Mathematics 13 : Elementary Statistics

Unit 4 : Section 2

Lesson 42 :

The Chi-Squared Goodness-of-Fit Test

The Chi-Squared Goodness-of-Fit Test

The Chi-Squared Goodness-of-Fit Test is a versatile inferential statistics method used in the analysis of categorical data. Specifically, the Chi-Squared Goodness-of-Fit Test is a hypothesis testing procedure used to determine if the expected frequencies for the categories of a qualitative variable reasonably match (or fit) the observed frequencies for these categories in a sample.

The Chi-Squared Goodness-of-Fit Test

The expected frequencies are generated according to the particular hypothesis under investigation. These expected frequencies are based on the predicted proportions (p_i) of each category according to the hypothesis being tested.

The observed frequencies are determined by the actual sample data values.

The Chi-Squared Goodness-of-Fit Test

The Chi-Squared Goodness-of-Fit Test

is used to determine if the expected frequencies fit the observed frequencies

State hypothesis
H_0: All of the expected frequencies fit the observed frequencies
H_1: Not all of the expected frequencies fit the observed frequencies

Use $\alpha = 0.05$
(unless stated otherwise)

Enter the observed frequencies (data) in L_1
Enter the expected frequencies ($n \cdot p_i$) in L_2

X^2GOF-Test
with df = c - 1

Decision:
Reject H_0 when p-value $\leq \alpha$
Otherwise do not reject H_0

State conclusion

The Chi-Squared Goodness-of-Fit Test begins with the formation of a hypothesis which is used to generate the expected frequencies.

The stated hypotheses (H_0 and H_1) are always expressed in the same manner.

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X^2GOF-Test
with df = c - 1

Decision:
Reject H_0 when p-value $\leq \alpha$
Otherwise do not reject H_0

State conclusion

Unless there exists a compelling reason to do so otherwise, hypothesis testing procedures are conducted using the customary 5% level of significance.

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X^2GOF-Test
with df = c - 1

Decision:
Reject H_0 when p-value ≤ α
Otherwise do not reject H_0

State conclusion

Category	Observed Frequency	Expected Frequency
1	O_1	$E_1 = n \cdot p_1$
2	O_2	$E_2 = n \cdot p_2$
⋮	⋮	⋮
c	O_c	$E_c = n \cdot p_c$

$O_1 + O_2 + \cdots + O_c = n$

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X^2GOF-Test
with df = c - 1
Decision:
Reject H_0 when p-value ≤ α
Otherwise do not reject H_0
State conclusion

After the observed frequencies are entered into L_1 and the expected frequencies are entered into L_2, the X^2GOF-Test command on the TI-84 calculator will calculate the desired p-value for the hypothesis test procedure.

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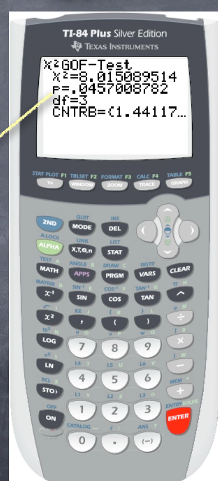
State conclusion



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X^2GOF-Test
with df = c - 1
Decision:
Reject H_0 when p-value ≤ α
Otherwise do not reject H_0
State conclusion

When the expected frequencies fit the observed frequencies, the Chi-Squared test statistic is relatively small (close to zero). This produces larger p-values.

$$X^2 = \sum_{i=1}^{c} \frac{(O_i - E_i)^2}{E_i}$$

The test statistic for this hypothesis testing procedure is denoted by X^2 (the Greek letter Chi squared).

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X^2GOF-Test
with df = c - 1
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Reject H_0 when p-value ≤ α
Otherwise do not reject H_0
State conclusion

In order for the Chi-Squared Goodness-of-Fit Test to be applied, the independent random sample must be sufficiently large. This can be accomplished by ensuring that the sample size is large enough so that all (or nearly all) of the expected frequencies are 5 or more. Also, none of the expected frequencies should equal 0.

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Use α = 0.05
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Enter the expected frequencies ($n \cdot p_i$) in L_2
X^2GOF-Test
with df = c - 1
Decision:
Reject H_0 when p-value ≤ α
Otherwise do not reject H_0
State conclusion

The calculated p-value is used to reach a decision regarding the validity of H_0.

Small p-values provide sample evidence contradicting H_0.

Large p-values provide sample evidence consistent with H_0.

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Enter the observed frequencies (data) in L_1
Enter the expected frequencies ($n \cdot p_i$) in L_2

X^2GOF-Test
with df = c - 1

Decision:
Reject H_0 when p-value $\leq \alpha$
Otherwise do not reject H_0

State conclusion

When H_0 is not rejected, the conclusion is that all of the expected frequencies fit the observed frequencies.

Thus, the hypothesis used to generate the expected frequencies is valid.

The Chi-Squared Goodness-of-Fit Test

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H_0: All of the expected frequencies fit the observed frequencies
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Use $\alpha = 0.05$
(unless stated otherwise)

Enter the observed frequencies (data) in L_1
Enter the expected frequencies ($n \cdot p_i$) in L_2

X^2GOF-Test
with df = c - 1

Decision:
Reject H_0 when p-value $\leq \alpha$
Otherwise do not reject H_0

State conclusion

When H_0 is rejected, the conclusion is that not all of the expected frequencies fit the observed frequencies.

Thus, the hypothesis used to generate the expected frequencies is not valid.

Example 1

Gregor Mendel is considered to be the father of genetics. His hybridization experiments on pea plants (Pisum sativum) lead to the development of the fundamental principals of heredity.

In one such experiment, Mendel performed a dihybrid cross between pea plants that were heterozygous for both the seed shape (Rw) and seed color (Yg) traits.

Example 1

When Mendel harvested the seeds produced by the pea plants resulting from this cross, he observed 315 seeds which were round in shape and yellow in color, 108 seeds which were round in shape and green in color, 101 seeds which were wrinkled in shape and yellow in color, and 32 seeds which were wrinkled in shape and green in color.

Example 1

According to Mendel's fundamental principles of segregation and independent assortment, if the round (R) seed shape trait is completely dominant over the wrinkled (w) seed shape trait and the yellow (Y) seed color trait is completely dominant over the green (g) seed color trait, the proportions of seeds produced by the pea plants resulting from this dihybrid cross are expected to be as follows :

Example 1

$$p_{\text{round and yellow}} = p_{\text{round}} \cdot p_{\text{yellow}} = \frac{3}{4} \cdot \frac{3}{4} = \frac{9}{16}$$

$$p_{\text{round and green}} = p_{\text{round}} \cdot p_{\text{green}} = \frac{3}{4} \cdot \frac{1}{4} = \frac{3}{16}$$

$$p_{\text{wrinkled and yellow}} = p_{\text{wrinkled}} \cdot p_{\text{yellow}} = \frac{1}{4} \cdot \frac{3}{4} = \frac{3}{16}$$

$$p_{\text{wrinkled and green}} = p_{\text{wrinkled}} \cdot p_{\text{green}} = \frac{1}{4} \cdot \frac{1}{4} = \frac{1}{16}$$

Example 1

Rw : Yg × Rw : Yg	R : Y	R : g	w : Y	w : g
R : Y	RR : YY	RR : Yg	Rw : YY	Rw : Yg
R : g	RR : gY	RR : gg	Rw : gY	Rw : gg
w : Y	wR : YY	wR : Yg	ww : YY	ww : Yg
w : g	wR : gY	wR : gg	ww : gY	ww : gg

$\frac{9}{16}$

$\frac{3}{16}$

$\frac{3}{16}$

$\frac{1}{16}$

Example 1

Test the validity of Mendel's fundamental principles of heredity by assessing the accuracy of the expected proportions of seed shape and seed color combinations produced by the pea plants resulting from this dihybrid cross to the actual frequencies observed by Mendel in his experiment.

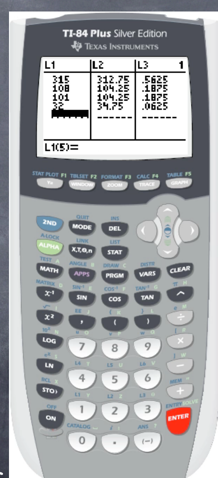
The Chi-Squared Goodness-of-Fit Test is used to determine if the expected frequencies (generated according to a hypothesis) fit the observed frequencies (determined by the actual sample data values).

Example 1

$$E = n \cdot p_i$$

Seed Shape and Color	Observed Frequency	Expected Frequency
Round and Yellow	315	$556 \cdot \frac{9}{16}$
Round and Green	108	$556 \cdot \frac{3}{16}$
Wrinkled and Yellow	101	$556 \cdot \frac{3}{16}$
Wrinkled and Green	32	$556 \cdot \frac{1}{16}$

n = 556



Example 1

H_0: All of the expected frequencies fit the observed frequencies

H_1: Not all of the expected frequencies fit the observed frequencies

Use $\alpha = 0.05$

X^2GOF-Test

with df = 4 - 1 = 3

p-value ≈ 0.925

Since the p-value of 0.925 is not 0.05 or less, the decision is to not reject H_0.

Example 1

Therefore, all of the expected frequencies (which were generated by using Mendel's fundamental principles of heredity) fit the observed frequencies.

As such, the results of this experiment corroborates the validity of Mendel's fundamental principles of heredity.

Example 2

The manager of a Round Table Pizza parlor kept track of the number of pizzas sold at his restaurant each day for an entire week.

That week, 54 pizzas were sold on Sunday, 67 on Monday, 49 on Tuesday, 52 on Wednesday, 55 on Thursday, 73 on Friday, and 78 on Saturday.

Example 2

Test the idea that the number of pizzas sold at this Round Table Pizza parlor is the same for each day of the week. Based on this result, what could the manager of this restaurant conclude?

Example 2

If the number of pizzas sold is the same for each day of the week, one would expect that each day of the week would account for 1/7 of the total number of pizzas sold that week.

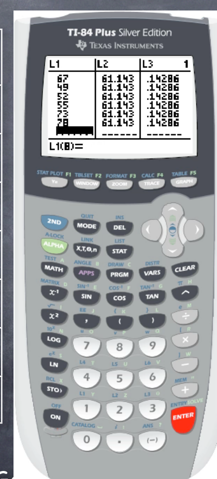
The Chi-Squared Goodness-of-Fit Test is used to determine if the expected frequencies (according to the idea that the number of pizzas sold is the same for each day of the week) fit the observed frequencies (the actual number of pizzas sold that week).

Example 2

$$E = n \cdot p_i$$

Day of the Week	Observed Frequencies	Expected Frequencies
Sunday	54	$428 \cdot \frac{1}{7}$
Monday	67	$428 \cdot \frac{1}{7}$
Tuesday	49	$428 \cdot \frac{1}{7}$
Wednesday	52	$428 \cdot \frac{1}{7}$
Thursday	55	$428 \cdot \frac{1}{7}$
Friday	73	$428 \cdot \frac{1}{7}$
Saturday	78	$428 \cdot \frac{1}{7}$

n = 428



Example 2

H_0: All of the expected frequencies fit the observed frequencies

H_1: Not all of the expected frequencies fit the observed frequencies

Use $\alpha = 0.05$

X^2GOF-Test
with df = 7 - 1 = 6
p-value $\approx$ 0.047

Since the p-value of 0.047 is 0.05 or less, the decision is to reject H_0.

Example 2

Therefore, not all of the expected frequencies fit the observed frequencies.

So, based on this result, the manager of this restaurant could conclude that the idea that the number of pizzas sold at this Round Table Pizza parlor is the same for each day of the week is not valid.

Example 2

The data indicate that this restaurant sold more pizzas than expected on Friday, Saturday, and Monday. Whereas, on Sunday, Tuesday, Wednesday, and Thursday, fewer pizzas were sold than expected.

Example 3

Use the Chi-Squared Goodness-of-Fit test and the Sierra College Elementary Statistics Student Survey to determine if it is reasonable to assume that the GPA of Sierra College Elementary Statistics students follows a normal distribution.

Example 3

The Chi-Squared Goodness-of-Fit Test is used to determine if the expected frequencies (generated according to a hypothesis) fit the observed frequencies (determined by the actual sample data values).

The GPAs collected in the Sierra College Elementary Statistics Student Survey will be used to determine the observed frequencies in the Chi-Squared Goodness-of-Fit Test.

The normal probability distribution will be used to generate the expected frequencies in the Chi-Squared Goodness-of-Fit Test.

Example 3

The standard score for a random variable that follows a normal probability distribution will take on the following values with these corresponding probabilities.

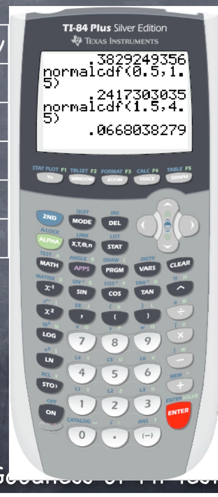
Standard Score	Normal Probability
-4.5 to -1.5	0.0668
-1.5 to -0.5	0.2417
-0.5 to +0.5	0.3829
+0.5 to +1.5	0.2417
+1.5 to +4.5	0.0668

Example 3

$$E = n \cdot p_i$$

Standard Score	Expected Frequency
-4.5 to -1.5	44·0.0668
-1.5 to -0.5	44·0.2417
-0.5 to +0.5	44·0.3829
+0.5 to +1.5	44·0.2417
+1.5 to +4.5	44·0.0668

n = 44



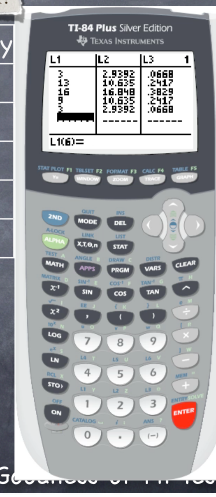
Example 3

Q5. What is your college GPA?

Standard Score	Observed Frequency
-4.5 to -1.5	3
-1.5 to -0.5	13
-0.5 to +0.5	16
+0.5 to +1.5	9
+1.5 to +4.5	3

n = 44

$$t = \frac{x_i - \bar{x}}{s_x}$$



Example 3

H_0: All of the expected frequencies fit the observed frequencies

H_1: Not all of the expected frequencies fit the observed frequencies

Use $\alpha = 0.05$

X^2GOF-Test

with df = 5 - 1 = 4

p-value ≈ 0.935

Since the p-value of 0.935 is not 0.05 or less, the decision is to not reject H_0.

Example 3

Therefore, all of the expected frequencies (which were generated by using the normal probability distribution) fit the observed frequencies.

So, it is reasonable to assume that the GPA of Sierra College Elementary Statistics students follows a normal distribution.

Your solutions should be clear, complete, and sufficiently detailed in order to demonstrate your understanding and communicate your reasoning and method of solving the problem.

Exercise 1

Over the past several semesters, 21.5% of students in Professor Brown's Experimental Psychology (PSYC 105) course earned an "A", 31.2% earned a "B", 30.1% earned a "C", 10.7% earned a "D", and 6.5% earned an "F". Last semester, Professor Brown covered the same curriculum in this course as in previous semesters, but she required her students to use a different textbook. That semester, 3 of Professor Brown's Experimental Psychology (PSYC 105) students received an "A", 7 received a "B", 5 received a "C", 2 received a "D", and 1 received an "F".

Test the hypothesis that changing the required textbook in this course resulted in no noticeable change in the final grade distribution of students. Based on this result, what can Professor Brown surmise regarding the final grade distribution of her students in this course last semester compared to previous semesters?

Exercise 2

A report published by the United States Census Bureau revealed that 68% of families have two parents present, 23% have only a mother present, 5% have only a father present, and 4% have no parent present. A random sample of 200 families in the Lucas Valley School District resulted in 122 with two parents present, 59 with only a mother present, 7 with only a father present, and 12 with no parent present.

Use a Chi-Squared test and a 0.05 level of significance to determine if the published population percentages accurately reflect the distribution of families in the Lucas Valley School District. Based on this result, how does the distribution of families in the Lucas Valley School District compare to the general population?

Exercise 3

Zentner Industries operates its manufacturing facility six days a week. The personnel department compiled a report detailing the sick leave usage by the company's employees. According to this report, in the past sixteen weeks a total of 29 sick leave days were used by employees on Monday, 17 on Tuesday, 14 on Wednesday, 16 on Thursday, 25 on Friday, and 32 on Saturday.

Use a Chi-Squared test with $\alpha = 0.05$ to decide if the total number of sick leave days used by employees of Zentner Industries is equally (or uniformly) distributed over the six days a week its manufacturing facility is in operation. Based on this result, what can the personnel department conclude about employee sick leave usage on Monday through Saturday?

Exercise 4

The standard score for a random variable that follows a normal probability distribution will take on the following values with these corresponding probabilities.

Standard Score	Normal Probability
- 4.5 to - 1.5	0.0668
- 1.5 to - 0.5	0.2417
- 0.5 to + 0.5	0.3829
+ 0.5 to + 1.5	0.2417
+ 1.5 to + 4.5	0.0668

Use the Chi-Squared Goodness-of-Fit test and the Movie Database Sample to determine if it is reasonable to assume that the running time of movies follows a normal distribution.

> Your solutions should be clear, complete, and sufficiently detailed in order to demonstrate your understanding and communicate your reasoning and method of solving the problem.

Exercise 1

Over the past several semesters, 21.5% of students in Professor Brown's Experimental Psychology (PSYC 105) course earned an "A", 31.2% earned a "B", 30.1% earned a "C", 10.7% earned a "D", and 6.5% earned an "F". Last semester, Professor Brown covered the same curriculum in this course as in previous semesters, but she required her students to use a different textbook. That semester, 3 of Professor Brown's Experimental Psychology (PSYC 105) students received an "A", 7 received a "B", 5 received a "C", 2 received a "D", and 1 received an "F".

Test the hypothesis that changing the required textbook in this course resulted in no noticeable change in the final grade distribution of students. Based on this result, what can Professor Brown surmise regarding the final grade distribution of her students in this course last semester compared to previous semesters?

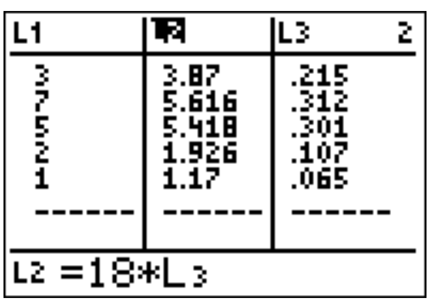
H_0 : All of the expected frequencies fit the observed frequencies.

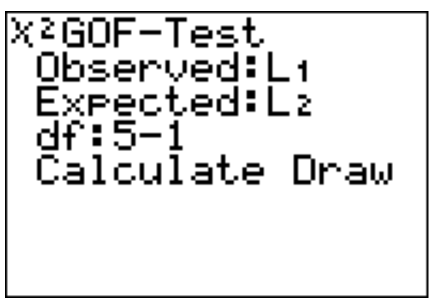
H_1 : Not all of the expected frequencies fit the observed frequencies.

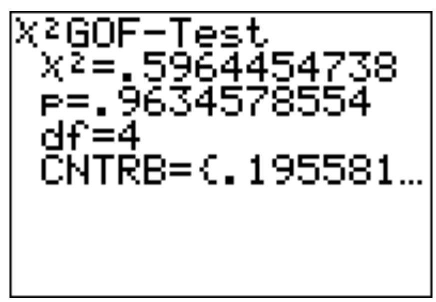
Use $\alpha = 0.05$

$n = 3 + 7 + 5 + 2 + 1 = 18$

$E_i = n \cdot p_i$ $\qquad df = c - 1 = 5 - 1 = 4$







p-value ≈ 0.963

Since the p-value of 0.963 is not 0.05 or less, the decision is to not reject H_0.

Therefore, all of the expected frequencies fit the observed frequencies. So, based on this result, Professor Brown should surmise that changing the required textbook in this course resulted in no noticeable change in the final grade distribution of her students compared to previous semesters.

Exercise 2

A report published by the United States Census Bureau revealed that 68% of families have two parents present, 23% have only a mother present, 5% have only a father present, and 4% have no parent present. A random sample of 200 families in the Lucas Valley School District resulted in 122 with two parents present, 59 with only a mother present, 7 with only a father present, and 12 with no parent present.

Use a Chi-Squared test and a 0.05 level of significance to determine if the published population percentages accurately reflect the distribution of families in the Lucas Valley School District. Based on this result, how does the distribution of families in the Lucas Valley School District compare to the general population?

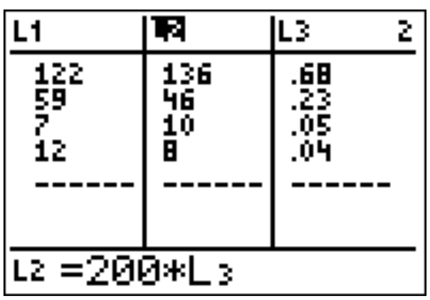
H_0 : All of the expected frequencies fit the observed frequencies.

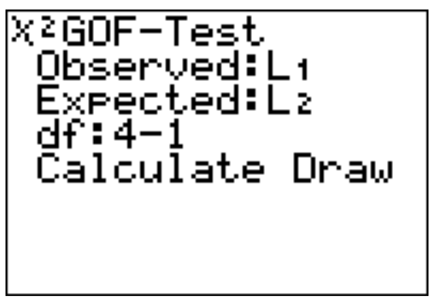
H_1 : Not all of the expected frequencies fit the observed frequencies.

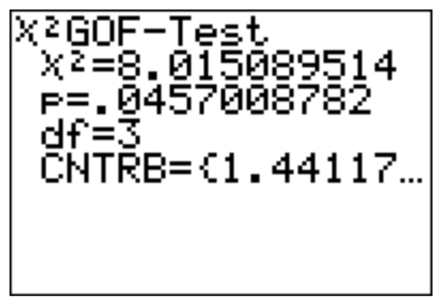
Use $\alpha = 0.05$

$$n = 122 + 59 + 7 + 12 = 200$$

$$E_i = n \cdot p_i \qquad df = c - 1 = 4 - 1 = 3$$







p-value ≈ 0.046

Since the p-value of 0.046 is 0.05 or less, the decision is to reject H_0.

Therefore, not all of the expected frequencies fit the observed frequencies. So, based on this result, the published population percentages do not accurately reflect the distribution of families in the Lucas Valley School District. The data indicate that the Lucas Valley School District has a higher percentage of families with only a mother present and no parent present and a lower percentage of families with two parents present and only a father present compared to the general population.

Exercise 3

Zentner Industries operates its manufacturing facility six days a week. The personnel department compiled a report detailing the sick leave usage by the company's employees. According to this report, in the past sixteen weeks a total of 29 sick leave days were used by employees on Monday, 17 on Tuesday, 14 on Wednesday, 16 on Thursday, 25 on Friday, and 32 on Saturday.

Use a Chi-Squared test with $\alpha = 0.05$ to decide if the total number of sick leave days used by employees of Zentner Industries is equally (or uniformly) distributed over the six days a week its manufacturing facility is in operation. Based on this result, what can the personnel department conclude about employee sick leave usage on Monday through Saturday?

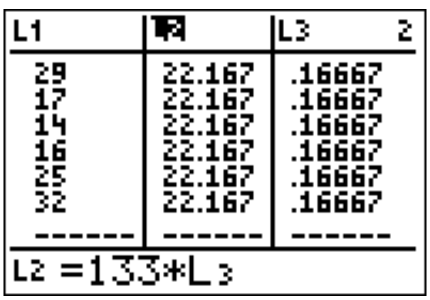
H_0 : All of the expected frequencies fit the observed frequencies.

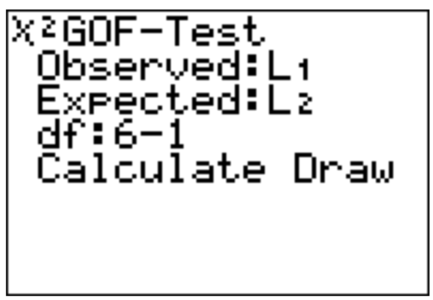
H_1 : Not all of the expected frequencies fit the observed frequencies.

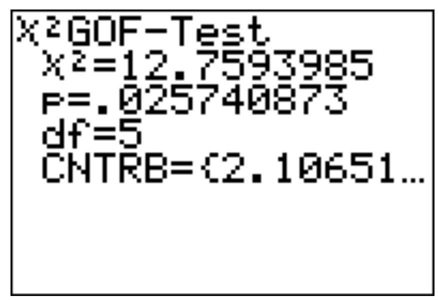
Use $\alpha = 0.05$

$n = 29 + 17 + 14 + 16 + 25 + 32 = 133$ $\qquad p_i = \frac{1}{6}$ when equally distributed over the six days a week

$E_i = n \cdot p_i$ $\qquad df = c - 1 = 6 - 1 = 5$







p-value ≈ 0.026

Since the p-value of 0.026 is 0.05 or less, the decision is to reject H_0.

Therefore, not all of the expected frequencies fit the observed frequencies. So, based on this result, the personnel department can conclude that the total number of sick leave days used by employees of Zentner Industries is not equally (or uniformly) distributed over the six days a week its manufacturing facility is in operation. The data indicate that a higher proportion of sick leave days are used on Saturday, Monday, and Friday, where as a lower proportion of sick leave days are used on Tuesday, Wednesday, and Thursday.

Exercise 4

The standard score for a random variable that follows a normal probability distribution will take on the following values with these corresponding probabilities.

Standard Score	Normal Probability
- 4.5 to - 1.5	0.0668
- 1.5 to - 0.5	0.2417
- 0.5 to + 0.5	0.3829
+ 0.5 to + 1.5	0.2417
+ 1.5 to + 4.5	0.0668

Observed Frequency
3
17
25
9
6

Use the Chi-Squared Goodness-of-Fit test and the Movie Database Sample to determine if it is reasonable to assume that the running time of movies follows a normal distribution.

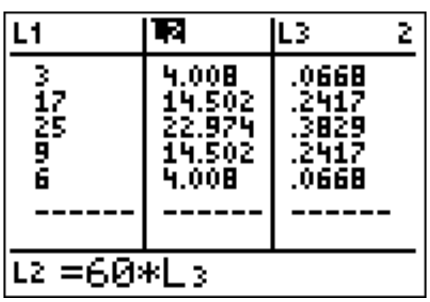
H_0 : All of the expected frequencies fit the observed frequencies.

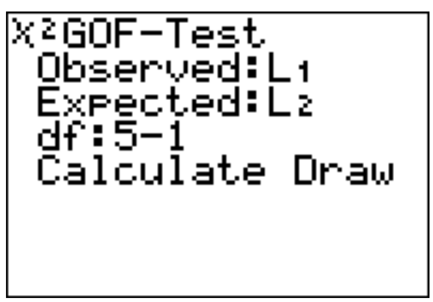
H_1 : Not all of the expected frequencies fit the observed frequencies.

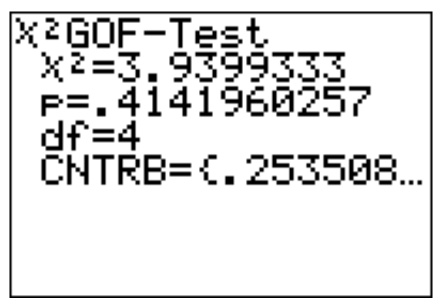
Use $\alpha = 0.05$

$n = 3 + 17 + 25 + 9 + 6 = 60$

$E_i = n \cdot p_i$ $\qquad df = c - 1 = 5 - 1 = 4$







p-value ≈ 0.414

Since the p-value of 0.414 is not 0.05 or less, the decision is to not reject H_0.

Therefore, all of the expected frequencies fit the observed frequencies. So, based on this result, it is reasonable to assume that the running time of movies follows a normal distribution.