17

PROBABILITY AND RELATIVE FREQUENCIES

PLAYING GAMES

17.01 How lucky are you?
17.02 Gambling games and systems
17.03 Coins and dice
17.04 Financial expectation
Keyword activity
Solution to chapter problem
SIMULATIONS
- perform simulations of experiments using technology (ACMEM150)
- identify factors that could complicate the simulation of real-world events. (ACMEM153)

PROBABILITY APPLICATIONS
- determine the probabilities associated with simple games (ACMEM157)

How are we ever going to use this?
- Determine experimental probabilities when we can't calculate a theoretical probability
- Solve chance problems when we can't work out a theoretical solution
- Calculate the expected financial gain or loss when we're playing chance games.

17.01 HOW LUCKY ARE YOU?

Most people think that success in games and gambling results from being lucky. While luck plays a part in lotteries and raffles, often knowledge of probability can give players an advantage when they are playing chance games.

INVESTIGATION How lucky are you?

You will need the spreadsheet 'How lucky are you?', which is available on NelsonNet, to complete this investigation.

In this activity you are going to assess your luck! The computer will be selecting one of the numbers 1, 2, 3, 4 or 5 at random. All you have to do is predict the computer's number accurately.

Work in pairs. One of you should make the predictions while the other records the number of times the prediction is right and the number of times it is wrong. Run the simulation 20 times, and then swap roles.

1. For any single guess, what is the probability that you will guess correctly?
2. How many times would you expect to guess correctly in 20 simulations?
3. Did you get more predictions correct than you estimated in question 2?
4. Assess your 'luck factor'. Are you luckier than normal?
You can be ‘lucky’ in situations other than games and gambling. Imagine that you have a life-threatening condition and your doctor is recommending surgery. Unfortunately, there is 1 chance in 10 that you will die during the operation. Will you be ‘lucky’ and survive the surgery?

**INVESTIGATION**  
**Will you be lucky in the surgery?**

To complete this investigation, you will need to use two spreadsheets, which are available on NelsonNet: ‘Will you survive the surgery?’ and ‘The life-threatening operation’.

1. There is 1 chance in 10 that you will die in the operation.
   a. What is the chance that you will survive the operation?
   b. Suggest some factors that can affect your chance of surviving the operation in real life.
   c. Run the ‘Will you survive the surgery?’ simulation. What happened? Were you ‘lucky’?
2. If 20 people in similar health had the operation, how many would you expect to die during the surgery?
3. Is the number you wrote for your answer to question 2, guaranteed?
4. Run the ‘Life-threatening operation’ spreadsheet 20 times. Record the most and the least number of people who died in the operation.
5. What conclusions can you make about chance situations and luck?

Can groups of people be ‘lucky’? Imagine that people entering a building are asked to guess a number from 1 to 20 without letting anyone else know the number. How many people do you think would need to make guesses before it is likely that any two of the people would have guessed the same number?

Believe it or not, if six people guess, it is more likely than not that two people will guess the same number! Check it out in the next investigation.
INVESTIGATION  

Guessing numbers from 1 to 20

You will need the spreadsheet ‘Guessing numbers from 1 to 20’ to complete this investigation. The spreadsheet is available on NelsonNet.

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<td>1</td>
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<td>20th person’s guess</td>
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</tbody>
</table>

1. Run the simulation 20 times and record the number of times the six guesses are all different.

2. In what percentage of the simulations did two or more people guess the same number?

3. Do you think that the people were just lucky or is something else happening?

4. Suggest some things that could complicate this guessing situation in a real-life context.

17.02 GAMBLING GAMES AND SYSTEMS

TV game shows, casino games and fundraising activities all have something in common. They are based on chance events. There are many systems and strategies that people use to ‘help them win’. In this section, we are going to look at some games.

Equipment required

To complete this section, each group will need:

- a normal deck of cards
- 4 place markers
- a set of 3 dice
- a large number of counters, approximately 200 per group
- computer access
EXERCISE 17.02 Gambling games and systems

1 The great race

In this game, four people use a deck of cards to play against the bank. Print a copy of the game sheet from NelsonNet to use in this investigation.

From a normal pack of 52 playing cards, select 10 cards as follows:
   one diamond       two clubs
   three spades       four hearts

Each player puts their counter on a different suit. The banker shuffles the 10 cards and deals one card face up from the top of the deck. The player with the same suit as that dealt moves their counter one space to the right. The banker replaces the card in the pack, shuffles the cards and continues to turn single cards up. The players move the corresponding counters until one counter reaches the finish. The first to reach the end of their row is the winner.

a  Play the game 20 times and record the winning suit each time.

b  For each suit, calculate the experimental probability of winning.

c  Explain why the game is not fair.

The bank charges players $1 each to enter the game, and it pays the winners different amounts. The table shows the amount the bank pays each winner.

<table>
<thead>
<tr>
<th>Suit</th>
<th>♠</th>
<th>♡</th>
<th>♣</th>
<th>♦</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prize</td>
<td>$6</td>
<td>$4</td>
<td>$3</td>
<td>$2</td>
</tr>
</tbody>
</table>

d  How much does the bank receive from 100 games?

e  Predict the number of times each suit will win in 100 games.

f  Predict the amount the bank will pay in prizes in 100 games.

g  How much profit can the bank expect to make from 100 games?

h  Explain why the bank requires four people to play each game.

i  Why do you think the bank pays the person who wins in the diamonds position more money than the winners in the other positions?

j  How could you change the rules to make this game fair?
2 Singles, doubles and triples

In this game, any number of people can use three dice to play against the bank. Print a copy of the game sheet from NelsonNet to use in this question.

The bank charges each player $1 to enter each game. Each player chooses a number from 1 to 6 and places their counter on the number. More than one person can choose the same number, and there can be numbers that aren't selected. The banker rolls three dice.

- If a player's number shows on one die, the banker pays the player $2.
- If a player's number shows on two dice, the banker pays the player $3.
- If the player's number shows on all three dice, the banker pays the player $4.
  a Roll three dice together 72 times and record the numbers of times the dice numbers are all different, two are the same and all three are the same.
  b Calculate the experimental probability of obtaining three single numbers, a double number and a triple number.
  c Do you think the payment system is fair to players? Why, or why not?

Give the banker about 80 counters and each player about 20 counters.

Play the game 20 times.

- How many players finished the 20 games with more than 20 counters?
- How did the numbers of counters that the bank had before and after the 20 games compare?
- How much profit can the bank expect to make from 100 games?

3 Roulette wheel

Roulette is a popular gambling game. There are 37 slots on an Australian roulette wheel. The slots are numbered from 0 to 36. The zero slot is green and there are an equal number of red and black slots for the numbers from 1 to 36. There are a variety of ways that people can gamble at roulette. Some people like to bet on the colour of the slot where the ball finishes.

Mike believes that he has a winning roulette strategy. He believes that it's unlikely for the ball to land on a black slot 4 times in a row. Mike watches the game and when the ball has landed on black 3 times in a row, he bets on red for the next roll. He claims that he always wins when he uses this strategy.

- Use the link to open the 'Roulette' spreadsheet.
- Find occasions in the simulation where the ball lands on black 3 times in a row and record the colour for the next time.
- Determine whether Mike's strategy is successful.
The TV game show

Imagine that you are the contestant on a TV game show. Behind one of three doors, Door 1, Door 2 or Door 3, there is a prize that you could win. The host asks you to choose a door and you choose Door 1. The host then shows you that the prize isn't behind Door 3. This means that the prize is behind Door 1 or Door 2. He invites you to change your mind. Should you stick with Door 1 or change to Door 2? Work in pairs to complete this activity. Each pair will need three cards from a normal pack of playing cards. You will also need a record sheet. To solve the game show dilemma, you are going to use three playing cards to determine how often the prize (represented by the joker) is the original card you selected and how often it is the other remaining card.

What you have to do

a. Decide who will be the 'game show host' and who will be the 'contestant'.

b. The host shuffles the cards, looks at them, then places them face down on the table.

c. The contestant chooses one card and moves it down.

d. The host displays one of the two remaining cards that is not the joker.

e. Turn over both of the remaining cards. Record whether the prize was the card originally selected by the contestant or whether it was the remaining card.

f. Perform the simulation at least 24 times.

g. Determine the percentage of the times that the prize was not the original card selected by the contestant.

h. Decide on the best strategy. Should the contestant stick with their original choice or change? Which position is the more likely to contain the prize?
COINS AND DICE

People have been playing games and gambling with coins and dice for thousands of years. The British Museum has dice that are probably more than 5000 years old, while traditionally, returned Australian soldiers play the coin game ‘Two-up’ on Anzac Day.

EXERCISE 17.03 Coins and dice

1 a What is the theoretical probability of getting a head when you toss a coin?
   b Toss a coin 40 times and record the number of heads that you get.
   c Use the data you obtained in part b to determine the experimental probability of getting a head when you toss a coin.
   d Calculate the difference between the theoretical probability of tossing a head and the experimental probability you obtained in part c.
   e Josie has been playing a game that involves tossing a coin. The coin was tossed 10 times and only landed heads three times. Josie thinks that either there is something wrong with the coin or that the people she is playing with are cheating. Follow the directions to help Josie decide whether her concerns are justified.
      i Use the link to open the ‘Heads and tails’ spreadsheet.
      ii Run the simulation 40 times and determine the experimental probability of getting 3 or fewer heads when you toss a coin 10 times.
      iii Josie expected to get heads about half of the time. Run the simulation numerous times and concentrate on the percentage of heads. In which group, 10, 50, 100, 200 or 300 tosses, does the percentage of heads change by the biggest amount?
      iv Write a sentence to explain how the percentage of heads obtained when you toss a coin changes as you increase the number of tosses.
      v Are Josie’s concerns about the coin, or the people she is playing with, justified? Explain.

2 Each group will need a pair of dice to complete this activity.

When you roll a pair of dice, which event do you think is more likely to happen?
   • a 1 or a 2 (or both) will show
   • neither a 1 nor a 2 will show
      a Roll the pair of dice 40 times and record how many times a 1 or a 2 (or both) shows.
      b Calculate the experimental probability that a 1 or a 2 (or both) shows.
      c Repeat your experiment to check your results.
      d The table lists all possible outcomes when a pair of dice is rolled.

<table>
<thead>
<tr>
<th>One die →</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</tbody>
</table>

What is the theoretical probability of rolling two numbers that are the same?
3 You will need to use the 'Sum of two dice' spreadsheet, available on NelsonNet, in this question.
This grid shows the possible outcomes when two dice are rolled together and the numbers showing on the dice are added together.
a Which sum occurs the most?
b Which two sums occur very infrequently?
c Which sum is more likely: a sum of 7 or a sum of 6?
d Which sum is more likely: a sum of 7 or a sum of 8?
Ross and Sam are playing a game. They are taking turns rolling a pair of dice and adding the numbers showing. Ross will win if he can roll a sum of 6 and a sum of 8 (or a sum of 8 and a sum of 6) before Sam can roll two sums of 7. Sam wins if two sums of 7 occur before a sum of 6 and a sum of 8.
e Who do you think will win more games: Ross or Sam? Why?
f Use the spreadsheet 'Sum of two dice' to simulate this game at least 24 times. Who won the most games in the simulation?
g Can you think of a reason why this person won more games? Was it just luck or is there a reason for the result?

4 Ari and Katrina are playing a dice game with three special dice.

RED

GREEN

BLUE

The numbers on the red die are 2, 2, 4, 4, 9 and 9.
The numbers on the green die are 1, 1, 6, 6, 8 and 8.
The numbers on the blue die are 3, 3, 5, 5, 7 and 7.
They each choose a die and then roll it. The winner is the person whose die shows the larger number.
This grid shows the die that wins when Ari and Katrina choose to roll the red and the green dice.
a Which die is more likely to win when Ari and Katrina use the red and green dice?
b Construct similar grids to determine which colour die is more likely to win when Katrina and Ari use the blue and green dice.
c Which die is more likely to win when they play with the red and the blue dice?
d If you were playing this game, what strategy could you use to give yourself the best chance of winning?

17.04 FINANCIAL EXPECTATION

The financial expectation of a chance situation involving money, such as a gambling game or the earnings from shares, is the average amount of money received from the situation over repeated trials. For example, a financial expectation of $2 means an average financial gain of $2 while a financial expectation of $-2 means an average financial loss of $2.

Financial expectation doesn't tell us anything about what will happen in each trial, only what will happen on average in the long run.

IMPORTANT

To calculate financial expectation, multiply each financial outcome by its probability and add the results together.

Example 1

Dimitri plays a game that involves tossing two coins. He wins $5 if both coins show heads and $1 if they show a head and a tail, but loses $6 if they both show tails. What is the financial expectation of this game?

Solution

Use a table to list the possible outcomes.

<table>
<thead>
<tr>
<th>First coin</th>
<th>H</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second coin</td>
<td>H</td>
<td>HH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HT</td>
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<tr>
<td></td>
<td>T</td>
<td>HT</td>
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<tr>
<td></td>
<td></td>
<td>TT</td>
</tr>
</tbody>
</table>

Use the table to write the probability of each outcome.

\[ P(HH) = \frac{1}{4} \]
\[ P(H \text{ and } T) = \frac{2}{4} \]
\[ P(TT) = \frac{1}{4} \]

Calculate the financial expectation.

Financial expectation
\[ = 5 \times P(HH) + 1 \times P(H \text{ and } T) + (-6) \times P(TT) \]
\[ = 5 \times \frac{1}{4} + 1 \times \frac{2}{4} - 6 \times \frac{1}{4} \]
\[ = 0.25 \]

Write the answer.

In the long run, Dimitri can expect to win an average of 25 cents each time he plays the game.
Financial expectation

1. Example 1: Jordan plays a game that involves tossing two coins. He wins $8 if both coins show tails, but loses $4 if the coins show one or two heads.
   a. Calculate the probability that the two tossed coins will show one or two heads.
   b. What is the financial expectation of this game?
   c. If Jordan plays the game once only, what are the possible financial outcomes?

2. Franko plays a game that involves rolling a pair of dice and adding the numbers that come up. He wins $20 if the sum is greater than 10 and loses $3 if the sum is 10 or less.
   a. Construct a grid to list all possible sums and use it to calculate the probability of rolling a sum greater than 10 on a pair of dice.
   b. What is the financial expectation of the game?
   c. What are the possible outcomes if Franko only plays the game once?

3. Samantha’s game involves rolling a pair of dice and selecting the higher number showing. She gains $36 if she scores a 1 or a 2 and she loses $4 if she scores any other number. You could use a spreadsheet or a grid from Exercise 17-03 to help you calculate the probabilities in this question.
   a. Calculate the probability that Samantha will score a number that is not 1 or 2.
   b. What is the financial expectation of this game?

4. Each time Jay rolls a die, he pays $2. If he rolls a 5 or a 6 he receives $7, if not he loses his $2. Calculate Jay’s financial expectation from the game.

5. Andrew is playing a gambling game with the following probabilities:
   - \(\frac{3}{8}\) chance of winning $100
   - \(\frac{1}{8}\) chance of winning $200
   - \(\frac{1}{2}\) chance of losing $150.
   What is Andrew’s financial expectation from this game?

6. Margo is selling raffle tickets to raise funds for the netball club. Tickets are $2 each and she sold 500. There are two cash prizes of $250 and $200. Bella bought one ticket.
   a. What is the probability that Bella won’t win either prize and will lose her $2 investment?
   b. Calculate Bella’s financial expectation from her single raffle ticket.

7. The table shows the possible outcomes when two 5-sided dice are rolled together.

<table>
<thead>
<tr>
<th>Second die</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>1</td>
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<td>5, 4</td>
<td>5, 5</td>
</tr>
</tbody>
</table>
a What is the probability of rolling two numbers that differ by 1?

b A dice game uses two 5-sided dice. A player's score is the difference between the higher and lower number showing on the dice. The table shows the payments in the game.

<table>
<thead>
<tr>
<th>Difference between the numbers</th>
<th>Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Win $2.50</td>
</tr>
<tr>
<td>2</td>
<td>Win $2</td>
</tr>
<tr>
<td>0, 3 or 4</td>
<td>Lose $3</td>
</tr>
</tbody>
</table>

Calculate the financial expectation of the game.

8 The probability of a ball stopping on a red number on a casino's roulette wheel is \( \frac{18}{37} \). The probability that the ball will stop on a black number is also \( \frac{18}{37} \), while the probability that it will stop on 0 (the only green number) is \( \frac{1}{37} \). Players pay $1 to play each game, and receive $2 if the ball lands on the colour they selected; otherwise they lose their $1 entry fee.

a Calculate a player's financial expectation for a $1 game.

b On average, over the long term, how much can the casino expect to win on each of these $1 bets?

c Write a short paragraph to explain why casinos rarely go broke.

**KEYWORD ACTIVITY**

Check your knowledge of chance words by completing this crossword. You can download a copy to write on from NelsonNet.

![Crossword](image)

**Clues**

**Across**

1 Without looking or trying

3 Two the same (plural)

5 Good fortune

7 The money you can expect to have at the end of a gambling session

8 A plan to help you win

9 Play games of chance to win money

10 Three the same (plural)

**Down clues**

1 A type of wheel used in gambling

2 A place used for gambling

4 A computer program we can use to simulate chance situations

6 A technique for imitating a situation

9 Predict the result without any thought or reason
CHAPTER PROBLEM

The Jets and the Rockets have made it into the basketball grand final series. The winner will be the first of the two teams to win four games. During the season, the Rockets have beaten the Jets in two of the five games they played against each other.

What is the most likely number of games that will be required to win the series?

SOLUTION TO THE CHAPTER PROBLEM

The probability that the Rockets will beat the Jets in any one game is \( \frac{2}{5} = 0.4 \). The solution to the problem is not obvious. The maximum number of games required in the series is 7.

A spreadsheet simulation is required. The following 100 pieces of data representing the number of games required was generated on the spreadsheet ‘The final series’ on NelsonNet.

<table>
<thead>
<tr>
<th>Number of games required</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>20</td>
<td>23</td>
<td>27</td>
<td>30</td>
</tr>
</tbody>
</table>

The most likely number of games required will be seven. Seven games will be required approximately 30% of the time. Only 20% of the time will the series be complete in four games.
CHAPTER PROBLEM

Grandma was born on 1 January 1940. Unfortunately, she can't look after herself at home anymore and she needs to enter an aged care facility. Aged care can be very expensive. She calculated that she will need $2850 per month to cover the facility charges and her other expenses.

Grandma has $150,000 in an allocated pension account earning 4.2% p.a. and she receives $900 per month from a Centrelink aged pension.

How long will Grandma's allocated pension last?