

MATH 140 PROJECT#4 Directions and Grading Rubric

ANOVA: Categorical – Quantitative Relationship Test

Use with Teachout textbook Chapter 3 and Section 4B / Updated Spring 2025

GRADING RUBRIC

- **Five StatKey Pictures:** (5 points each, 25 points total)
 - One Quantitative and one categorical variable menu: Histograms** (Histograms of your quantitative data for each group. You should have multiple histograms. If the sample sizes are very small, it is best to set the slider to 3 buckets (3 bars).
 - ANOVA for Difference in Means “Original Sample” Table** (Summary Statistics for your quantitative data by group showing the F-test statistic, and the samples sizes for each group, sample means for each group, and the sample standard deviations for each group),
 - ANOVA for Difference in Means “ANOVA Table”** (Showing the various degrees of freedom, SS, MS, and the F-test statistic),
 - Theoretical Distributions “F” Critical Value Graph** (F – Distribution graph corresponding to correct degrees of freedom between the groups and degrees of freedom within the groups and 0.05 significance level in the top box in right tail and critical value in bottom box of right tail),
 - Theoretical Distributions “F” P-value Graph** (F – Distribution graph corresponding to correct degrees of freedom between the groups and degrees of freedom within the groups and with the F – test statistic in the bottom box in the right tail and the P-value in top box in the right tail).
- **First and Last name, Project title, Instructor’s Name, Section#, Semester and Year** (2 points)
- **Anti-cheating statement** (1 point)
- **Assumptions, F-test stat sentence, P-value sentence, Conclusion, Relationship sentence** (3 points each, 24 points total)
- **All other problems.** (2 points each, 48 points total)

Part I: Name, Title, Cheating Statement, First six questions.

NOTE: Use the two columns of data you collected this semester. The categorical data should be the column on the left and the quantitative data should be the column on the right. You will be copy and pasting both columns into Statkey.

Put the following title at the top of your report.

First and Last Name

Math 140 Project#5 ANOVA – Categorical / Quantitative Relationship Test

Instructor’s Name

Section# for your class

Semester and Year

Cheating Statement: Confirm that you did not cheat. If true, write the following on your report:

I did not cheat on this project. I did not copy someone else’s answers. I collected the data and did the work myself. No one else did this project for me.

REPORT QUESTIONS: Put the answers to these questions on the Project Report:

1. What was the categorical question for your data?
2. What was the quantitative question for your data? What are the units?

3. **What was your population of interest?** (See project 1 grading comments. Many students get this question wrong in the project#1. Mr. Teachout may have told you what your population should be.)
4. **Condition #1 (Random Sample): Was your sample data collected randomly? If the data was not collected randomly, what method was used? Does your data pass this condition? Explain why or why not.** (Note: If the data was collected randomly, then it passes the random condition. If your data was collected with convenience or voluntary response, it fails the condition.)

Example: The PA student pressure and homework hours data was not collected randomly so the data fails the random condition.

5. **Condition #2 (Independence): Do you think the individuals in your data are independent of each other or are they related. Does your data pass this assumption? Explain why or why not.** (If individual observations in your data are not related (independent) then it passes the assumption. If they are related in some way, it fails the assumption.)

Example: The PA students may have been in the same classes or have the same major so probably fails the independence condition.

6. **CLAIM: Do you think your categorical variable is related to your quantitative variable for your population or do you think they are not related?** (Remember related does not mean causation.)

Example: I think the pressure PA students feel IS RELATED to how much time they spend on their homework each week.

Part II: Write the Null Hypothesis and the Alternative Hypothesis. Remember EQUAL MEANS NOT RELATED!
NOT EQUAL MEANS RELATED!

7. **Write your null hypothesis that the population mean average (μ) is equal for each of your groups. This implies that the categorical and quantitative variables are NOT RELATED. You must write " H_0 ", the μ_i equal for each group, and the not related statement in context for full credit.**

Example (Four groups): $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$ (The pressure a PA student feels is NOT RELATED to the number of hours they spend on homework each week.)

8. **Write your alternative hypothesis that at least one of the population mean average (μ) is not equal. This implies that the categorical and quantitative variables ARE RELATED. You must write " H_A ", at least one of the μ_i not equal, and the related statement in context for full credit.**

Example (Four groups): $H_A : \text{At least one of the } \mu_i \text{ are not equal to the others.}$ (The pressure a PA student feels IS RELATED to the number of hours they spend on homework each week.)

9. **Is your claim from #6 the null hypothesis (H_0) or the alternative hypothesis (H_A) ?**

Example: My claim in #6 was that the pressure PA students feel is related to how much time they spend on their homework each week. This means that H_A (**Related**) is the claim.

10. **Is your hypothesis test a "right-tailed test", a "left-tailed test" or a "two-tailed test"? ANOVA uses the F-distribution which is always a right tailed test.**

Example: An ANOVA test is always right-tailed since it uses the F-distribution.
So this hypothesis test is right-tailed.

Part III: Paste your Data into StatKey and check the shape of the data for each group.

Open the updated version of the two columns of data you collected and fixed. The categorical column of words has to be on the column on the left and the quantitative numerical measurement column has to be the column on the right. Highlight both columns, right click and copy.

Open StatKey at www.lock5stat.com, click on "One Quantitative and One Categorical Variable" under the "Descriptive Statistics and Graphs" menu in StatKey.

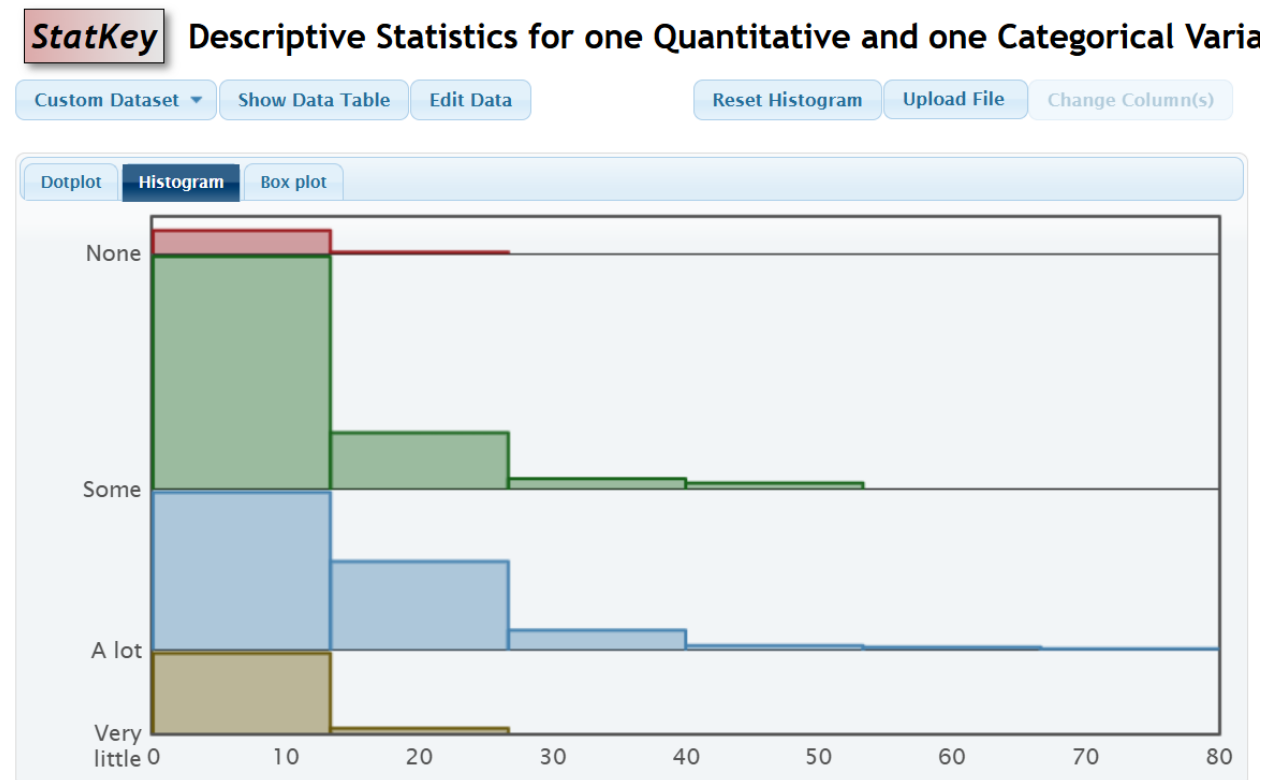
Click on "Edit Data" and Copy and Paste the two columns of data (categorical on left and quantitative on the right) into StatKey. Check the box for "header row" and push OK.

Click on "Histogram". You should now see multiple histograms describing the quantitative data from each group in your data. Take a picture of your Histograms.

Put these on the Project Report:

- 11. Copy and Paste a picture of the histograms into your project report. If the sample sizes are very small, it is best to set the slider in StatKey to 3 buckets (3 bars).**

Example (Four groups): Pressure PA students are under and hours of homework per week.



- 12. What is the shape of each of the histograms?** (Normal bell shaped, skewed right, skewed left or uniform.)
Example: All four of the histograms are skewed right.

Part IV: Paste your Data into StatKey and find your F-test statistic, Sample Statistics for each group, and degrees of freedom between the groups and degrees of freedom within the groups.

Open the updated version of the two columns of data you collected and fixed. The categorical column of words has to be on the column on the left and the quantitative numerical measurement column has to be the column on the right. Highlight both columns, right click and copy.

Open StatKey at www.lock5stat.com. Go to the “ANOVA for Difference in Means” under the “More Advanced Randomization Tests” menu.

Click on “Edit Data” and Copy and Paste the two columns of data (categorical on left and quantitative on the right) into StatKey. Your data should have titles. If so, check the box for “header row” and push OK. If your data does not have titles, uncheck the box for “header row” and push OK.

On the top right, you should see the “Original Sample” table with the F-test statistic for your data, the sample sizes for each group, the sample means for each group and the sample standard deviations for each group. Take a picture of the “Original Sample” table.

Next to the “Original Sample” table, you will see a button saying “ANOVA Table”. Click on “ANOVA Table”. You will see a table showing how the F-test statistic was calculated including the degrees of freedom between the groups (Groups), the degrees of freedom within the groups (Error), and the total degrees of freedom. You will also see the sum of squares calculations (SS), the variance between the groups (MS Groups) and the variance within the groups (MS Error). Take a picture of the “ANOVA Table”.

Put these on the Project Report:

13. Copy and Paste a picture of the ANOVA “Original Sample Statistics” printout into your Project report.

Example: Pressure on PA students and number of hours per week they spend on homework.

Original Sample

ANOVA Table

$n = 451, F = 21.525$

Statistics	Very little	A lot	Some	None	Overall
Sample Size	55	180	200	16	451
Mean	3.6	14.0	9.4	2.9	10.3
Standard Deviation	5.0	11.4	9.0	3.9	10.2

14. Copy and Paste a picture of the “ANOVA Table” printout into your Project report.

Example: Pressure on PA students and number of hours per week they spend on homework.

ANOVA Table				
	df	SS	MS	F
Groups	3	5926.3	1975.44	21.525
Error	447	41023.8	91.78	
Total	450	46950.1		

- 15. Look at the “Original Sample” table. Give the sample sizes for each of your groups. You do NOT need to give the total “Overall” sample size. Just the individual sample sizes for each group.**

Example: 55 PA students answered “Very Little” pressure.
180 PA students answered “A Lot” of pressure.
200 PA students answered “Some” pressure.
16 PA students answered “None”.

- 16. Condition #3: “Sample size at least 30 or Normal” for each group in your data. Does your data pass this assumption? Explain why or why not.** Each group’s quantitative data should have a normal bell-shaped histogram or have a sample size of 30 in order to pass. Any groups whose histograms are normal (bell-shaped) pass the condition. Any groups whose sample size is 30 or more pass the condition. If a group has a skewed histogram AND have sample size below 30, then it fails the assumption.

Example: The “very little”, “a lot”, and “some” pressure groups passed the 30 or normal condition. Even though the shapes were skewed right the sample sizes (55,180,200) were greater than 30. The “none” group failed the 30 or normal condition. It was skewed right and had a samples size (16) lower than 30.

- 17. Look at the “Original Sample” table. Give the sample standard deviations for each of your groups. You do NOT need to give the total “Overall” standard deviation. Just the individual standard deviations for each group.**

Example: Sample standard deviations are 5, 11.4, 9, 3.9

- 18. Condition #4: In the “Summary Statistics” table, there should not be any sample standard deviations that are more than twice as large as any other sample standard deviation. Does your data pass this Condition? Explain why or why not.** (The sample data passes the condition if the sample standard deviations are close. The sample data fails the condition if at least one sample standard deviation that is more than twice as large as the others.)

Example: The sample standard deviations fail the close standard deviations condition. The smallest standard deviation is 3.9 and $2 \times 3.9 = 7.8$. 11.4 and 9 are larger than 7.8 so there are standard deviations that are more than twice as large as some of the others.

- 19. Look at the “Original Sample” statistics table or the ANOVA table. What is the F-test statistic in these tables?**

Example: F-test stat = 21.525

- 20. Write the definition sentence explaining the F-test statistic.**

Example: The ratio of the variance between the groups to the variance within the groups is 21.525.

- 21. Look at the “ANOVA Table”. What is the degrees of freedom between the groups (df numerator)?** You will find this number under “df Groups” in the ANOVA table. **What is the degrees of freedom within the groups (df denominator)?** You will find this number under “df Error” in the ANOVA table.

Example: The ANOVA table shows that the “df Groups” is 3, so the degrees of freedom between the groups (df numerator) is 3. There were four groups in the data so this makes sense ($4 - 1 = 3$). The ANOVA table shows that the “df Error” is 447, so the degrees of freedom within the groups (df denominator) is 447. This makes sense since the total sample size was 451 and there were 4 groups ($451 - 4 = 447$).

	df	SS	MS	F
Groups	3	5926.3	1975.44	21.525
Error	447	41023.8	91.78	
Total	450	46950.1		

Part V: Use the F-distribution in StatKey and a 5% Significance Level to calculate your Critical Value:

Go to StatKey at www.lock5stat.com. Under "Theoretical Distributions", click on "F". Under "Numerator df:", enter the degrees of freedom between the groups you listed in #21. Under "Denominator df:", enter the degrees of freedom within the groups you listed in #21. Take a picture of your degrees of freedom box. Now push OK. Check the box that says "Right Tail". In the top box in the right tail put the significance level (0.05). The graph will now show the critical value in the bottom box of the right tail. This is where the right tail begins. For the test statistic to be in the tail, the original sample F-test statistic in #20 must be larger than the critical value. If the F-test statistic is smaller than the critical value, then the F-test statistic does NOT fall in the tail.

- 22. Copy and Paste a picture of the F-Distribution "Edit Parameters" Degrees of Freedom printout into your Project report. Be sure to use the same degrees of freedom listed in the ANOVA table. The "Numerator df" should be the same as "df Groups" in the ANOVA table. The "Denominator df" should be the same as "df Error" in the ANOVA table. (See #21).**

Example: Looking at the ANOVA table we see that "df Groups" = 3. So, in the edit parameters screen type in 3 where it says "Numerator df". Looking at the ANOVA table we see that "df Error" = 447. So, in the edit parameters screen type in 447 where it says "Denominator df".

Edit Parameters

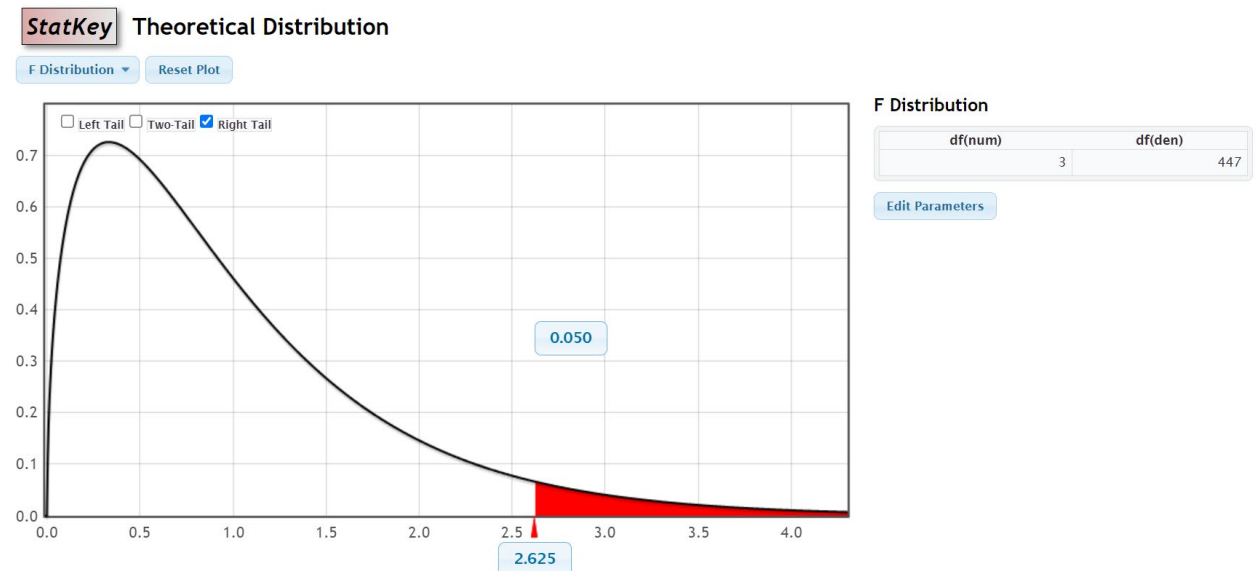
Please select degrees of freedom.

Numerator df:

Denominator df:

Ok (or hit Enter)

23. Copy and Paste a picture of the F-Distribution right tail with the correct degrees of freedom, 0.05 in the upper box and the critical value in the lower box.



24. What is your critical value where the right tail in the F-distribution begins?

Example: The right tail for 0.05 in the F-distribution begins at 2.625 so that is my critical value.

25. Look at your F – Test Statistic answer in #19 and the right tail with your critical value. Does your F – Test Statistic fall in the tail or not?

Example: The right tail starts at 2.625 so my F – Test Statistic would need to be larger than 2.625 for it to be in the tail. My “Original Sample” F – Test Statistic in #19 is 21.525 and this is larger than 2.625. My F – Test Statistic does fall in the tail.

26. Is the variance between the groups significantly higher than the variance within the groups? **Explain why.** F-test statistic in tail means that the variance between the groups IS significantly higher than the variance within the groups. F-test statistic NOT in tail means that the variance between the groups is NOT significantly higher than the variance within the groups.

Example: Since my F-test statistic falls in the right tail, that the variance between the groups IS SIGNIFICANTLY HIGHER than the variance within the groups.

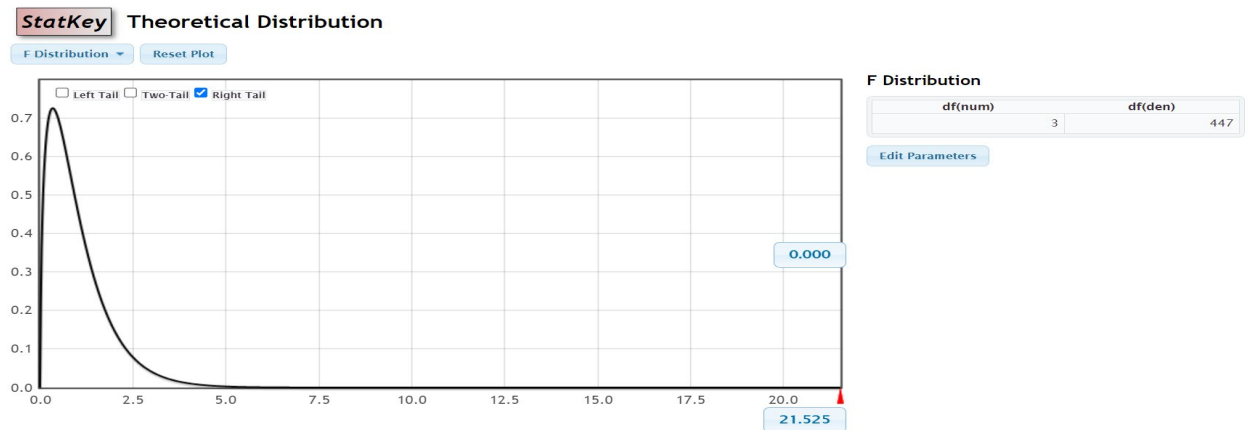
27. Does the sample data significantly disagree with the null hypothesis or does the sample data not significantly disagree with the null hypothesis? **Explain why.** F-test statistic in tail means that the sample data SIGNIFICANTLY DISAGREES with the null hypothesis. F-test statistic NOT in tail means that sample data does NOT significantly disagree with the null hypothesis.

Example: Since my F-test statistic falls in the right tail, my sample data significantly disagrees with the null hypothesis.

Part VI: Use the F-distribution in StatKey and the “Original Sample” F – Test Statistic to calculate your P – Value: Go to StatKey. Under “Theoretical Distributions”, click on “ F “. Under “Numerator df.”, enter the degrees of freedom between the groups you listed in #21. Under “Denominator df.”, enter the degrees of freedom within the groups you listed in #21. Now push OK. Check the box that says “Right Tail”. In the bottom box in the right tail put the F – Test Statistic from #19. The graph will now show the P – Value in the top box of the right tail.

- 28. Copy and Paste a picture of the F-Distribution right tail with the correct degrees of freedom numerator and denominator, the F – Test Statistic from #19 in the lower box in the right tail and the P – Value in the upper box in the right tail.**

Example:



- 29. What is your P-value? Write your P-value as a decimal proportion AND as a percentage.**

Example: The upper box in my F-distribution corresponding to my F test statistic was 0.
So my P-value = 0 = 0%.

- 30. Write the P-value definition sentence in context to explain your P-value.**

Example: “If the null hypothesis is true and the pressure a PA student is under is NOT RELATED to the number of hours of homework they do per week, then there is a 0% probability of getting this sample data or more extreme by sampling variability.”

- 31. Is your P-value lower or higher than your 5% significance level? Is your P-value low or high?** “If the P-value is 5% or lower, it is considered a Low P-value. If the P-value is higher than 5%, it is considered a High P-value.

Example: The P-value of 0% is lower than the 5% significance level so it is considered a low P-value.

- 32. Assuming the null hypothesis was true, could the F test statistic or more extreme have occurred because of sampling variability or is it unlikely for your sample data to have occurred sampling variability?** Low P-value indicates that the sample data is unlikely to have occurred because of sampling variability. High P-value indicates that the sample data could have occurred because of sampling variability.

Example: Since the P-value (0%) is low, it is unlikely to be sampling variability.

- 33. Did your data pass all four conditions in #4, #5, #16 and #18? Explain why or why not.**

Example: The PA student pressure and homework data did not pass all of the conditions. The data was not collected randomly. It also did not pass the independence condition. The “no pressure” group failed the 30 or normal condition. The standard deviations failed the “close” condition.

34. Considering the conditions, is your P-value significant evidence or not significant evidence?

Explain your answer. If the P-value is low and the data passed all the conditions, the P-value is considered significant evidence. If the P-value is low and the data did NOT pass all of the conditions, then the P-value is NOT significant evidence. A high P-value is never significant. If the P-value is high and the data passed all of the conditions, then the P-value is NOT significant evidence. If the P-value is high and the data did NOT pass all of the conditions, then the P-value is NOT significant evidence.

Example: The P-value (0%) was low, but the data did not pass all of the conditions. It is therefore not significant evidence.

PART VII: Interpretations and Final Conclusion

35. Considering the conditions and P-value, should we Reject the Null Hypothesis or Fail to reject the Null Hypothesis? (If the P-value is low and the data passed all the conditions, then you should REJECT the NULL HYPOTHESIS. If the P-value is low and the data did NOT pass all of the conditions, then you should FAIL TO REJECT THE NULL HYPOTHESIS. A high P-value always indicates fail to reject. If the P-value is high and the data passed all of the conditions, then you should FAIL TO REJECT THE NULL HYPOTHESIS. If the P-value is high and the data did NOT pass all of the conditions, then you should FAIL TO REJECT THE NULL HYPOTHESIS.)

Example: The P-value (0%) was low, but the data did not pass all of the conditions. We should therefore fail to reject the null hypothesis.

36. Write the standard conclusion sentence in context for your test addressing evidence, assumptions and the claim that your categorical and quantitative variable are related or not related. Here is the conclusion sentence. There (**is** or **is not**) significant evidence to (**reject** or **support**) the claim that the type of sandwich and the number of ants are (**related** or **not related**). You have to pick between “significant evidence” or “not significant evidence”, “reject” or “support”, “related” or “not related” depending on your P-value, passing or failing the assumptions, claim and your null and alternative hypothesis. Use “reject” and “not related” in your sentence if H_0 was your claim in #9. Use “support” and “related” if H_a was your claim in #9. If your P-value was higher than the 5% significance level or if the data did not pass ALL of the assumptions, then you should say there is “not significant evidence”. Only if your P-value is LOWER than the significance level AND your data PASSED all the conditions, then you can say there “is significant evidence”.

Example: There is not significant evidence to support the claim that the pressure PA students feel is related to the number of hours they spend on their homework.

37. Does the data indicate that your categorical data is related or NOT related to your quantitative data? Write the answer in context. Explain your answer.

- High P-value with Passing Conditions: High P-value from good data indicates the variables could be NOT RELATED, sampling variability could be involved, and we do NOT have evidence.
- High P-value but One or More Conditions failed: High P-value indicates the variables may be NOT RELATED and sampling variability could be involved. Since the data did not pass conditions, we do not have evidence and we should not make a decision based on this data.
- Low P-value with Passing Conditions: Low P-value from good data indicates the variables are probably RELATED and WE HAVE EVIDENCE!
- Low P-value but One or More Conditions failed: Low P-value indicates the variables could be RELATED. However, since the data did not pass conditions, we do not have evidence and we should not make a decision based on this data.

Example: The PA student pressure and homework hours per week have a low P-value. This indicates that they could be related. However, since the data did not pass all the conditions, we do not have evidence and we should not make a decision based on this data.
