teaching in 2017

Y432/01 Summer 2023 series

Version 1

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers is also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

Paper Y432/01 series overview

This is the Statistics Minor option component of the MEI Further Mathematics course.

This component was accessible to most candidates who typically attempted to answer all questions.

Questions involving calculations (Questions 1, 3 (b), 4 (a), 4 (b), 5 (a), 5 (b), 6 (b)) were usually done well. These accounted for just over one third of the marks in the component.

For the two questions involving hypothesis tests (Questions 4 (c), 6 (c)) candidates demonstrated a good understanding of the required structure. Hypotheses were stated, critical values were found, and comparisons made with test statistics. Conclusions were then usually suitably non-assertive. More successful responses ensured that the conclusion referred to the context of the question. To improve further, candidates should make sure that the null hypothesis is chosen correctly and includes just the right amount of detail. They should also take care to know how to identify the correct critical value, in particular when identifying the number of degrees of freedom in chi-squared test.

While candidates did not perform so well on 'explain' and 'comment' questions (Questions 2, 4 (d), 5 (c), 5 (d), 6 (a)) there was evidence that these skills had improved on previous years. Centres should continue to make sure that sufficient attention is given to these questions when preparing candidates. Words such as 'random', 'unbiased' and 'independent' are not interchangeable and candidates need to be aware of which is appropriate under different scenarios.

Candidates need to recognise the difference between a sum of independent random variables and a multiple of a single random variable (Questions 3 (c), 7 (b)), in particular on how this affects the variance.

Candidates should be encouraged to write neatly. A number of responses to the 'explain' and 'comment' questions were challenging to read.

Useful information regarding sampling, bivariate data and modelling assumptions can be found in the specification for this component.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• made appropriate and accurate use of statistical and probability functions on their calculator • used subject specific terminology correctly • showed good understanding of limitations and assumptions associated with various statistical processes • carried out tests accurately stating correct hypotheses, identifying correct critical values, and drawing non-assertive conclusions that were stated in context.	• carried out standard calculations correctly though may not have maintained sufficient accuracy in their working • found it difficult to identify the key points in 'explain' and 'comment' questions • did not show sufficient working in 'show that', 'determine' and 'detailed reasoning' questions.

OCR support

A review of the command words used in questions, and the expected level of written response, is outlined in section 2b of the specification. A useful classroom poster, and student version, is available on Teach Cambridge.

Question 1 (a)

1 A fair spinner has ten sectors, labelled 1, 2, …, 10. In order to start a game, Kofi has to obtain an 8, 9 or 10 on the spinner.

(a) Find the probability that Kofi starts the game on the third spin. **[2]**

This question was answered correctly by the great majority of candidates.

Question 1 (b)

(b) Find the probability that Kofi takes at least 5 spins to start the game. **[1]**

This question was answered correctly by most candidates.

Unsuccessful responses typically demonstrated one of two misconceptions as outlined below.

Misconception

First misconception: $p(X \geq 5) = 0.7^5$ overlooking the distinction between an inclusive and exclusive inequality.

Second misconception: $p(X \geq 5) = 1 - 0.7^4$ leading to the complement of the required value.

Assessment for learning

It may be helpful for less confident candidates to develop the habit of using a 'number line' diagram when finding probabilities including inequalities with discrete distributions.

For example, in this question:

1 2 3 4 | 5 6 …

the line between the 4 and 5 helps to clarify that what is required here is a run of four 'failures'. This can guide candidates towards the correct power (first misconception) and realise that there is no need to subtract from 1 (second misconception).

Question 1 (c)

(c) Determine the probability that the number of spins required to start the game is within 1 standard deviation of its mean. **[5]**

In successful responses, candidates took note of the 'determine' command word, setting out the steps in their working clearly. They showed their calculations for the mean and standard deviation, then clearly showed the upper and lower bound, taking care to convert to integer values, giving them either as a list, or appropriate inequalities.

As with part (b) above, some candidates did not obtain the final answer due to misunderstanding how to work with their correct integer inequality to obtain the required probability. There were also a number of responses where candidates did not convert their bounds to integer values before calculating the probability.

A more common misunderstanding is illustrated in Exemplar 1 below.

Exemplar 1

Uniform $\{1, 2, \ldots 10\}$

$E(x) = \frac{10+1}{2} = 5 \cdot 5$

$Var(x) = \frac{1}{12}(10^2 - 1) = \frac{99}{12} = 8 \cdot 25$

$\therefore \; sd(x) = 2 \cdot 87 \ldots$

Geo $(0 \cdot 3)$

$P(5 \cdot 5 - 2 \cdot 87 < x < 5 \cdot 5 + 2 \cdot 87)$

$P(2 \cdot 63 < x < 8 \cdot 37)$

~~[illegible]~~

$P(x \leq 8) - P(x \leq 2) = 0 \cdot 4324$

Here the candidate has mistakenly used a uniform distribution to find the mean and standard deviation of the values on the spinner, rather than the number of spins required to start the game. While they were unable to be given the first 3 marks, they have then used their bounds to correctly identify the associated integer range and probability using the geometric distribution. This demonstrates the value of setting all stages of working out clearly as they were credited with the final 2 marks, benefitting from the follow through available.

Question 2 (a) (i)

2 A company manufactures batches of twenty thousand tins which are subsequently filled with fruit. The company tests tins from each batch to make sure that they are strong enough. The test is easy and cheap to carry out, but when a tin has been tested it is no longer suitable for filling with fruit.

(a) **(i)** Explain why a sample size of 5 tins per batch may not be appropriate in this case. **[1]**

Note that the question does not say how the sample was collected. It may, or may not, have been a random sample.

Responses that claimed inferences could not be made from the sample were not credited. It would be possible to draw inferences, but only with a high degree of uncertainty.

This lack of confidence in any conclusions that could be drawn was the key feature that responses needed to highlight. The most common successful response was when candidates explained that such a small sample would be unlikely to be representative of the population.

Question 2 (a) (ii)

(ii) Explain why a sample size of 1000 tins per batch may not be appropriate in this case. **[1]**

This was successfully answered by many candidates. The key point to note was the destructive nature of the test.

Comments that focused on the test would be time consuming or costly overlooked the information that it is both 'easy and cheap to carry out'. Comments that focused on fruit being wasted also overlooked the information in the initial paragraph.

Question 2 (b)

The company tests a sample of 30 tins from each batch.

(b) Explain why it would **not** be sensible for the sample to consist of the final 30 tins produced in a batch. **[1]**

Responses that simply stated this is not a random sample were not credited unless they went on to explain that inferences about the whole batch (population) could not then be drawn.

Responses that simply stated the sample would not be representative of the population were not credited unless they went on to explain why this might be. Successful responses noted that the quality of production of the tins could vary over time.

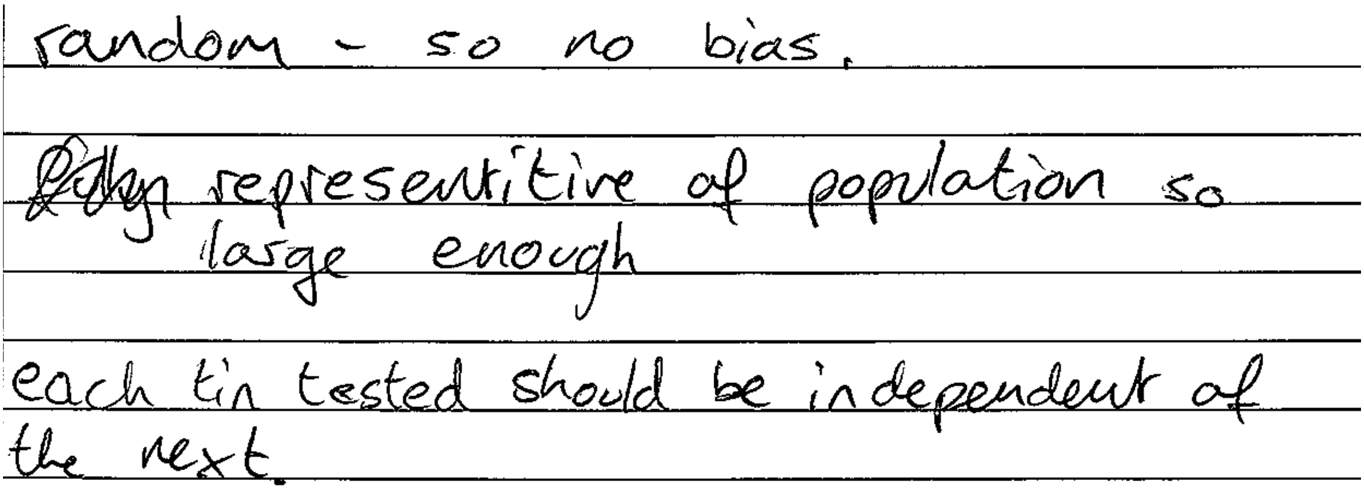
Question 2 (c)

(c) Give two features that the sample should have. **[2]**

Some candidates focused their response on describing a sampling method (often systematic) rather than the features that the sample should have. This alone was not credited unless the points in the mark scheme were also covered.

In seeking to describe two features some candidates referred to randomness and also each member of the population having the same chance of being selected. These were not credited as two distinct points.

Exemplar 2


random - so no bias.

representitive of population so large enough

each tin tested should be independent of the next.

This response was given both marks. It also highlights some misconceptions about the meaning of certain words.

The marks were given for saying that the sample should be random and also representative of the population.

Misconceptions

First misconception: 'random' does not imply 'unbiased'. These are two separate features that are desirable, but it is possible for a sample to be one without being the other.

Second misconception: while it is true that a very small sample is unlikely to be representative of the population – see (a) (i), it does not follow that a larger sample will necessarily be representative – see (b).

Third misconception: independence is not a feature of the sample. It is the trials that may or may not be independent; in this context this would mean the production of each tin being independent of the production of the other tins. A questionable assumption – see (b).

Question 3 (a)

3 A fair four-sided dice has its faces numbered 0, 1, 2, 3. The dice is rolled three times. The discrete random variable X is the sum of the lowest and highest scores obtained.

(a) Show that $\mathrm{P}(X=1)=\frac{3}{32}$. **[3]**

Being a 'show that' question it was important for candidates to give sufficient detail at every stage in their response.

A common approach was to initially identify that there would be 64 possible outcomes, perhaps by stating that the probability of each was $\frac{1}{64}$. Candidates then knew that they would need 6 of these to produce the required $\frac{3}{32}$ but were often not able to justify where those 6 alternatives came from, so could only be credited with 1 of the 3 marks available.

In more successful responses, candidates identified both cases (two 0s and a 1, one 0 and two 1s) leading to $X = 1$.

Question 3 (b)

The table below shows the probability distribution of X.

r	0	1	2	3	4	5	6
$\mathrm{P}(X=r)$	$\frac{1}{64}$	$\frac{3}{32}$	$\frac{13}{64}$	$\frac{3}{8}$	$\frac{13}{64}$	$\frac{3}{32}$	$\frac{1}{64}$

(b) In this question you must show detailed reasoning.

Find each of the following.

- $\mathrm{E}(X)$
- $\mathrm{Var}(X)$ **[4]**

This question requires a detailed and complete method to be shown and so it was possible not to score full marks even if the correct values for the mean and variance were found.

When finding E(X), almost all candidates showed the sum of terms. In a few of the most successful responses, candidates viewed the table as a whole and realised that the symmetry of the distribution allowed them to state the result directly.

Most candidates were successful in showing a sufficient level of detail when finding Var(X). In less successful responses, candidates tended only to quote the value of $\mathrm{E}(X^2)$ without showing any of the terms in the summation. A few candidates mistook $\mathrm{E}(X^2)$ for Var(X).

Question 3 (c) (i)

(c) The random variable Y represents the sum of 10 values of X.

(i) State a property of the 10 values of X that would make it possible to deduce the standard deviation of Y. **[1]**

A good proportion of candidates correctly identified independence as the required property.

Some of the more common incorrect responses were that the values needed to be random, or discrete. These responses both overlooked the fact that the start of question 3 tells us that X is a discrete random variable.

Question 3 (c) (ii)

(ii) Given that this property holds, determine the standard deviation of Y. **[2]**

The most common error in unsuccessful responses to this question was to consider Y to be a single value of X multiplied by 10 rather than the sum of ten distinct values.

This led to the incorrect statement $\text{Var}(Y) = 10^2 \times \text{Var}(X)$.

In some more successful responses, candidates correctly found $\text{Var}(Y)$ but then stopped.

Assessment for learning

Centres can help candidates avoid this common error by encouraging them to use a different notation for sums of random variables and multiples of a single random variable.

For example,

$\text{Var}(aX)$ exclusively for a single value multiplied by a, giving $a^2\text{Var}(X)$

$\text{Var}(X_1+X_2+\ldots+X_a)$ for a sum of a independent values, giving $a\text{Var}(X)$

Question 4 (a)

4 Eve lives in a narrow lane in the country. She wonders whether the number of vehicles passing her house per minute can be modelled by a Poisson distribution with mean μ. She counts the number of vehicles passing her house over 100 randomly selected one-minute intervals. The results are shown in **Table 4.1**.

Table 4.1

Number of vehicles	0	1	2	3	4	5	6	7	8	9	10	$\geqslant 11$
Frequency	36	33	14	10	4	1	0	0	1	0	1	0

(a) Use the results to find an estimate for μ. **[1]**

The great majority of candidates were able to correctly find the mean of the sample and were given the mark. It was, however, common to the see incorrect statement $\mu = 1.3$.

Misconception

?

The mean of the sample is being used to estimate the mean of the population (which we do not know).

A correct statement would be $\bar{x}=1.3$.

OCR support

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See the appendix 5c on page 139 of the course specification for standard notation.

Question 4 (b)

The spreadsheet in **Fig. 4.2** shows data for a χ^2 test to assess the goodness of fit of a Poisson model. The sample mean from part **(a)** has been used as an estimate for the population mean. Some of the values in the spreadsheet have been deliberately omitted.

Fig. 4.2

	A	B	C	D	E
1	Number of vehicles	Observed frequency	Poisson probability	Expected frequency	Chi-squared contribution
2	0	36	0.2725	27.2532	2.8073
3	1	33	0.3543	35.4291	
4	2	14			3.5400
5	⩾3	17			0.5145
6					

(b) Calculate the missing values in each of the following cells, giving your answers correct to **4** decimal places.

- C4
- D5
- E3 **[4]**

This question was generally well answered. There was good evidence that candidates are able to efficiently use the probability distribution functions on their calculators.

Where full marks were not obtained it was usually because of a lack of attention to the accuracy required. Both the question itself, and the preceding table make it clear that 4 decimal places are required.

One specific error that was seen from time to time was in the calculation of cell D5. Candidates sometimes found the probability (cell C5), writing it as 0.1429, before multiplying by 100 and giving their response for D5 as either 14.29 or 14.2900.

Question 4 (c)

(c) In this question you must show detailed reasoning.

Carry out the χ^2 test at the 5% significance level. **[6]**

Typically, candidates demonstrated a good understanding of the structure required for the hypothesis test. Taking each stage in turn:

- Hypotheses were sometimes stated the wrong way round. There were also responses that incorrectly included the mean value, 1.3; this value has been estimated from the data.
- Most candidates correctly gave the test statistic as 7.0283.
- For the degrees of freedom many candidates correctly identified this as 2. Sometimes this was given incorrectly as 3 leading to an incorrect critical value, usually due to not realising that the reliance on the data to generate a value for the mean added a restriction.
- Candidates generally compared their test statistic and critical value leading to a suitably non-assertive conclusion. Less successful responses often only made a generic statement whereas more successful candidates ensured the conclusion referred to the context of the number of vehicles passing Eve's house. It was not uncommon to see 'vehicles' replaced with 'cars' but this was not penalised.

Question 4 (d)

(d) Eve checks her data and notices that the two largest numbers of vehicles per minute (8 and 10) occurred when some horses were being ridden along the lane, causing delays to the vehicles. She therefore repeats the analysis, missing out these two items of data. She finds that the value of the χ^2 test statistic is now 4.748. The number of degrees of freedom of the test is unchanged.

Make **two** comments about this revised test. **[2]**

The 2 marks for this question are for two distinct comments.

1 mark is for noting the effect of Eve's new analysis on the conclusion. If a candidate had come to the correct conclusion in part (c) they would now note a change. Those working with 3 degrees of freedom in (c) would not have rejected the null hypothesis previously and could still be credited in (d) for noting there was no change.

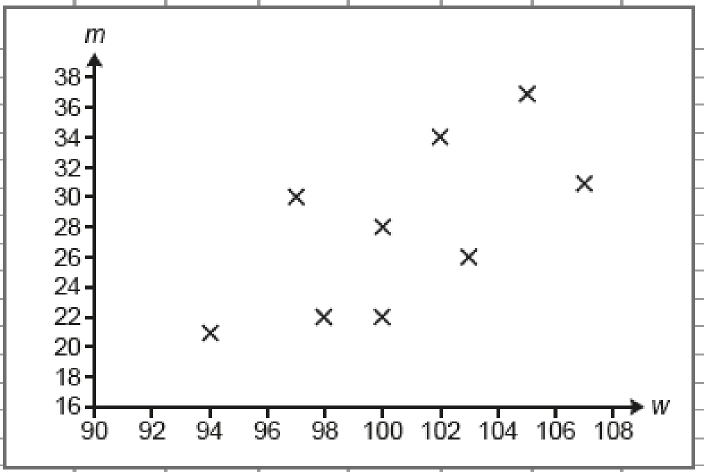
The other mark is for commenting on whether or not Eve was justified in her decision to remove the two items of data. Comments that focused solely on these being outliers were not given the mark. Successful candidates referred to the circumstances under which those items had been recorded and concluded that it was appropriate to remove them. The most convincing responses also made reference to the conditions required for a Poisson distribution (independence and a constant average rate).

Some candidates made comments about the calculations that would be required for this new test. These were not credited.

Question 5 (a)

5 An ornithologist is investigating the link between the wing length and the mass of small birds, in order to try to predict the mass from the wing length without having to weigh birds. The ornithologist takes a random sample of 9 birds and measures their wing lengths w mm and their masses m g. The spreadsheet below shows the data, together with a scatter diagram which illustrates the data.

	A	B
1	Wing length w mm	Mass m g
2	100	28
3	98	22
4	107	31
5	100	22
6	97	30
7	103	26
8	105	37
9	102	34
10	94	21



(a) Find the equation of the regression line of m on w, giving the coefficients correct to 3 significant figures. **[2]**

This question was correctly answered by most candidates. Since the individual data points are provided it was sufficient to directly write down the equation having made use of the relevant statistical function on a calculator. Some candidates were only given 1 of the 2 marks because they did not observe the requirement for 3 significant figures, or because they used y and x rather than m and w.

Less successful responses saw candidates attempt to calculate the coefficients themselves, possibly because the equivalent question in 2022 had only provided summary statistics and so this had been necessary.

Assessment for learning

Centres can help candidates by making sure they practise examples that require both kinds of approach and encouraging them to use appropriate calculator technology whenever possible.

Question 5 (b)

(b) Use the equation which you found in part **(a)** to estimate the mass for each of the following wing lengths.

- 99 mm
- 110 mm **[2]**

Responses to this question showed a marked improvement on an equivalent question in 2022. Using their equation from (a) successful candidates understood the need to give their estimates to a degree of accuracy appropriate to the context.

Less successful responses gave values to greater than 1 decimal place and were only credited with 1 of the 2 marks.

Question 5 (c)

(c) Comment on the reliability of your estimates. **[2]**

In less successful responses, candidates used 'accurate' for 'reliable' in this question and were not given any marks.

Most candidates showed understanding of interpolation and extrapolation in relation to the reliability of estimates. More successful responses saw candidates then consider the scatter of the points as an indication of only moderate linear correlation and so tempered their conclusion about the reliability of the estimate for the mass of a bird with wing length 99 mm.

Question 5 (d)

(d) The equation of the regression line of w on m is $w = 0.473m + 87.5$. A friend of the ornithologist suggests that this equation could also be used to estimate the masses of birds from their wing lengths.

Comment on this suggestion. **[2]**

Some candidates claimed that it would be appropriate to use this equation as this is an example of 'random on random' bivariate data. They were not given any marks.

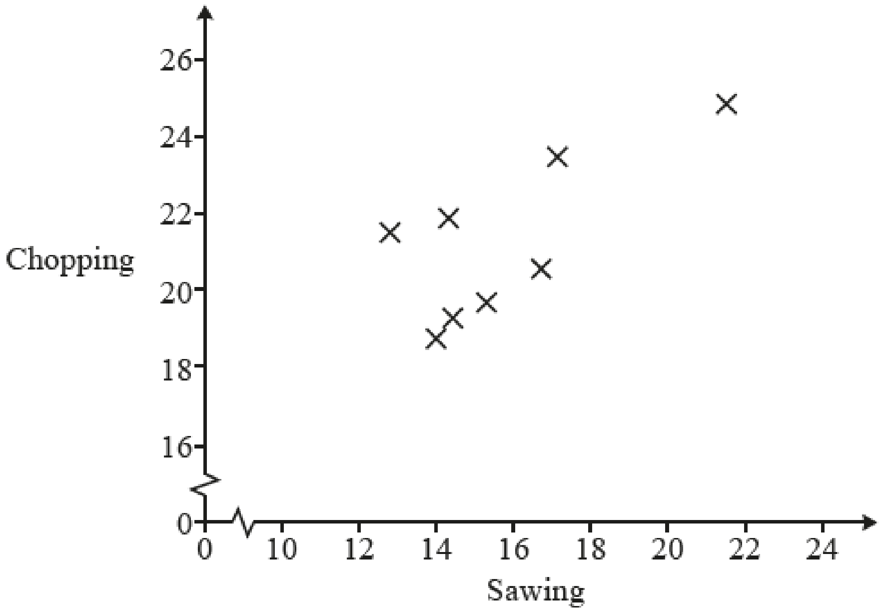
Others based their argument on the fact that rearranging this equation would give a less accurate estimate. This alone was not credited.

In successful responses, candidates realised that this suggestion is not appropriate because the two regression lines serve different purposes and are not interchangeable. There were some impressive responses that showed thorough understanding of how the calculations for the two lines are based on different residuals.

Question 6 (a)

6 Each competitor in a lumberjacking competition has to perform various disciplines for which they are timed. A spectator thinks that the times for two of the disciplines, chopping wood and sawing wood, are related. The table and the scatter diagram below show the times of a random sample of 8 competitors in these two disciplines.

Competitor	A	B	C	D	E	F	G	H
Sawing	17.1	16.7	14.3	14.0	12.8	21.5	15.3	14.4
Chopping	23.5	20.6	21.9	18.8	21.5	24.8	19.7	19.3



(a) The spectator decides to carry out a hypothesis test to investigate whether there is any relationship.

Explain why the spectator decides that a test based on Pearson's product moment correlation coefficient may **not** be valid. **[2]**

Responses to this question showed increasing understanding compared with equivalent questions in previous years.

While there were still some references to an 'oval' spread of points, which was not credited, most candidates used the correct terminology of 'ellipse', or 'elliptical'. It was also pleasing to note that responses referring to a 'normal bivariate' rather than 'bivariate normal' distribution are now rare.

Some candidates, rather than referring to the scatter of points, made a comment along the lines of 'an ellipse cannot be drawn around the points'. Such comments are to be discouraged.

Less successful responses stated that the data itself has a bivariate normal distribution. More successful responses showed understanding that the scatter diagram gave an indication that the underlying population may not have a bivariate normal distribution.

Question 6 (b)

(b) Determine the value of Spearman's rank correlation coefficient. **[3]**

This question was answered correctly by most candidates. Ranking was carried out correctly and consistently for the two variables.

Because the question has 'determine' as the command word, some level of detail in working was expected.

Question 6 (c)

(c) Carry out a hypothesis test at the 5% significance level to investigate whether there is positive association between sawing and chopping times. **[5]**

As with Question 4 (c), candidates demonstrated a good understanding of the structure required for the hypothesis test. Taking each stage in turn:

- Hypotheses were sometimes stated the wrong way round. There were more candidates correctly referring to the population in the hypotheses than in previous years. Less successful responses referred to correlation rather than association. Some omitted 'positive' when stating their alternative hypothesis. Others incorrectly stated 'there is no positive association' in their null hypothesis. There were also a number of candidates stating their hypotheses in terms of a letter (see Assessment for learning item below).
- The correct critical value was identified by most candidates. The most common error was use of the two-tailed value (0.7381), usually due to the omission of 'positive' from their alternative hypothesis. Some candidates wrongly used the table for the product moment correlation coefficient.
- The comparison of test statistic and critical value was usually done well.
- Conclusions usually mentioned the context. While some were too assertive, and some incorrectly referred to correlation rather than association, generally this was done well.

Assessment for learning

Candidates should be discouraged from stating hypotheses for tests of association using letters.

Use of r or r_s is incorrect as these refer to sample statistics.

Use of ρ is incorrect as this is defined as the product moment correlation coefficient for a population.

Use of ρ_s is to be discouraged as it has no recognised definition in this course.

Centres can help candidates by instructing them to write the hypotheses as full sentences referring to association.

Question 7 (a)

7 The discrete random variable X has a uniform distribution over the set of all integers between 100 and n inclusive, where n is a positive integer with $n > 100$.

(a) Given that n is even, determine $\mathrm{P}\left(X < \frac{100+n}{2}\right)$. **[3]**

Many candidates understood that they needed to find the total number of possible outcomes and also the total number of outcomes satisfying the inequality.

For the total number of outcomes, a common error was to conclude that there were $n - 100$ rather than $n - 99$. This may have been due to a misunderstanding of the word 'inclusive', or candidates misinterpreting the $n > 100$ statement.

In more successful responses, candidates were able to correctly identify that there would be $\frac{1}{2}(n - 100)$ outcomes satisfying the inequality.

Some candidates, unsure about how to generalise, pragmatically used an investigative approach. Choosing values of n they were able to generate several numerical probabilities and then make a correct conjecture as to the general expression. Such responses were given full marks.

Question 7 (b)

(b) Determine the variance of the sum of 50 independent values of X, giving your answer in the form $a(n^2 + bn + c)$, where a, b and c are constants. **[3]**

Most candidates recognised the need to use the formula for the variance of a discrete uniform distribution provided in the formula booklet. In less successful responses, candidates were unsure how to adapt the formula for the number of terms.

in more successful responses, candidates replaced n with $(n - 99)$.

In the most successful responses, candidates then recognised that dealing with a sum of 50 independent values required multiplication by 50 rather than 50^2.

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