AP® STATISTICS
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Question 1

Intent of Question

The primary goals of this question are to assess a student's ability to (1) identify which one of two histograms is more likely to represent the data from a particular situation; (2) describe the distribution of a quantitative variable based on a histogram that would result from combining two separate histograms; and (3) describe a sampling distribution of the mean when provided with a population mean, population standard deviation, sample size and shape of the population.

Solution

Part (a):

Histogram II is more likely to represent the Group R completion times. As noted, students in Group S typically took less time to complete the task, and although the two histograms show the same range, the values in Histogram I are generally smaller than those in Histogram II. So Histogram I is likely to represent students in Group S and Histogram II is likely to represent students in Group R.

Part (b):

If the two histograms were to be combined, the distribution of completion times would be bimodal. All values would be in the interval from 35 to 115. There would be more completion times in the intervals from 35 to 55 and 95 to 115 than in the middle interval of 65 to 85.

Part (c):

The sampling distribution of the sample mean will be approximately normal with mean $\mu_{\bar{x}} = 70$ minutes and standard deviation $\sigma_{\bar{x}} = \frac{26.5}{\sqrt{50}} = 3.75$ minutes. Although the original distribution of completion times is bimodal, the Central Limit theorem applies in this situation because the sample size of 50 is fairly large, especially because there are no major outliers or skewness. Therefore, the sampling distribution is approximately normal.

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Question 1 (continued)

Scoring

Parts (a), (b) and (c) are each scored as essentially correct (E), partially correct (P), or incorrect (I).

Part (a) is scored as follows:

Essentially correct (E) if the response correctly provides the following three components:

1. States that Histogram II is more likely to be Group R.
2. Refers to the fact that Group R should have longer completion times (or Group S should have shorter completion times).
3. Justifies the choice based on a comparison of the locations of the peaks or of the ranges in Histograms I and II.

Partially correct (P) if the response provides component 1 and one of the other two components required for E.

Incorrect if the response does not meet the criteria for E or P.

Note: Labeling Histogram II as being "Group R" is sufficient to satisfy the requirement of stating that Histogram II is more likely to be Group R.

Part (b) is scored as follows:

Essentially correct (E) if the response states that the shape would be bimodal AND provides a reasonable description of the distinct nature of the peaks. Examples of reasonable descriptions include drawing a picture showing the approximate heights of the bars in each interval, or noting that the distribution will have a distinct peak on each side.

Partially correct (P) if the response simply states that the shape is bimodal, without sufficient explanation;
OR
if the response provides a description or drawing illustrating the bimodal shape, but never uses the term "bimodal."

Incorrect (I) if the response does not meet the criteria for E or P.

Note: The question asks about the shape of the histogram, so any computations or reference to center and spread can be ignored, whether they are correct or incorrect.

Question 1 (continued)

Part (c) is scored as follows:

Essentially correct (E) if the response correctly provides the following four components:

1. States that the mean of the sampling distribution is 70 minutes.
2. Correctly calculates the standard deviation of the sampling distribution as 3.75 minutes, with enough work shown to know how the value was calculated.
3. States that the shape is *approximately* normal.
4. Justifies the shape by noting that the sample size of 50 is large.

Partially correct (P) if the response correctly provides only two or three of the four components required for E.

Incorrect (I) if the student provides at most one of the components required for E.

Notes

- Describing the sampling distribution as *normal* instead of *approximately* normal does not satisfy component 3.
- Component 2 is satisfied if the formula $\frac{26.5}{\sqrt{50}}$ is shown but the computation showing 3.75 as the answer is not performed.
- Context ("minutes") is not required to satisfy components 1 and 2.

Question 1 (continued)

4 Complete Response

Three parts essentially correct

3 Substantial Response

Two parts essentially correct and one part partially correct

2 Developing Response

Two parts essentially correct and no parts partially correct

OR

One part essentially correct and one or two parts partially correct

OR

Three parts partially correct

1 Minimal Response

One part essentially correct

OR

No parts essentially correct and two parts partially correct

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Question 2

Intent of Question

The primary goals of this question are to assess a student's ability to (1) explain why blocking is used in an experiment; (2) explain why random assignment of treatments is used in an experiment; and (3) explain how and why replication is used in an experiment.

Solution

Part (a):

Blocking is used to account for a known source of variation in the response to allow for a more precise comparison of the treatments. In this situation the response variable is running speed. Professional runners are likely to have higher running speeds than recreational runners, so the variability in speed across runners should be smaller within each classification group than it is for all runners combined. Having smaller variability in responses makes it easier to detect a difference between the two shoe types, if it exists.

Part (b):

Randomization is used to reduce or eliminate the effect of confounding variables that might be related to the explanatory variable (shoe type, in this case) and might also be associated with differences in the response (running speed, in this case). If runners were allowed to choose which shoe to wear, it's possible that the runners who choose type A might differ in other ways from the runners who choose type B, and that those differences might be related to running speed.

Part (c):

The design addresses replication by assigning multiple runners in each classification to wear each shoe type. Replication is important in order to estimate the natural variability in running speeds within each type of runner and shoe type. The estimate of natural variability is needed so that the mean running speeds for the two types of shoes can be compared. Without an estimate of natural variability there is no way to know if the difference in mean running times for the two shoe types within each runner classification is larger than would be expected by chance.

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Question 2 (continued)

Scoring

Parts (a), (b) and (c) are each scored as essentially correct (E), partially correct (P), or incorrect (I).

Part (a) is scored as follows:

Essentially correct (E) if the response includes both of the following components:

1. A reasonable description that blocking on classification of runner accounts for a known source of variation in times, in context, and
2. A reasonable explanation of the fact that blocking on a known source of variability in the response allows for a more precise comparison of treatment groups.

Partially correct (P) if the response includes one but not both of the components required for an E.

Incorrect (I) if the response does not meet the criteria for E or P.

Part (b) is scored as follows:

Essentially correct (E) if the response includes the following two components.

1. A reasonable explanation of the fact that randomizing treatments is used to reduce or eliminate the possibility of confounding variables, and
2. A reasonable explanation of how self-selection to treatments could introduce a confounding variable, in context, by name or by example.

Partially correct (P) if the response includes one but not both of the components required for E.

Incorrect (I) if the response does not meet the criteria for E or P.

Notes:

- A response cannot earn an E if it explicitly describes random sampling.
- An explanation that randomizing treatments is necessary for a cause and effect conclusion earns credit for component (1).

Question 2 (continued)

Part (c) is scored as follows:

Essentially correct (E) if the response includes the following two components.

1. An explanation of how replication is addressed in the design that includes the fact that multiple runners are used.
2. Recognition that a benefit of replication is to obtain an estimate of variability in the response.

Partially correct (P) if the response includes one but not both of the components required for E.

Incorrect (I) if the response does not meet the criteria for E or P.

Notes:

- An explanation that a benefit of replication is to enable a statistical comparison of treatments earns credit for component (2).
- An explanation that larger sample sizes increase the precision of comparisons earns credit for component (2).
- If the response does not earn credit for component (1), an explanation of a statistical benefit of replication which is tied to component (1) (e.g., the benefit of repeated measurement on the same individual, or the benefit of using both professional and recreational runners) can earn credit for component (2).

Question 2 (continued)

4 Complete Response

Three parts essentially correct

3 Substantial Response

Two parts essentially correct and one part partially correct

2 Developing Response

Two parts essentially correct and no parts partially correct

OR

One part essentially correct and one or two parts partially correct

OR

Three parts partially correct

1 Minimal Response

One part essentially correct

OR

No parts essentially correct and two parts partially correct

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Question 3

Intent of Question

The primary goals of this question are to assess a student's ability to (1) find probabilities for a discrete random variable using a probability distribution presented in table form; (2) recognize a binomial random variable and compute a cumulative probability for it; and (3) compare the likelihoods of a particular event based on whether a simple random sample or a stratified random sample is selected.

Solution

Part (a):

The selected woman will not meet the age requirement if she is 17, 18 or 19 years old. Therefore, the probability that the selected woman will not meet the age requirement is $0.005 + 0.107 + 0.111 = 0.223$.

Part (b):

Let X represent the number of women in the sample who do not meet the age requirement. X is a binomial random variable with $n = 100$ and $p = 0.223$, as found in part (a). At least 30% of the sample will not meet the age requirement if $X \geq 30$. Using an exact binomial probability gives $P(X \geq 30) = 1 - P(X \leq 29) = 1 - 0.9547 = 0.0453$.

Part (c):

As shown in part (a), the proportion of women in the population who do not meet the age requirement is 0.223. With a simple random sample of 100, the expected percent who do not meet the age requirement is 22.3%. But with the stratified sample, the actual percent who do not meet the age requirement is set at 30%. Therefore, a woman who does not meet the age requirement is more likely to make it into the stratified sample than the simple random sample.

Scoring

Parts (a), (b) and (c) are scored as essentially correct (E), partially correct (P), or incorrect (I).

Part (a) is scored as follows:

Essentially correct (E) if the probability is computed correctly with work shown.

Partially correct (P) if the correct answer is given but no work is shown;
OR
if the correct probabilities are used to find the answer to a different related question, such as the probability that the woman will be at least 20 years old, or exactly 20 years old.

Incorrect (I) if no reasonable probability for answering the question is calculated.

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Question 3 (continued)

Part (b) is scored as follows:

Essentially correct (E) if the response includes the following three components.

1. States that the number of women in the sample who do not meet the age requirement is a binomial random variable or specifies the correct values for n and p.
2. Provides the correct answer using either an exact binomial calculation, or a normal approximation to the binomial.
3. Shows sufficient work to understand how the answer was calculated.

Partially correct (P) if the response includes two of the three components required for E.

Incorrect if the response does not meet the criteria for E or P.

Notes:

- The correct value of p can either be recomputed in part (b) or defined as whatever value the response in part (a) reported for the probability that a randomly selected woman will not meet the age requirement.
- Component 3 can be satisfied using calculator notation as long as n, p, and X are labeled.

Part (c) is scored as follows:

Essentially correct (E) if the response includes the following two components:

1. Correctly states that a woman who does not meet the age requirement is more likely to be included in the stratified random sample than with the simple random sample
2. Justifies the choice by comparing the expected percentage of women who do not meet the age requirement for the simple random sample (22.3%) with the percentage for the stratified random sample (30%).

Partially correct (P) if the response:

1. Correctly states that a woman who does not meet the age requirement is more likely to be included in the stratified random sample than with the simple random sample, *AND*
2. Provides only a weak justification, such as correctly mentioning one percentage, but not both.

Incorrect if the response does not meet the criteria for E or P.

Note: Component 2 is satisfied by comparing the expected counts (as opposed to percentages) for the two sampling methods.

Question 3 (continued)

4 Complete Response

Three parts essentially correct

3 Substantial Response

Two parts essentially correct and one part partially correct

2 Developing Response

Two parts essentially correct and no parts partially correct

OR

One part essentially correct and one or two parts partially correct

OR

Three parts partially correct

1 Minimal Response

One part essentially correct

OR

No parts essentially correct and two parts partially correct

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Question 4

Intent of Question

The primary goals of this question are to assess a student's ability to (1) identify and compute an appropriate confidence interval after checking the necessary conditions, (2) interpret the confidence interval in context, and (3) determine whether it is appropriate to use the interval to answer a question about an individual.

Solution

Part (a):

Step 1: Identify the appropriate confidence interval (by name or formula) and check appropriate conditions.

The appropriate procedure is a one-sample *t*-interval for a population mean.

Conditions: 1. The sample is randomly selected from the population.
2. The population has a normal distribution, or the sample size is large.

Condition 1 is met because the stem states that a random sample was selected.
Condition 2 is met because the sample size of 61 is greater than 30.

Step 2: Correct mechanics

A confidence interval for the population mean is given by $\bar{x} \pm t^* \frac{s}{\sqrt{n}}$. The critical value for 99% confidence, based on $61-1=60$ degrees of freedom, is $t^* = 2.660$. The 99% confidence interval for the population mean number of steps taken per workday is

$$9{,}797 \pm 2.66\left(\frac{2{,}313}{\sqrt{61}}\right) = 9{,}797 \pm 787.76, \text{ or}$$

9,009.24 to 10,584.76, or

9,009 steps to 10,585 steps, rounded.

Step 3: Interpretation

We can be 99% confident that for the population of people working in New York City who wear fitness trackers the mean number of steps taken per workday is between 9,009 and 10,585.

Part (b):

No, it is not appropriate. A confidence interval provides an estimate of the population mean value, but does not provide information about the range of individual values.

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Question 4 (continued)

Scoring

The question is scored in four sections. Section 1 consist of part (a), step 1; section 2 consists of part (a), step 2; section 3 consists of part (a), step 3 and section 4 consists of part (b). Each section is scored as essentially correct (E), partially correct (P), or incorrect (I).

Section 1 is scored as follows:

Essentially correct (E) if the response includes all three of the following components:
1. Identifies a one-sample *t*-interval (either by name or by formula).
2. States that random sampling is a required condition for inference and explains how the condition is satisfied.
3. States that either the population distribution must be normal or the sample size must be large and justifies that the condition is satisfied.

Partially correct (P) if the response includes component (1) and one of the two remaining components required for an E.

Incorrect (I) if the response does not meet the criteria for E or P.

Note: Component (1) cannot be satisfied by a formula that uses incorrect statistical notation, such as μ or σ, instead of $\bar{x}$ or s.

Section 2 is scored as follows:

Essentially correct (E) if the response gives the correct confidence interval. Supporting work is not required, but if included, it must be correct.

Partially correct (P) if the response has the correct interval with an error in the supporting work;
OR
the response has an incorrect interval resulting from one or more errors in the supporting work shown. Examples of possible errors include: using the *t* multiplier for a 95% confidence interval, or using the wrong degrees of freedom for the multiplier for a 99% confidence interval, or dividing by $\sqrt{60}$ instead of $\sqrt{61}$.

Incorrect if the response does not meet the criteria for E or P.

Notes:
- A minor arithmetic error or transcription error, such as writing 9,779 instead of 9,797 or 2,331 instead of 2,313, does not reduce the score from E to P or P to I.
- Providing the appropriate formula for the *t*-interval using μ or σ, instead of $\bar{x}$ or s does not reduce the score from E to P or P to I.

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Question 4 (continued)

Section 3 is scored as follows:

Essentially correct (E) if the response gives a reasonable interpretation of the interval that includes the following four components.

1. 99% confidence interval statement
2. Estimate is for a mean
3. Inference is about a population
4. Context ("number of steps" is sufficient for context)

Partially correct (P) if the response gives a reasonable interpretation of the interval that includes component (1) AND two of the remaining three components required for an (E);

OR

if the response gives a correct interpretation of the confidence level in context but does not attempt to interpret the confidence interval.

Incorrect (I) if the response does not meet the criteria for E or P.

Note: If a 95% confidence interval is constructed in section 2, then the interpretation in section 3 is scored as essentially correct if component (1) is stated as 95% confidence and the other components are all correct.

Section 4 is scored as follows:

Essentially correct (E) if the response in part (b) correctly notes that the interval cannot be used to conduct the investigation *AND* gives a justification that illustrates understanding that confidence intervals are not about individual values.

Note: Examples of acceptable justification include noting that an individual value could be investigated by constructing an interval using the sample mean and standard deviation only, or constructing such an interval, or computing a *z*-score using the sample mean and standard deviation only.

Partially correct (P) if the response correctly notes that it is not appropriate to use the interval, with weak, but reasonable justification.

Note: An example of an unreasonable justification is explaining that 8,500 is unusual (i.e., an outlier) because it lies outside of the interval in part (a).

Incorrect (I) if the response does not meet the criteria for E or P.

Question 4 (continued)

Each essentially correct (E) section counts as 1 point, and a partially correct (P) section counts as ½ point.

4 **Complete Response**

3 **Substantial Response**

2 **Developing Response**

1 **Minimal Response**

If a response is between two scores (for example, 2½ points), use a holistic approach to decide whether to score up or down, depending on the strength of the response and communication.

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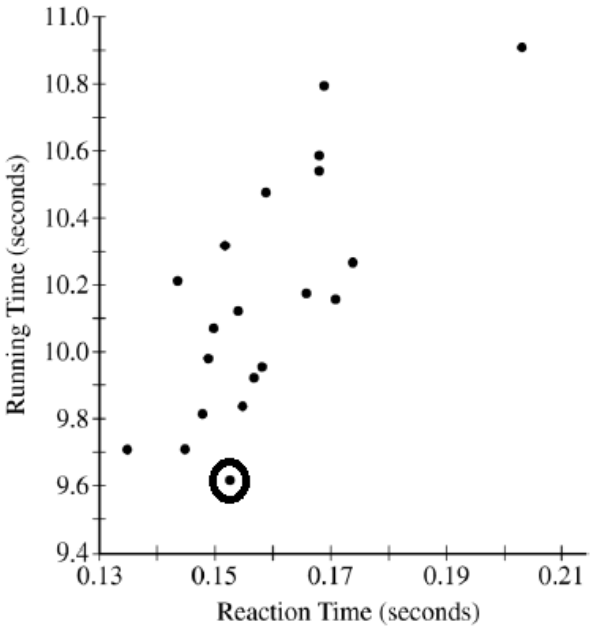
Question 5

Intent of Question

The primary goals of this question are to assess a student's ability to (1) interpret information in a scatter plot; (2) assess whether two quantitative variables are independent based on a scatter plot; and (3) assess whether data illustrated in a scatter plot can be used to predict a *y*-value for an *x*-value outside the range of the data.

Solution

Part (a):



The runner who won the race would be the one with the lowest sum of the two variables, which is the runner whose reaction time was about 0.152 seconds and running time was about 9.61 seconds, for a total of about 9.762 seconds.

Part (b):

It is not reasonable to assume that reaction time and running time are independent. There is a strong linear relationship between them, illustrated by the scatter plot.

Part (c):

It might not be appropriate to predict the running time for a runner whose reaction time is 0.30 seconds because the highest observed reaction time in the graph is only about 0.202 seconds, and 0.30 seconds is substantially slower than 0.202. It also might not be appropriate to extrapolate beyond the value of 0.202 seconds because the relationship between the *x*- and *y*-variables may be different for higher reaction time values.

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Question 5 (continued)

Scoring

Parts (a), (b) and (c) are each scored as essentially correct (E), partially correct (P), or incorrect (I).

Part (a) is scored as follows:

Essentially correct (E) if the response indicates the correct point on the graph and provides a good approximation for the total time of the race for that runner.

Partially correct (P) if the response chooses the wrong point, but provides a good approximation for the total time of the race for the runner chosen;
OR
if the response circles the correct point but does not provide a good approximation for the total time for that runner.

Incorrect (I) if the response does not meet the criteria for E or P.

Note: An approximation for total time that falls between 9.75 and 9.765 seconds is acceptable for part (a), even with no work shown. Due to different scales on the axes, reasonable justification must be provided for values of total time outside the interval from 9.75 and 9.765 seconds. Examples of reasonable justification include writing the approximate values for reaction time and running time, drawing relevant tick marks on the graph, or drawing relevant lines on the graph.

Part (b) is scored as follows:

Essentially correct (E) if the response says that it is not reasonable because of the presence of a clear, positive association.

Partially correct (P) if the response says that it is not reasonable but provides only a weak justification, such as “correlation” or “association”;
OR
if the response says that it *is* reasonable to assume they are independent, but then provides an explanation indicating the presence of a clear, positive association.

Incorrect if the response does not meet the criteria for E or P.

Part (c) is scored as follows:

Essentially correct (E) if the response includes the following two components
1. Notes that 0.30 is longer than the slowest reaction time shown in the graph, and
2. States that the relationship may be different outside of the range shown, or argues that the model may provide an unreasonable prediction for a reaction time of 0.3 seconds.

Partially correct (P) if the response includes only one of the two components required for E.

Incorrect if the response does not meet the criteria for E or P.

Question 5 (continued)

4 Complete Response

Three parts essentially correct

3 Substantial Response

Two parts essentially correct and one part partially correct

2 Developing Response

Two parts essentially correct and no parts partially correct

OR

One part essentially correct and one or two parts partially correct

OR

Three parts partially correct

1 Minimal Response

One part essentially correct

OR

No parts essentially correct and two parts partially correct

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Question 6

Intent of Question

The primary goals of this question are to assess a student's ability to (1) explain how to determine whether a sampling distribution is approximately normal; (2) calculate the standard error for the sampling distribution of a proportion and compare it to a value; (3) calculate the standard error for the average of two independent random variables; (4) conduct a test of hypotheses in a non-standard situation, using a rule called Chebyshev's inequality.

Solution

Part (a):

It is reasonable to assume that the distribution is approximately normal. The required condition is that there are at least 10 successes and 10 failures in the sample. In this case there are 44 defective lightbulbs and 356 non-defective lightbulbs, thus both exceed the minimum of 10 required.

Part (b):

Note that $\hat{p}_X = \frac{44}{400} = 0.11$. So the standard error of $\hat{p}_X$ is $\sqrt{\frac{\hat{p}_X(1-\hat{p}_X)}{n}} = \sqrt{\frac{(0.11)(0.89)}{400}} = 0.0156$.

Part (c):

Since $\hat{p}_X = 0.11$, $0.11 - 0.10 = 0.01$, so that $\hat{p}_X$ is $\frac{0.01}{0.0156} = 0.64$ standard error away from 0.10.

Part (d):

(i) First compute $\hat{p}_Y = \frac{104}{400} = 0.26$. So $\hat{D} = \frac{0.11 + 0.26}{2} = 0.185$.

(ii) The standard error of $\hat{p}_X = 0.0156$ is obtained from part (b). The standard error of $\hat{p}_Y$ is $\sqrt{\frac{\hat{p}_Y(1-\hat{p}_Y)}{n}} = \sqrt{\frac{(0.26)(0.74)}{400}} = 0.0219$. So the standard error of $\hat{D}$ is $s_{\hat{D}} = \sqrt{\frac{1}{4}\left(0.0156^2 + 0.0219^2\right)} = 0.0134$.

Part (e)

$W = \frac{0.185 - 0.10}{0.0134} = 6.34$.

Question 6 (continued)

Part (f)

Suppose the true mean D is 0.10. Then the observed value of $\hat{D} = 0.185$ is 6.34 standard errors from the mean D. Using Chebyshev's inequality, the probability of observing a value of $\hat{D}$ within 6.34 standard errors of the mean of 0.10 is at least $1 - \frac{1}{6.34^2} = 0.975$. So the probability of observing a value as far from 0.10 as the one observed, or farther, is at most 0.025 if the true mean really is 0.10. Therefore, the p-value for this test is at most 0.025, which is less than 0.05, so the null hypothesis can be rejected. There is sufficient statistical evidence at the 0.05 level to conclude that the average proportion for all products that are defective is greater than 0.10.

Scoring

This question is scored in three sections. Section 1 consists of parts (a), (b) and (c), section 2 consists of part (d), and section 3 consists of parts (e) and (f). Each section is scored as essentially correct (E), partially correct (P), or incorrect (I).

Section 1 is scored as follows:

Essentially correct (E) if the response includes the following four components:

1. In part (a), states that it is reasonable to assume the condition is met *AND* provides appropriate justification by comparing the number of defectives and non-defectives to a reasonable number.
2. In part (b), calculates $\hat{p}_X$ correctly, either separately or in the process of showing the computation for its standard error.
3. In part (b), gives the correct formula for the standard error of $\hat{p}_X$.
4. In part (c), states the correct number of standard errors $\hat{p}_X$ is from 0.10.

Partially correct (P) if the response includes only two or three of the four components.

Incorrect (I) if the response includes at most one of the four components.

Notes

- In component 1, it is acceptable to check the sample size condition using $400 \times 0.1 = 40$ instead of the observed value of 44, because the sampling distribution refers to all possible samples.
- In component 4, transcription errors should not penalize a response if there is no ambiguity in how the error occurred. For instance, $\frac{0.11 - 0.10}{0.0156} = \frac{0.1}{0.0156} = 6.41$ is an acceptable transcription error.

Question 6 (continued)

Section 2 is scored as follows:

Essentially correct (E) if the response includes the following four components in part (d):

1. Correctly calculates $\hat{p}_Y$ either separately or in the process of showing the computation of $\hat{D}$.
2. Correctly calculates $\hat{D}$.
3. Gives the correct formula for the standard error of an average of two independent random variables.
4. Correctly computes the standard error of $\hat{D}$ *OR* if an incorrect but reasonable formula is given for the standard error, plugs the correct values into that formula. For instance, an incorrect but reasonable formula might use the standard errors rather than the squared standard errors of the estimated proportions.

Partially correct (P) if the response includes only two or three of the four components.

Incorrect if the response includes at most one of the four components.

Section 3 is scored as follows:

Essentially correct (E) if the response includes the following four components:

1. In part (e), correctly calculates W using the values from part (d).
2. In part (f), recognizes that Chebyshev's inequality should be used by substituting W for k.
3. In part (f), applies reasonable logic to make a conclusion based on using W and Chebyshev's inequality.
4. In part (f), makes a conclusion including linkage and context, consistent with the logic given in component 3.

Partially correct if the response includes only two or three of the four components.

Incorrect if the response includes at most one of the four components.

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Question 6 (continued)

4 Complete Response

Three sections essentially correct

3 Substantial Response

Two sections essentially correct and one section partially correct

2 Developing Response

Two sections essentially correct and no sections partially correct

OR

One section essentially correct and one or two sections partially correct

OR

Three sections partially correct

1 Minimal Response

One section essentially correct

OR

No sections essentially correct and two sections partially correct