Lesson 4

Estimating Probabilities Through Repeated Experiments

Goals

- Describe (orally and in writing) patterns observed on a table or graph that show the relative frequency for a repeated experiment.
- Generalize (orally) that the cumulative relative frequency approaches the probability of the event as an experiment is repeated many times.
- Generate possible results that would or would not be surprising for a repeated experiment, and justify (orally) the reasoning.

Learning Targets

- I can estimate the probability of an event based on the results from repeating an experiment.
- I can explain whether certain results from repeated experiments would be surprising or not.

Access for Students with Diverse Abilities

- Action and Expression (Activity 1)

Access for Multilingual Learners

- MLR8: Discussion Supports (Activity 1)

Required Materials

Materials to Gather

- Graph paper: Activity 1
- Number cubes: Activity 1

Required Preparation

Activity 1:
Requires 1 number cube for every 3 students. Access to graph paper may be useful, but is not required.

Lesson Narrative

In this lesson students roll a number cube many times and calculate the cumulative fraction of the trials for which an event occurs to see that in the long run this relative frequency approaches the probability of the event. Students must examine the structure of the repeated trials to recognize the connection between long-run frequency and probability. They also see that the relative frequency of a chance event will not usually exactly match the actual probability. For example, when flipping a coin 100 times, the coin may land showing a head 46 times instead of exactly 50 times and not be considered unreasonable.

Student Learning Goal

Let's do some experimenting.

Lesson Timeline

Warm-up	Activity 1	Activity 2	Lesson Synthesis	Cool-down (Assessment)
5 min	20 min	10 min	10 min	5 min

Warm-up
Decimals on the Number Line

5 min

Activity Narrative

The purpose of this *Warm-up* is for students to practice placing numbers represented with decimals on a number line and thinking about probabilities of events that involve the values of the numbers. Values between 0 and 1, such as the ones found here, are related to probabilities students will see in later activities. They will also need to be able to plot probabilities.

Launch

Arrange students in groups of 2.

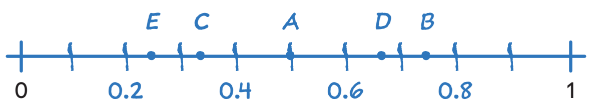
Give students 2 minutes of quiet work time followed by time to share their responses with a partner.

Follow with a whole-class discussion.

Student Task Statement

1. Locate and label these numbers on the number line.

A. 0.5
B. 0.75
C. 0.33
D. 0.67
E. 0.25



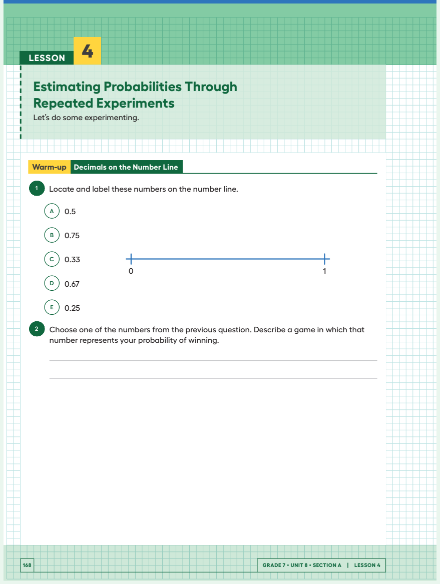
2. Choose one of the numbers from the previous question. Describe a game in which that number represents your probability of winning.

Sample response: Get blue when randomly selecting a color from the primary colors: red, yellow, and blue. This has a probability of 0.33.

Activity Synthesis

Select some partners to share their responses and methods for positioning the points on the number line. If time allows, select students to share a chance event for each of the values listed.

Student Workbook


LESSON 4

Estimating Probabilities Through Repeated Experiments

Let's do some experimenting.

Warm-up Decimals on the Number Line

1 Locate and label these numbers on the number line.

A 0.5
B 0.75
C 0.33
D 0.67
E 0.25

0 1

2 Choose one of the numbers from the previous question. Describe a game in which that number represents your probability of winning.

Activity 1

In the Long Run

20 min

Activity Narrative

There is a digital version of this activity.

This activity begins to address how to find the probability when the sample space is not known. Students have the opportunity to use this experiment for which the sample space is available to check its agreement and estimate based on repeating the experiment many times.

Students make the connection between probability and the fraction of outcomes for which the event occurs in the long-run. This activity highlights that a probability describes what happens in the long run and that it does not guarantee that the event will occur a specific number of times after any specific number of trials. For example, an event that has probability 0.6 means that the event will occur about 60% of the time in the long run, but it does not mean that it will occur exactly 60 times when the experiment is performed 100 times.

In the digital version of the activity, students use an applet to play and plot the cumulative fraction of wins for a game. The applet allows students to focus on visualizing the cumulative fraction as narrowing in on the probability. Use the digital version if students would benefit from concentrating on the current mathematical goals rather than reviewing how to plot values on a coordinate plane.

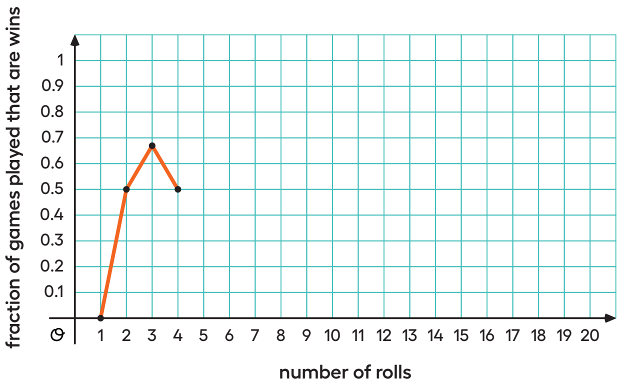
Launch

Arrange students in groups of 3. Provide 1 standard number cube for each group. Following the teacher demonstration, allow 10 minutes for group work, followed by a whole-class discussion.

Read or ask a student to read the problem stem explaining the win condition for Mai.

Display the table and graph for all to see as an example of how to fill in the table and graph the results. Demonstrate how to compute and plot the current fraction of the games that are wins. Display possible results such as these.

roll	number rolled	total number of wins for Mai	fraction of games that are wins
1	5	0	0
2	1	1	$\frac{1}{2} = 0.50$
3	2	2	$\frac{2}{3} \approx 0.67$
4	4	2	$\frac{2}{4} = 0.50$



To help students understand the graph, consider asking these questions.

"Why does the y-axis only show 0 to 1?"

It represents the cumulative fraction of games that are won. It only makes sense to win all of the time with 1, none of the time with 0, or with values between.

"What does the point at (3,0.67) represent?"

It means that after 3 times playing the game, Mai has won about 67% of the time.

Student Task Statement

Mai plays a game in which she only wins if she rolls a 1 or a 2 with a standard number cube.

1. List the outcomes in the sample space for rolling the number cube.

   Sample space: 1, 2, 3, 4, 5, 6.

2. What is the probability Mai will win the game? Explain your reasoning.

   Mai should win with probability $\frac{2}{6} = \frac{1}{3}$, since 2 out of the 6 numbers win.

Building on Student Thinking

Students may not notice a pattern in the graph. Ask if they can see a pattern with the decimal values for the fraction of wins in their table. If their data does not fit the expected pattern, tell them that this is not typical and ask them to look at another group's results.

Student Workbook


1 In the Long Run

Mai plays a game in which she only wins if she rolls a 1 or a 2 with a standard number cube.

1. List the outcomes in the sample space for rolling the number cube.

2. What is the probability Mai will win the game? Explain your reasoning.

3. If Mai is given the option to flip a coin and win if it comes up heads, is that a better option for her to win?

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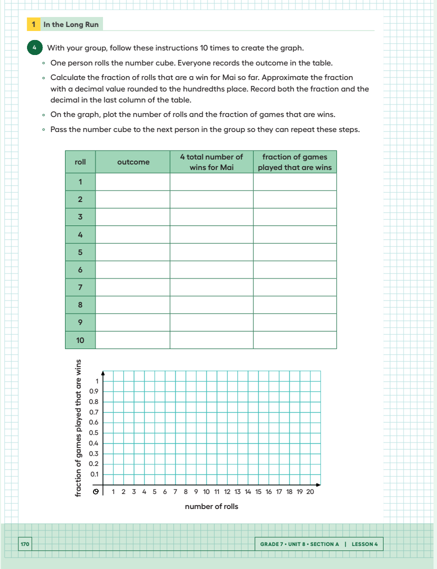
Student Workbook


1 In the Long Run

4 With your group, follow these instructions 10 times to create the graph.

- One person rolls the number cube. Everyone records the outcome in the table.
- Calculate the fraction of rolls that are a win for Mai so far. Approximate the fraction with a decimal value rounded to the hundredths place. Record both the fraction and the decimal in the last column of the table.
- On the graph, plot the number of rolls and the fraction of games that are wins.
- Pass the number cube to the next person in the group so they can repeat these steps.

roll	outcome	4 total number of wins for Mai	fraction of games played that are wins
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

3. If Mai is given the option to flip a coin and win if it comes up heads, is that a better option for her to win?

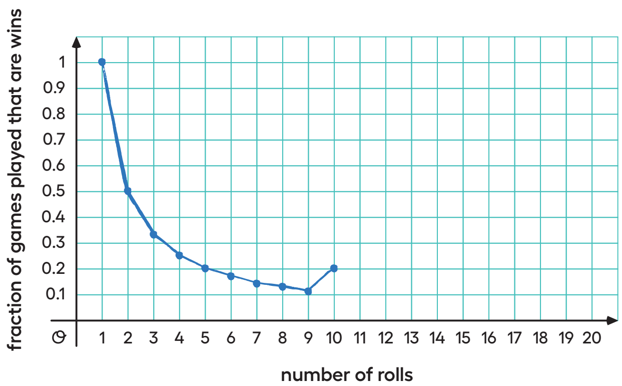
Flipping the coin gives Mai a better chance of winning, since the probability of getting heads is $\frac{1}{2}$. That is greater than $\frac{1}{3}$ for the number cube.

4. With your group, follow these instructions 10 times to create the graph.

- One person rolls the number cube. Everyone records the outcome in the table.
- Calculate the fraction of rolls that are a win for Mai so far. Approximate the fraction with a decimal value rounded to the hundredths place. Record both the fraction and the decimal in the last column of the table.
- On the graph, plot the number of rolls and the fraction of games that are wins.
- Pass the number cube to the next person in the group so they can repeat these steps.

Sample response:

roll	outcome	total number of wins for Mai	fraction of games played that are wins
1	2	1	$\frac{1}{1} = 1$
2	3	1	$\frac{1}{2} = 0.5$
3	6	1	$\frac{1}{3} \approx 0.33$
4	4	1	$\frac{1}{4} = 0.25$
5	5	1	$\frac{1}{5} = 0.2$
6	3	1	$\frac{1}{6} \approx 0.17$
7	5	1	$\frac{1}{7} \approx 0.14$
8	4	1	$\frac{1}{8} \approx 0.13$
9	5	1	$\frac{1}{9} \approx 0.11$
10	2	2	$\frac{2}{10} = 0.2$



5. Describe how the graph changes as the number of rolls increases.

Sample response: The graph starts at 1 since the first roll was a win, and then it keeps decreasing toward 0.1 since rolls 2–9 were losses. Then there is a slight increase at roll 10 since that roll was a win.

6. a. After 10 rolls, what fraction of the total rolls are a win?

Sample response: $\frac{2}{10}$

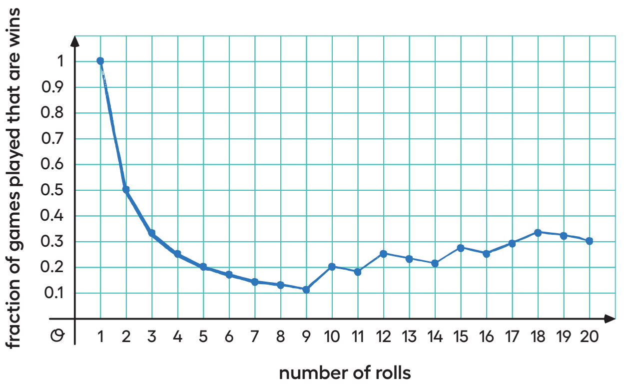
b. How close is this fraction to the probability that Mai will win?

Sample response: $\frac{2}{15} \approx 0.13$ below the expected probability since $\frac{1}{3} - \frac{2}{10} = \frac{2}{15}$

7. Roll the number cube 10 more times. Record your results in this table and on the graph from earlier.

Sample response:

roll	outcome	total number of wins for Mai	fraction of games played that are wins
11	6	2	$\frac{2}{11} \approx 0.18$
12	1	3	$\frac{3}{12} = 0.25$
13	6	3	$\frac{3}{13} \approx 0.23$
14	5	3	$\frac{3}{14} \approx 0.21$
15	1	4	$\frac{4}{15} \approx 0.27$
16	6	4	$\frac{4}{16} = 0.25$
17	1	5	$\frac{5}{17} \approx 0.29$
18	2	6	$\frac{6}{18} \approx 0.33$
19	5	6	$\frac{6}{19} \approx 0.32$
20	4	6	$\frac{6}{20} = 0.3$



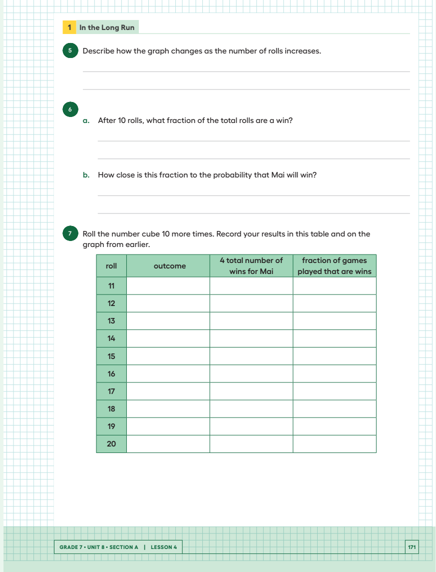
8. a. After 20 rolls, what fraction of the total rolls are wins?

Sample response: $\frac{6}{20}$

b. How close is this fraction to the probability that Mai will win?

Sample response: The current fraction of rolls that are wins is $\frac{6}{20}$, but I expect the probability to be $\frac{2}{6}$, so they are about 0.03 apart.

Student Workbook


1 In the Long Run

5 Describe how the graph changes as the number of rolls increases.

6 a. After 10 rolls, what fraction of the total rolls are a win?

b. How close is this fraction to the probability that Mai will win?

7 Roll the number cube 10 more times. Record your results in this table and on the graph from earlier.

roll	outcome	total number of wins for Mai	fraction of games played that are wins
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

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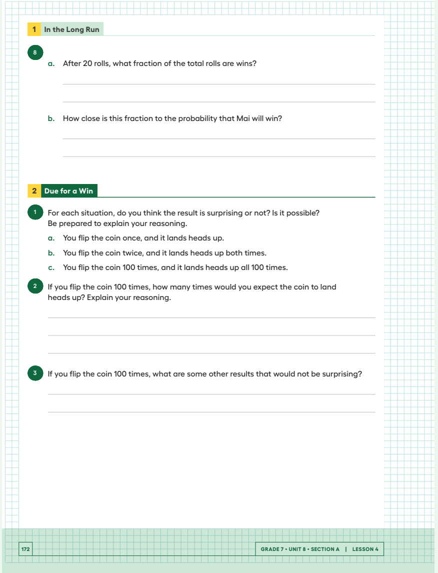
Student Workbook


1 In the Long Run

8 a. After 20 rolls, what fraction of the total rolls are wins?

b. How close is this fraction to the probability that Mai will win?

2 Due for a Win

1 For each situation, do you think the result is surprising or not? Is it possible? Be prepared to explain your reasoning.

a. You flip the coin once, and it lands heads up.

b. You flip the coin twice, and it lands heads up both times.

c. You flip the coin 100 times, and it lands heads up all 100 times.

2 If you flip the coin 100 times, how many times would you expect the coin to land heads up? Explain your reasoning.

3 If you flip the coin 100 times, what are some other results that would not be surprising?

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Access for Students with Diverse Abilities (Activity 1, Synthesis)

Action and Expression: Provide Access for Physical Action. Support effective and efficient use of tools and assistive technologies. To use the table or the digital applet, some students may benefit from a demonstration or access to step-by-step instructions.

Supports accessibility for: Organization, Memory, Attention

Access for Multilingual Learners (Activity 1, Synthesis)

MLR8: Discussion Supports. Revoice student ideas to demonstrate and amplify mathematical language use. For example, revoice the student statement “at the end it goes like this” as “in the long run the graph levels out.”

Advances: Speaking, Representing

Activity Synthesis

The purpose of this discussion is for students to understand that computing the fraction of the time an event occurs can be used to estimate the probability of the event and that more repetitions should make the estimation more accurate.

Select some students to share their answer and reasoning for the probability that Mai will win the game. If it is not mentioned by students, tell them that the probability of an event is the number of outcomes in the given event divided by the number of outcomes in the sample space. In this example, there are 2 outcomes that win (a roll of 1 or 2), and 6 outcomes in the sample space, so the probability of winning is $\frac{2}{6}$, which is equivalent to $\frac{1}{3}$.

Collect the number of 1s and 2s for each group and compute the fraction for the whole class with all the data. The value should be very close to $\frac{1}{3}$.

Select students to share their thoughts on what appears to be happening with the points on their graph. (They are leveling out around 0.33.) If students struggle with noticing that the points are leveling out at a y-value around 0.33, ask them to draw a horizontal line on their graph at their answer for the probability they got in the second question.

Ask the class how many times the entire class rolled number cubes. Then ask,

“Based on the probability predicted in the second question, how many times do we expect the class to have simulated a win for Mai? How does this compare to the actual number of wins the class rolled?”

Collect the number of wins for each group and compute the fraction for the whole class with all the data. The value should be very close to $\frac{1}{3}$.

A probability tells us how likely an event is to occur. While it is not guaranteed to be an exact match, if the chance experiment is repeated many times, we expect the fraction of times that an event occurs to be fairly close to the calculated probability.

Activity 2
Due for a Win

10 min

Activity Narrative

This activity gives students the opportunity to see that an estimate of the probability for an event should be close to what is expected from the exact probability in the long run. However, the outcome for a chance event is not guaranteed, and estimates of the probability for an event using short-term results will not usually match the actual probability exactly.

Launch

Tell students that the probability of a coin landing heads up after a flip is $\frac{1}{2}$.

Give students 5 minutes of quiet work time, and follow with a whole-class discussion.

Student Task Statement

1. For each situation, do you think the result is surprising or not? Is it possible? Be prepared to explain your reasoning.

   a. You flip the coin once, and it lands heads up.

   It is not surprising, and it is possible.

   b. You flip the coin twice, and it lands heads up both times.

   It is a little more rare than the first one, but not very surprising. It is possible.

   c. You flip the coin 100 times, and it lands heads up all 100 times.

   It is very surprising, and we may suspect the coin is not fair. It is possible, though.

2. If you flip the coin 100 times, how many times would you expect the coin to land heads up? Explain your reasoning.

   It should be heads up about 50 times out of the 100

   Sample reasoning: Since the probability is $\frac{1}{2}$, there should be about the same number of heads and tails.

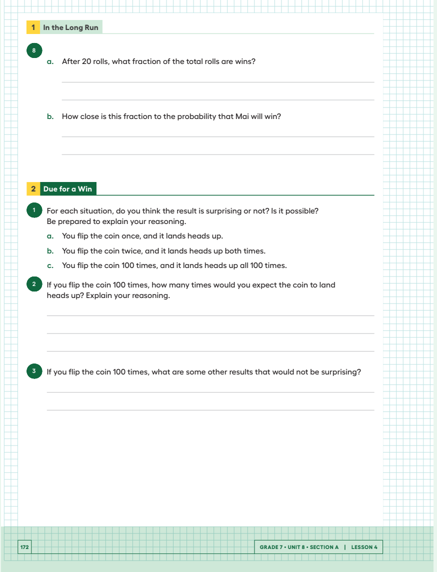
3. If you flip the coin 100 times, what are some other results that would not be surprising?

   Answers should range from approximately 40 to 60.

4. You've flipped the coin 3 times, and it has landed heads up once. The cumulative fraction of heads is currently $\frac{1}{3}$. If you flip the coin one more time, will it land heads up to make the cumulative fraction $\frac{2}{4}$?

   Not necessarily. There's still a 50% chance it will come up tails.

Student Workbook



1 In the Long Run

8

a. After 20 rolls, what fraction of the total rolls are wins?

b. How close is this fraction to the probability that Mai will win?

2 Due for a Win

1 For each situation, do you think the result is surprising or not? Is it possible? Be prepared to explain your reasoning.

a. You flip the coin once, and it lands heads up.

b. You flip the coin twice, and it lands heads up both times.

c. You flip the coin 100 times, and it lands heads up all 100 times.

2 If you flip the coin 100 times, how many times would you expect the coin to land heads up? Explain your reasoning.

3 If you flip the coin 100 times, what are some other results that would not be surprising?

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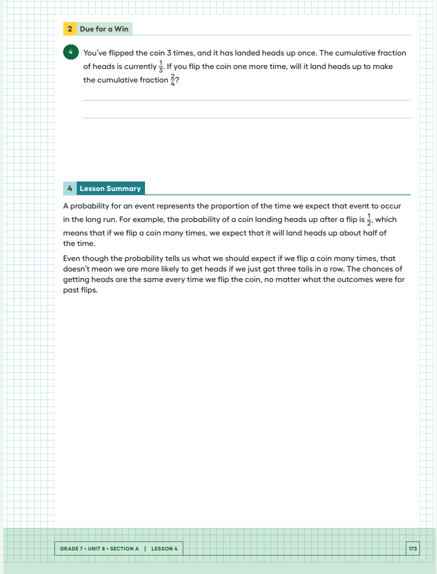
Activity Synthesis

The purpose of the discussion is for students to recognize that the actual results from repeating an experiment should be close to the expected probability, but may not match exactly.

For the first problem, ask students to indicate whether or not they think each result seems surprising. For the second and third questions, select several students to provide answers and display for all to see, then create a range of values that might not be surprising based on student responses. Ask the class if they agree with this range or to provide a reason the range is too large. It is not important for the class to get exact values, but a general agreement should arise that some range of values makes sense so that there does not need to be exactly 50 heads from the 100 flips.

An interesting problem in statistics is trying to define when things get "surprising." Flipping a fair coin 100 times and getting 55 heads should not be surprising, but getting either 5 or 95 heads probably is. Although there is not a definite answer for this, a deeper study of statistics using additional concepts in a later course can provide more information to help choose a good range of values.

Student Workbook



2 Due for a Win

4 You've flipped the coin 3 times, and it has landed heads up once. The cumulative fraction of heads is currently $\frac{1}{3}$. If you flip the coin one more time, will it land heads up to make the cumulative fraction $\frac{2}{4}$?

4 Lesson Summary

A probability for an event represents the proportion of the time we expect that event to occur in the long run. For example, the probability of a coin landing heads up after a flip is $\frac{1}{2}$, which means that if we flip a coin many times, we expect that it will land heads up about half of the time.

Even though the probability tells us what we should expect if we flip a coin many times, that doesn't mean we are more likely to get heads if we just got three tails in a row. The chances of getting heads are the same every time we flip the coin, no matter what the outcomes were for past flips.

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Explain that a probability represents the expected likelihood of an event occurring for a single trial of an experiment. Regardless of what has come before, each coin flip should still be equally likely to land heads up as tails up.

As another example: A basketball player who tends to make 75% of their free throw shots will probably make about $\frac{3}{4}$ of the free throws they attempt, but there is no guarantee they will make any individual shot even if they have missed a few in a row.

Lesson Synthesis

Consider asking these questions:

- *"You conduct a chance experiment many times and record the outcomes. How are these outcomes related to the probability of a certain event occurring?"*

  The fraction of times the event occurs after many repetitions should be fairly close to the expected probability of the event.

- *"What is the probability of rolling a 2, 3, or 4 on a standard number cube? If you roll 3 times and none of them result in a 2, 3, or 4, does the probability of getting one of those values change with the next roll?"*

  The probability is 0.5 since 3 outcomes out of 6 possible are in the event. The probability should not change after 3 times. If a 2, 3, or 4 does not appear after a lot of rolls—say, 100—then we might suspect the number cube of being non-standard.

- *"The probability of getting the flu during flu season is 18. If a family has 8 people living in the same house, is it guaranteed that one of them will get the flu? If a country has 8 million people, about how many do you expect will get the flu? Does this number have to be exact?"*

  No, it is possible that none of the people in the family will get the flu, and it is also possible that more than 1 person will get the flu. We might expect about 1 million people in the country to get the flu, but this is probably not exact.

Lesson Summary

A probability for an event represents the proportion of the time we expect that event to occur in the long run. For example, the probability of a coin landing heads up after a flip is $\frac{1}{2}$, which means that if we flip a coin many times, we expect that it will land heads up about half of the time.

Even though the probability tells us what we should expect if we flip a coin many times, that doesn't mean we are more likely to get heads if we just got three tails in a row. The chances of getting heads are the same every time we flip the coin, no matter what the outcomes were for past flips.

Cool-down

Fiction or Nonfiction?

5 min

Student Task Statement

A librarian is curious about the habits of the library's patrons. He records the type of item that the first 10 patrons check out from the library.

patron	item type
1	fiction book
2	nonfiction book
3	fiction book
4	fiction book
5	audiobook
6	nonfiction book
7	DVD
8	nonfiction book
9	fiction book
10	DVD

Based on the information from these patrons ...

1. Estimate the probability that the next patron will check out a fiction book. Explain your reasoning.

   $\frac{4}{10}$ or equivalent

   Sample reasoning: 4 of the 10 patrons in the list checked out fiction books.

2. Estimate the number of DVDs that will be checked out for every 100 patrons. Explain your reasoning.

   20 DVDs

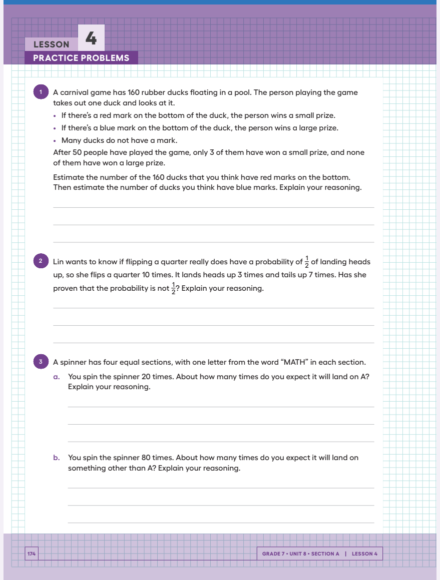
   Sample reasoning: Since 2 of the 10 patrons in the list checked out DVDs, which is $\frac{1}{5}$ of the patrons, we can expect $\frac{1}{5}$ of every 100 patrons to check out DVDs. $\frac{1}{5}$ of 100 is 20.

Responding To Student Thinking

Points to Emphasize
If students struggle with estimating probabilities from the results of a few trials, revisit this as opportunities arise over the next several lessons. For example, the activity referred to here can be used to discuss strategies for using experimental results to estimate probability.

Unit 8, Lesson 5, Activity 1 Making My Head Spin

Student Workbook


LESSON 4
PRACTICE PROBLEMS

1. A carnival game has 160 rubber ducks floating in a pool. The person playing the game takes out one duck and looks at it.
- If there's a red mark on the bottom of the duck, the person wins a small prize.
- If there's a blue mark on the bottom of the duck, the person wins a large prize.
- Many ducks do not have a mark.

After 50 people have played the game, only 3 of them have won a small prize, and none of them have won a large prize.

Estimate the number of the 160 ducks that you think have red marks on the bottom. Then estimate the number of ducks you think have blue marks. Explain your reasoning.

2. Lin wants to know if flipping a quarter really does have a probability of $\frac{1}{2}$ of landing heads up, so she flips a quarter 10 times. It lands heads up 3 times and tails up 7 times. Has she proven that the probability is not $\frac{1}{2}$? Explain your reasoning.

3. A spinner has four equal sections, with one letter from the word "MATH" in each section.

a. You spin the spinner 20 times. About how many times do you expect it will land on A? Explain your reasoning.

b. You spin the spinner 80 times. About how many times do you expect it will land on something other than A? Explain your reasoning.

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Lesson 4

Practice Problems

6 Problems

Problem 1

A carnival game has 160 rubber ducks floating in a pool. The person playing the game takes out one duck and looks at it.

- If there's a red mark on the bottom of the duck, the person wins a small prize.
- If there's a blue mark on the bottom of the duck, the person wins a large prize.
- Many ducks do not have a mark.

After 50 people have played the game, only 3 of them have won a small prize, and none of them have won a large prize.

Estimate the number of the 160 ducks that you think have red marks on the bottom. Then estimate the number of ducks you think have blue marks. Explain your reasoning.

Sample response: There are about 10 ducks with red marks on the bottom and 3 or fewer ducks with blue marks on the bottom.

- Since $\frac{3}{50}$ of the people won a small prize, the probability of getting a duck with a red mark appears to be around 0.06. Since $0.06 \cdot 160 = 9.6$, there are probably 9 or 10 ducks that have red marks out of the 160. If 9 of the ducks have a red mark, then the probability is $\frac{9}{160} = 0.05625$. If 10 of the ducks have a red mark, then the probability is $\frac{10}{160} = 0.0625$.
- The probability of getting a duck with a blue mark appears to be less than $\frac{1}{50}$, or 0.02. Since $0.02 \cdot 160 = 3.2$, there are probably 3 or fewer ducks that have a blue mark out of the 160. If 3 ducks have a blue mark, then the probability is $\frac{3}{160} = 0.01875$. If 1 or 2 ducks have a blue mark, then the probability is lower but still positive.

Problem 2

Lin wants to know if flipping a quarter really does have a probability of $\frac{1}{2}$ of landing heads up, so she flips a quarter 10 times. It lands heads up 3 times and tails up 7 times. Has she proven that the probability is not $\frac{1}{2}$? Explain your reasoning.

No

Sample reasoning: The actual results from experiments may only get close to the expected probability if they are done many, many times. Ten flips may not be enough to get close to the expected $\frac{1}{2}$ probability.

Problem 3

A spinner has four equal sections, with one letter from the word "MATH" in each section.

a. You spin the spinner 20 times. About how many times do you expect it will land on A? Explain your reasoning.

About 5 times

Sample reasoning: $\frac{1}{4} \cdot 20 = 5$.

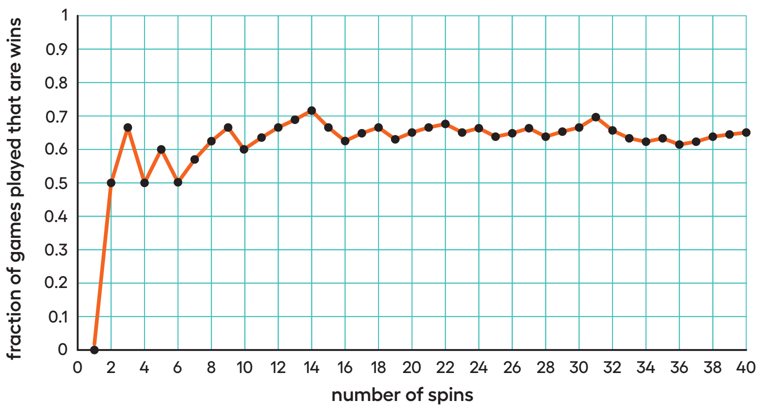
b. You spin the spinner 80 times. About how many times do you expect it will land on something other than A? Explain your reasoning.

About 60 times

Sample reasoning: $\frac{3}{4} \cdot 80 = 60$.

Problem 4

A spinner is spun 40 times for a game. Here is a graph showing the fraction of games that are wins under some conditions.



Estimate the probability of a spin winning this game based on the graph.

0.65

Problem 5

from Unit 8, Lesson 2

Which event is more likely: rolling a standard number cube and getting an even number, or flipping a coin and having it land heads up? Explain your reasoning.

Both events are equally likely.

Sample reasoning:

- Each event has a 50% chance of occurring.
- Both events are as likely to happen as to not happen.

Student Workbook


4 Practice Problems

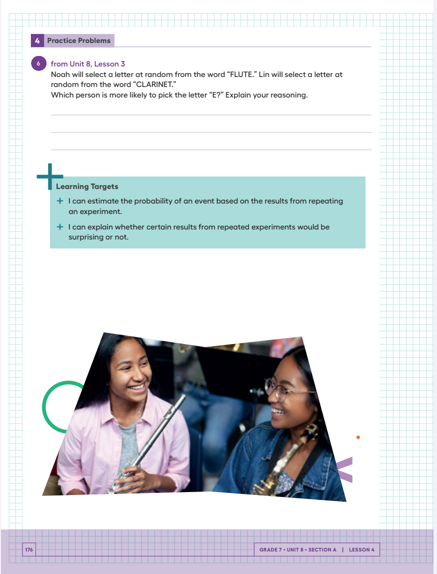
4 A spinner is spun 40 times for a game. Here is a graph showing the fraction of games that are wins under some conditions.

Estimate the probability of a spin winning this game based on the graph.

5 from Unit 8, Lesson 2

Which event is more likely: rolling a standard number cube and getting an even number, or flipping a coin and having it land heads up? Explain your reasoning.

Student Workbook


Practice Problems

6 from Unit 8, Lesson 3

Noah will select a letter at random from the word "FLUTE." Lin will select a letter at random from the word "CLARINET."

Which person is more likely to pick the letter "E?" Explain your reasoning.

Learning Targets

+ I can estimate the probability of an event based on the results from repeating an experiment.
+ I can explain whether certain results from repeated experiments would be surprising or not.

Problem 6

from Unit 8, Lesson 3

Noah will select a letter at random from the word "FLUTE." Lin will select a letter at random from the word "CLARINET."

Which person is more likely to pick the letter "E?" Explain your reasoning.

Noah

Sample reasoning: Getting the letter "E" is more likely when selecting from the word "FLUTE" because there are fewer possible outcomes in the sample space, and each outcome is equally likely.