MATH 1700

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Chapter 5

Department of Mathematical and Statistical Sciences

CHAPTER 5

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Be The Difference.

- Random Variables
  - Discrete
  - Continuous
- Probability function
- Probability distribution
- Mean
- Variance
- Standard deviation
- Binomial
  - Probability experiment
  - Probability function
  - Mean
  - Variance

USA AND ITS AUTOMOBILES AND RANDOM VARIABLE

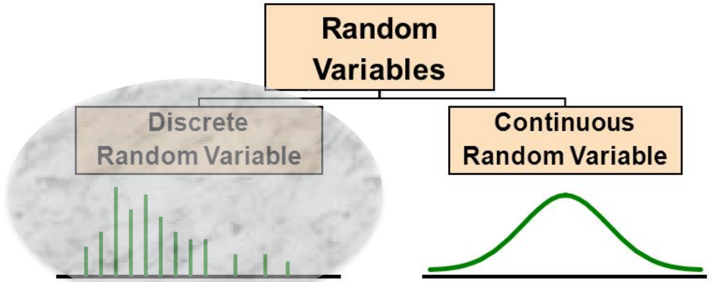
- The national average is 2.28 vehicles per household, with nearly 34% being single-vehicle and 31% being two-vehicle households. However, nearly 35% of all households have three or more vehicles.

Vehicles, *x*	1	2	3	4	5	6	7	8
P(*x*)	0.34	0.31	0.22	0.06	0.03	0.02	0.01	0.01

- **Random variable** A variable that assumes a unique numerical value for each of the outcomes in the sample space of a probability experiment.
  - X = # of vehicles in a household is a random variable

- Another example: Let Y = the number of heads when we flip a coin twice.
  - Sample Space: $S = \{TT, TH, HT, HH\}$
  - Random Variable: $Y = \{0, 1, 2\}$

RANDOM VARIABLES - EXAMPLES



- **Discrete random variable** A quantitative random variable that can assume a countable number of values. Examples:
  - We toss five coins and observe the "number of heads" visible. The random variable x is the number of heads observed and may take on integer values from 0 to 5.
  - Let the "number of phone calls received" per day by a company be the random variable. Integer values ranging from zero to some very large number are possible values.

- **Continuous random variable** A quantitative random variable that can assume an uncountable (continuum of values) number of values. Example:
  - Let the "length of the cord" on an electrical appliance be a random variable. The random variable is a numerical value between 12 and 72 inches for most appliances.

PROBABILITY DISTRIBUTIONS OF A DISCRETE RANDOM VARIABLE

$S = \{HH, HT, TH, TT\}$

- **Consider a coin-tossing experiment where two coins are tossed and no heads, one head, or two heads are observed.**
- **If we define the random variable x to be the number of heads observed when two coins are tossed, then**
  - $P\,(x = 0) = P\,(\text{no H}) = P\,(TT) = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4} = \; 0.25$
  - $P\,(x = 1) = P\,(\text{one H}) = P\,(HT\ or\ TH) = \frac{1}{2} \times \frac{1}{2} + \frac{1}{2} \times \frac{1}{2} = \frac{1}{2} = 0.50$
  - $P\,(x = 2) = P\,(\text{two H}) = P\,(HH) = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4} = \; 0.25$
- **Probability distribution: A distribution of the probabilities associated with each of the values of a random variable. The probability distribution is a theoretical distribution; it is used to represent populations.**

x	*P*(*x*)
0	0.25
1	0.50
2	0.25

Probability Distribution: Tossing Two Coins

PROBABILITY DISTRIBUTIONS OF A DISCRETE RANDOM VARIABLE

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- **Another example: Rolling a die**

x	1	2	3	4	5	6
$P(x)$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$

- **Probability function A rule, $P(x)$, that assigns probabilities to the values of the random variables.**
  - **The probability function for the experiment of rolling a die is**
    - $\underbrace{P(x) = \frac{1}{6}}$, for $x = 1, 2, 3, 4, 5, 6$
  - **The probability function for the number of heads observed when two coins are tossed:**
    - $P(x) = \frac{2!}{x!(2-x)!}\left(\frac{1}{2}\right)^{x}\left(\frac{1}{2}\right)^{2-x}$, for $x = 0,1,2$

x	P(x)
0	0.25
1	0.50
2	0.25

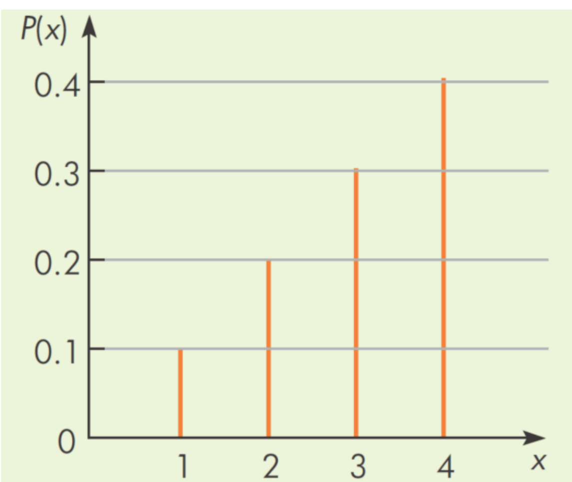
- **Properties:**
  - **Property 1:** $0 \leq P(x) \leq 1$
  - **Property 2:** $\sum_{\text{all x}} P(x) = 1$

EXAMPLE 2 – DETERMINING A PROBABILITY FUNCTION

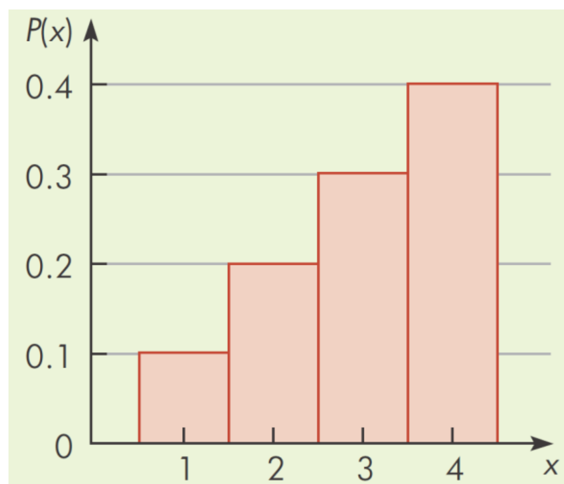
- **Example: Is $P(x) = \frac{x}{10}$, for $x = 1, 2, 3, 4$ a probability function?**
- **Solution:**
  - **Property 1:** $0 \leq P(x) \leq 1$
  - **Property 2:** $\sum_{\text{all x}} P(x) = 1$
- **Question: What is $P(x = 5)$?**
  - $P(x = 5) = 0$

x	$P(x)$
1	$\frac{1}{10} = 0.1$ ✓
2	$\frac{2}{10} = 0.2$ ✓
3	$\frac{3}{10} = 0.3$ ✓
4	$\frac{4}{10} = 0.4$ ✓
	$\frac{10}{10} = 1.0$

Probability Distribution for $P(x) = \frac{x}{10}$, for $x = 1, 2, 3, 4$



Line Representation: Probability Distribution for $P(x) = \frac{x}{10}$, for $x = 1, 2, 3, 4$



Histogram: Probability Distribution for $P(x) = \frac{x}{10}$, for $x = 1, 2, 3, 4$

MEAN AND VARIANCE OF A DISCRETE PROBABILITY DISTRIBUTION

- **Remember that:**
  - **We used sample statistics to describe a sample.**
  - $\bar{x}$ **is the sample mean**
  - s^2 **is the sample variance (**s **is the sample standard deviation).**
- **Probability distributions may be used to represent theoretical populations, the counterpart to samples.**
- **We use population parameters (mean, variance, and standard deviation) to describe these probability distributions.**
  - μ **(the Greek letter lower case mu) is the population mean.**
  - σ^2 **(the Greek letter lower case sigma) is the population variance**
  - $\sigma = \sqrt{\sigma^2}$ **is the population standard deviation.**
  - μ, σ^2 **and** σ **are called *population parameters*. (A parameter is a constant, and typically unknown value in real statistics problems.)**

MEAN AND VARIANCE OF A DISCRETE PROBABILITY DISTRIBUTION

- **Mean of a discrete random variable (expected value):**
  The mean, μ, of a discrete random variable x is found by multiplying each possible value of x by its own probability and then adding all the products together:
  - **mean of x:** mu $=$ sum of (each x multiplied by its own probability)
  - $\mu = \sum_{i=1}^{n}[x_i P(x_i)]$
  - $\mu = x_1 P(x_1) + x_2 P(x_2) + \cdots + x_n P(x_n)$

- **For the** # of H **when we flip a coin twice discrete distribution:**
  - $\mu = x_1 P(x_1) + x_2 P(x_2) + x_3 P(x_3)$
  - $= 0 \times \frac{1}{4} \quad + 1 \times \frac{1}{2} \quad + 2 \times \frac{1}{4}$
  - $= 1$

	x	P(x)	
x_1	0	0.25	$P(x_1)$
x_2	1	0.50	$P(x_2)$
x_3	2	0.25	$P(x_3)$

MEAN AND VARIANCE OF A DISCRETE PROBABILITY DISTRIBUTION

- **Variance of a discrete random variable:**
  The variance, σ^2, of a discrete random variable x is found by multiplying each possible value of the squared deviation from the mean, $(x-\mu)^2$, by its own probability and then adding all the products together:
  P(x)
  - **variance:** sigma squared = sum of (squared deviation times probability)
  - $\sigma^2 = \sum_{i=1}^{n}[(x_i-\mu)^2 P(x_i)]$
  - $\sigma^2 = (x_1-\mu)^2P(x_1) + (x_2-\mu)^2P(x_2) + \cdots + (x_n-\mu)^2P(x_n)$

- **For the** # of H **when we flip a coin twice discrete distribution:**
  - $\sigma^2 = (x_1-\mu)^2P(x_1) + (x_2-\mu)^2P(x_2) + (x_3-\mu)^2P(x_3)$
  - $= (0-1)^2 \times \frac{1}{4} \quad + (1-1)^2 \times \frac{1}{2} \quad + (2-1)^2 \times \frac{1}{4}$
  - $= \frac{1}{2} = 0.5$

	x	P(x)	
x_1	0	0.25	$P(x_1)$
x_2	1	0.50	$P(x_2)$
x_3	2	0.25	$P(x_3)$

- **Alternative formula:** $\sigma^2 = \sum_{i=1}^{n}[x_i^2 P(x_i)] - \mu^2$

MEAN AND VARIANCE OF A DISCRETE PROBABILITY DISTRIBUTION

- **Likewise, standard deviation of a random variable is calculated in the same manner as is the standard deviation of sample data.**

- **Standard deviation of a discrete random variable:**
  The positive square root of variance.
  - **standard deviation:** $\sigma = \sqrt{\sigma^2}$

- **For the** # of H **when we flip a coin twice discrete distribution:**
  - $\sigma = \sqrt{0.5}$
  - $= 0.707$
  - $= \mathbf{0.71}$

THE BINOMIAL PROBABILITY DISTRIBUTION

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- Consider the following probability experiment. I give you a surprise four-question multiple-choice quiz.
- You have not studied the material, and therefore you decide to answer the four questions by randomly guessing.
- Here are some questions for you?

Answer Page to Quiz

Directions: Circle the best answer to each question.

1.	a	b	c
2.	a	b	c
3.	a	b	c
4.	a	b	c

1. How many of the four questions are you likely to have answered correctly?
2. How likely are you to have more than half of the answers correct?
3. What is the probability that you selected the correct answers to all four questions?
4. What is the probability that you selected wrong answers for all four questions?
5. If an entire class answers the quiz by guessing, what do you think the class “average” number of correct answers will be?

THE BINOMIAL PROBABILITY DISTRIBUTION

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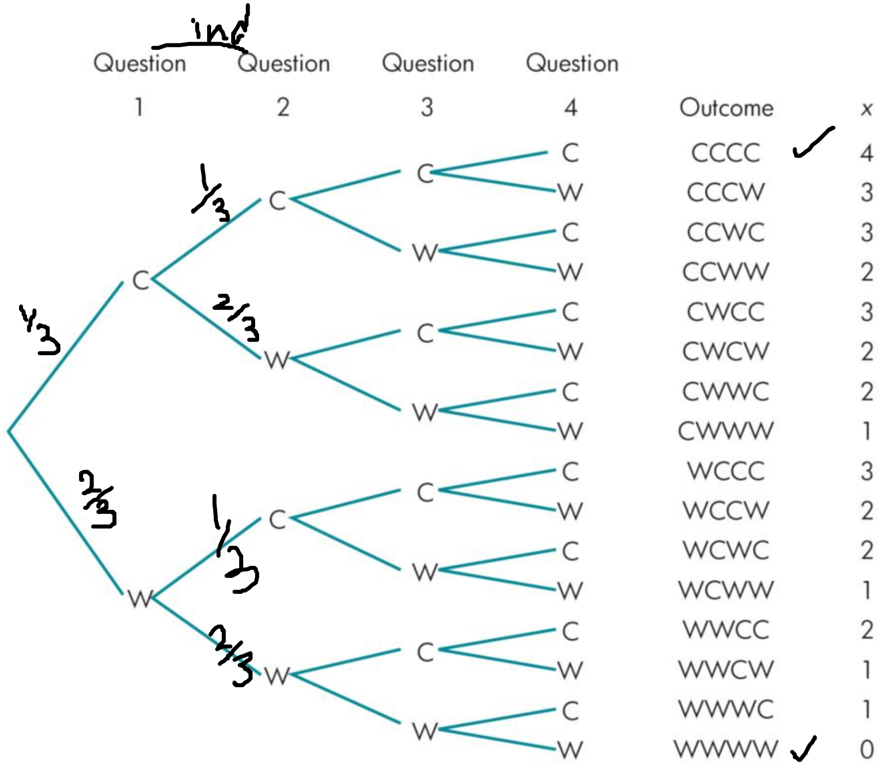
- To find the answers to these questions, let's start with a tree diagram



- Each of the four questions is answered with the correct answer (C) or with a wrong answer (W).
- x is the "number of correct answers" on one person's quiz when the quiz was taken by randomly guessing.

THE BINOMIAL PROBABILITY DISTRIBUTION

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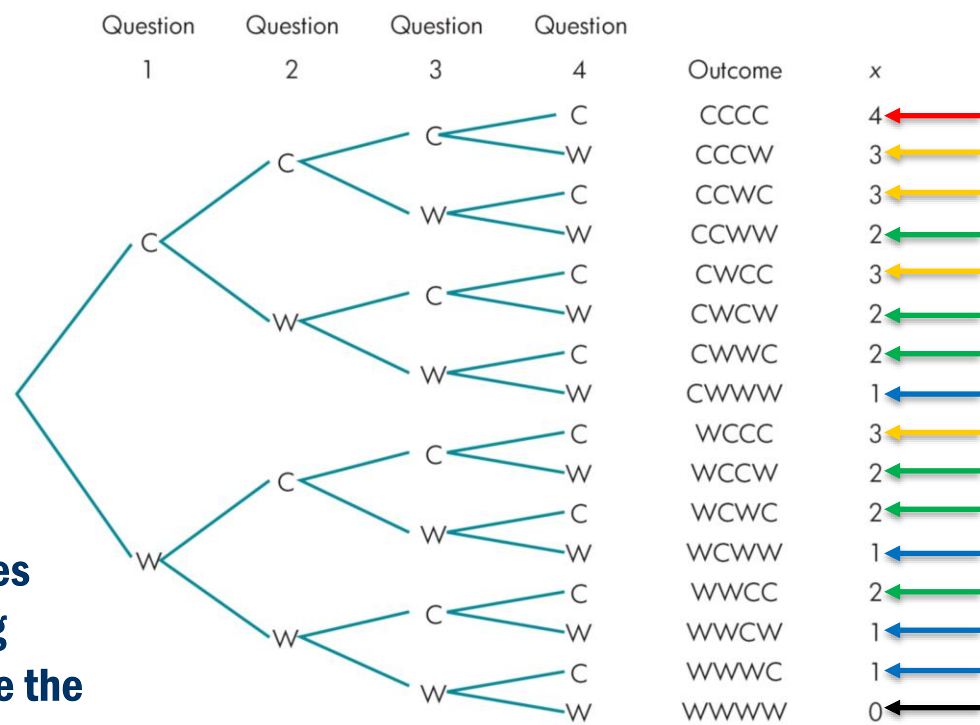
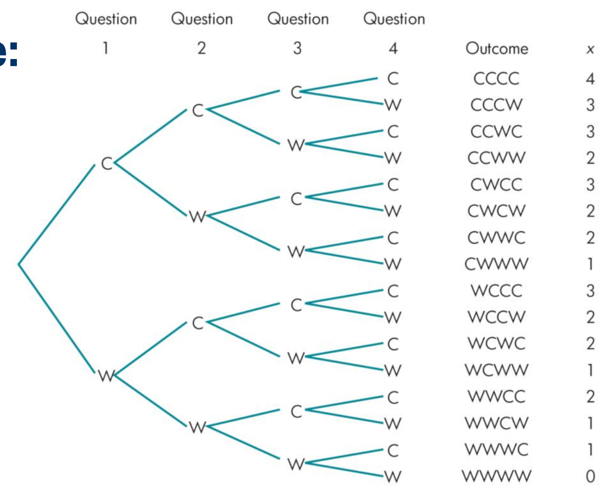
- **Notice that:**
  - The event $x = 4$, "four correct answers," is shown on the top branch.
  - The event $x = 0$, "zero correct answers," is shown on the bottom branch.
  - The event $x = 1$ occurs on four different branches.
  - The event $x = 2$ occurs on six branches.
  - The event $x = 3$ occurs on four branches.

  - Each individual question has only one correct answer.
  - The probability of selecting the correct answer to each question is $\frac{1}{3}$.
  - The probability that a wrong answer is selected is $\frac{2}{3}$.
  - The probability of each value of x can be found by calculating the probabilities of all the branches and then combining the probabilities for branches that have the same x values.



THE BINOMIAL PROBABILITY DISTRIBUTION

- $P(x = 0)$ **is the probability that the correct answers are given for zero questions.**
  - $P(x=0) = \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} = \left(\frac{2}{3}\right)^4 = \frac{16}{81} = \mathbf{0.198}$
  - **Note: Answering each individual question is a separate and independent event, thereby we can use:**
  - $P\,(A \text{ and } B) = P(A) \cdot P(B)$



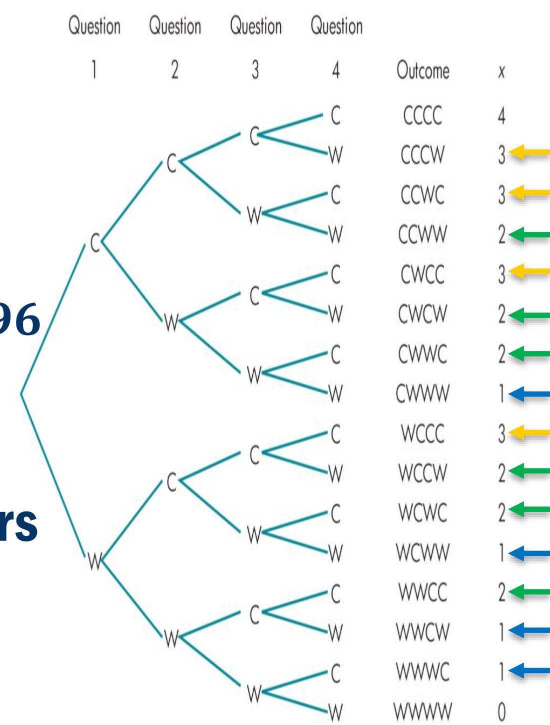
- $P(x = 4)$ **is the probability that correct answers are given for all four questions.**
  - $P(x=4) = \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} = \left(\frac{1}{3}\right)^4 = \frac{1}{81} = \mathbf{0.012}$

THE BINOMIAL PROBABILITY DISTRIBUTION

- $P\ (x = 1)$ **is the probability that the correct answer is given for exactly one question and wrong answers are given for the other three (there are four branches: CWWW, WCWW, WWCW, WWWC—and each has the same probability):**
  - $P(x = 1) = 4 \times \frac{1}{3} \times \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} = 4 \times \frac{1}{3} \times \left(\frac{2}{3}\right)^3 = \mathbf{0.395}$

- $P\ (x = 2)$ **is the probability that correct answers are given for exactly two questions and wrong answers are given for the other two (there are six branches) :**
  - $P(x = 2) = 6 \times \frac{1}{3} \times \frac{1}{3} \times \frac{2}{3} \times \frac{2}{3} = 6 \times \left(\frac{1}{3}\right)^2 \times \left(\frac{2}{3}\right)^2 = \mathbf{0.296}$

- $P\ (x = 3)$ **is the probability that correct answers are given for exactly three questions and wrong answers are given for the other one(there are four branches) :**
  - $P(x = 3) = 4 \times \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times \frac{2}{3} = 4 \times \left(\frac{1}{3}\right)^3 \times \frac{2}{3} = \mathbf{0.099}$

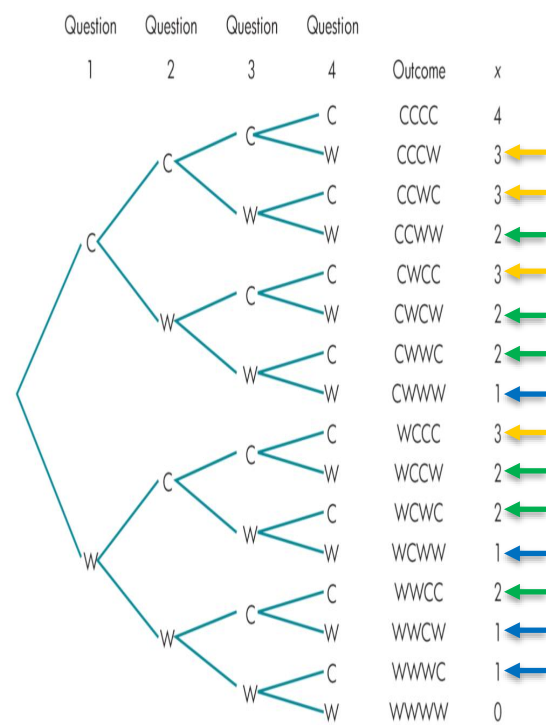


THE BINOMIAL PROBABILITY DISTRIBUTION

- $P(x=0) = \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} = \left(\frac{2}{3}\right)^4 = \frac{16}{81} = \mathbf{0.198}$
- $P(x=1) = 4 \times \frac{1}{3} \times \frac{2}{3} \times \frac{2}{3} \times \frac{2}{3} = 4 \times \frac{1}{3} \times \left(\frac{2}{3}\right)^3 = \mathbf{0.395}$
- $P(x=2) = 6 \times \frac{1}{3} \times \frac{1}{3} \times \frac{2}{3} \times \frac{2}{3} = 6 \times \left(\frac{1}{3}\right)^2 \times \left(\frac{2}{3}\right)^2 = \mathbf{0.296}$
- $P(x=3) = 4 \times \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times \frac{2}{3} = 4 \times \left(\frac{1}{3}\right)^3 \times \frac{2}{3} = \mathbf{0.099}$
- $P(x=4) = \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} \times \frac{1}{3} = \left(\frac{1}{3}\right)^4 = \frac{1}{81} = \mathbf{0.012}$
- **In general:**
- $\boxed{P(x=k) = \frac{4!}{k!(4-k)!} \times \left(\frac{1}{3}\right)^k \times \left(\frac{2}{3}\right)^{4-k}, \quad \textbf{for } k = 0,1,2,3,4}$
- **Probability distribution:**

x	$P(x)$
0	0.198
1	0.395
2	0.296
3	0.099
4	0.012
	1.000

Probability Distribution for the Four-Question Quiz



THE BINOMIAL PROBABILITY DISTRIBUTION

- **Now we can answer those five questions.**

1. **How many of the four questions are you likely to have answered correctly?**

➢ **The most likely occurrence would be to get one answer correct; it has a probability of 0.395.**

x	$P(x)$
0	0.198
1	0.395
2	0.296
3	0.099
4	0.012
	1.000

Probability Distribution for the Four-Question Quiz

2. **How likely are you to have more than half of the answers correct?**

➢ **Having more than half correct is represented by $x = 3$ or 4; their total probability is $0.099 + 0.012 = 0.111$. (You will pass this quiz with 11% chance by random guess.)**

3. **What is the probability that you selected the correct answers to all four questions?**

➢ $P(\text{all four correct}) = P(x = 4) = 0.012$. **(All correct occurs only 1% of the time.)**

4. **What is the probability that you selected wrong answers for all four questions?**

➢ $P(\text{all four wrong}) = P(x = 0) = 0.198$. **(That's almost 20% of the time.)**

5. **If an entire class answers the quiz by guessing, what do you think the class "average" number of correct answers will be?**

➢ **The class average is expected to be $\frac{1}{3}$ of 4, or 1.33 correct answers.**

THE BINOMIAL PROBABILITY DISTRIBUTION

- **Many experiments are composed of repeated trials whose outcomes can be classified into one of two categories: success or failure.**
  - Examples of such experiments are coin tosses, right/wrong quiz answers, and other, more practical experiments such as determining whether a product did or did not do its prescribed job and whether a candidate gets elected or not.

- **There are experiments in which the trials have many outcomes that, under the right conditions, may fit this general description of being classified in one of two categories.**
  - For example, when we roll a single die, we usually consider six possible outcomes.
  - However, if we are interested only in knowing whether a "one" shows or not, there are really only two outcomes: the "one" shows or "something else" shows.

- **The experiments just described are called binomial probability experiments.**

THE BINOMIAL PROBABILITY DISTRIBUTION

- **Binomial probability experiment: An experiment that is made up of repeated trials that possess the following properties:**
  1. **There are n repeated identical independent trials.**
  2. **Each trial has two possible outcomes (success or failure).**
  3. $P(\text{success}) = p$, $P(\text{failure}) = q$, **and** $p + q = 1$.
  4. **The binomial random variable x is the count of the number of successful trials that occur; x may take on any integer value from zero to n.**

- **Binomial probability function For a binomial experiment, let p represent the probability of a "success" and q represent the probability of a "failure" on a single trial. Then $P(x)$, the probability that there will be exactly x successes in n trials, is**

- $P(x) = \binom{n}{x}(p^x)(q^{n-x}), \quad \text{for } x = 0, 1, 2, \cdots, n$

THE BINOMIAL PROBABILITY DISTRIBUTION

- $P(x) = \binom{n}{x}(p^x)(q^{n-x}), \quad \text{for } x = 0, 1, 2, \cdots, n$

- **When you look at the probability function, you notice that it is the product of three basic factors:**

1. **The number of ways that exactly x successes can occur in n trials, $\binom{n}{x}$**

– **This term is called the binomial coefficient and is found by using the formula:**

– $\binom{n}{x} = \frac{n!}{x!(n-x)!}$

2. **The probability of exactly x successes, p^x**

3. **The probability of failure on the remaining $(n-x)$ trials, q^{n-x}**

THE BINOMIAL PROBABILITY DISTRIBUTION

- **A coin is tossed three times and we observe the number of heads that occur in the three tosses. This is a binomial experiment because it displays all the properties:**
  1. **There are $n = 3$ repeated independent trials.**
  2. **Each trial (each toss of the coin) results in one of two possible outcomes: success = heads or failure = tails.**
  3. **The probability of success is $p = P(H) = 0.5$, and the probability of failure is $q = P(T) = 0.5$, $\quad [p + q = 0.5 + 0.5 = 1]$**
  4. **The random variable x is the number of heads that occur in the three trials. x will assume exactly one of the values $0, 1, 2, \text{or } 3$.**
- **The binomial probability function for the tossing of three coins is:**
  - $P(x) = \binom{n}{x}(p^x)(q^{n-x}) = \binom{3}{x}(0.5)^x(0.5)^{3-x}, \quad \text{for } x = 0, 1, 2, 3$
- **Let's find the probability $x = 1$ of using the preceding binomial probability function:**
  - $P(x = 1) = \binom{3}{1}(0.5)^1(0.5)^{3-1} = 3(0.5)(0.25) = \mathbf{0.375}$

EXAMPLE 9 – BINOMIAL PROBABILITY OF "BAD EGGS"

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- **The manager of Steve's Food Market guarantees that none of his cartons of a dozen eggs will contain more than one bad egg.**
- **If a carton contains more than one bad egg, he will replace the whole dozen and allow the customer to keep the original eggs.**
- **If the probability that an individual egg is bad is 0.05, what is the probability that the manager will have to replace a given carton of eggs?**
- **Solution:**
  - **The manager's situation appears to fit the properties of a binomial experiment. Let x be the number of bad eggs found in a carton of a dozen eggs, therefore $p = P(\text{bad}) = 0.05$, and $q = P(\text{not bad}) = 0.95$.**
  - **There will be $n = 12$ trials to account for the 12 eggs in a carton.**
  - $P(x) = \binom{12}{x}(0.05)^x(0.95)^{12-x}, \quad \text{for } x = 0, 1, 2, \cdots, 12$

EXAMPLE 9 – SOLUTION

- **Solution Cont'd:**
  - $P(x) = \binom{12}{x}(0.05)^x(0.95)^{12-x}, \quad \text{for } x = 0, 1, 2, \cdots, 12$
  - **The probability that the manager will replace a dozen eggs is the probability that $x = 2, 3, 4, \ldots, 12$.**
  - **We know that $\sum_{\text{all x}} P(x) = 1$; that is,**
  - $P(0) + P(1) + P(2) + \cdots + P(12) = 1$
  - $P(\text{replacement}) = P(2) + P(3) + \cdots + P(12)$
  - $= 1 - [P(0) + P(1)]$
  - $P(0) = \binom{12}{0}(0.05)^0(0.95)^{12} = \mathbf{0.540}$
  - $P(1) = \binom{12}{1}(0.05)^1(0.95)^{11} = \mathbf{0.341}$
  - $P(\text{replacement}) = 1 - (0.540 + 0.341)$
  - $= \mathbf{0.119 = 11.9\%}$

THE BINOMIAL PROBABILITY DISTRIBUTION

- **Note : The value of many binomial probabilities for values of $n \leq 15$ and common values of p are found in Table 2 of Appendix B. In this example, we have $n = 12$ and $p = 0.05$, and we want the probabilities for $x = 0$ and 1.**

		p													
n	x	0.01	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	0.99	x
	⋮														
12	0	.886	.540	.282	.069	.014	.002	0+	0+	0+	0+	0+	0+	0+	0
	1	.107	.341	.377	.206	.071	.017	.003	0+	0+	0+	0+	0+	0+	1
	2	.006	.099	.230	.283	.168	.064	.016	.002	0+	0+	0+	0+	0+	2
	3	0+	.017	.085	.236	.240	.142	.054	.012	.001	0+	0+	0+	0+	3
	4	0+	.002	.021	.133	.231	.213	.121	.042	.008	.001	0+	0+	0+	4
	⋮														

Excerpt of Table 2 in Appendix B, Binomial Probabilities

- **TI-83 Calculator:**
  - **Binomialpdf**$(n, p, x) = P(x)$
- **Shiny App:**
  - [**Binomial Calculator**]

MEAN AND STANDARD DEVIATION OF THE BINOMIAL DISTRIBUTION

- **The mean and standard deviation of a theoretical binomial probability distribution can be found by using these two formulas:**

- **Mean of Binomial Distribution**
- $\mu = \sum_{x=0}^{n}[xP(x)] = \sum_{i=1}^{n}\left[x\binom{n}{x}(p^x)(q^{n-x})\right]$
- $$\mu = np$$

- **Variance and Standard Deviation of Binomial Distribution**
- $\sigma^2 = \sum_{x=0}^{n}[(x-\mu)^2 P(x)] = \sum_{i=1}^{n}\left[(x-\mu)^2\binom{n}{x}(p^x)(q^{n-x})\right]$
- $$\sigma^2 = npq$$
- $$\sigma = \sqrt{npq}$$

EXAMPLE 11 – CALCULATING THE MEAN AND STANDARD DEVIATION OF A BINOMIAL DISTRIBUTION

- **Find the mean and standard deviation of the binomial distribution when $n = 20$ and $p = \frac{1}{5}$ (or 0.2, in decimal form).**

- **We know that the "binomial distribution where and " has the probability function**

- $$P\,(x) = \binom{20}{x}(0.2)^x(0.8)^{20-x} \quad \text{for} \quad x = 0, 1, 2, \dots, 20$$

- **and a corresponding distribution with 21 x values and 21 probabilities.**

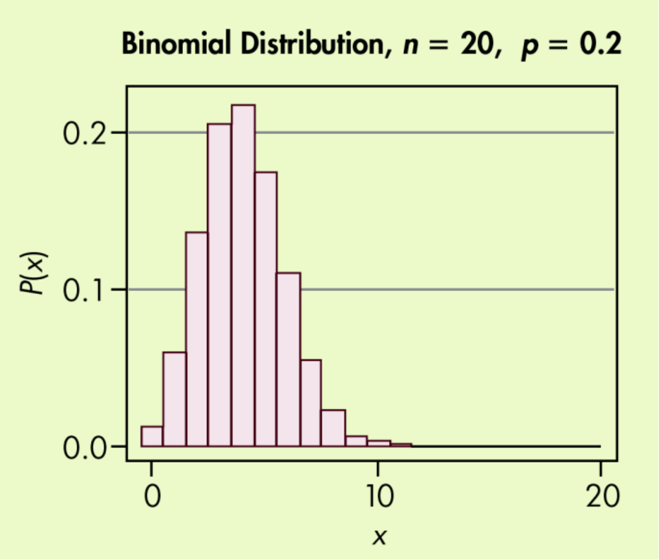
EXAMPLE 11 – CALCULATING THE MEAN AND STANDARD DEVIATION OF A BINOMIAL DISTRIBUTION

- **As shown in the distribution chart, Table 5.9, and on the histogram in Figure 5.5.**

x	$P(x)$
0	0.012
1	0.058
2	0.137
3	0.205
4	0.218
5	0.175
6	0.109
7	0.055
8	0.022
9	0.007
10	0.002
11	0+
12	0+
13	0+
⋮	⋮
20	0+

Binomial Distribution: $n = 20$, $p = 0.2$

Table 5.9



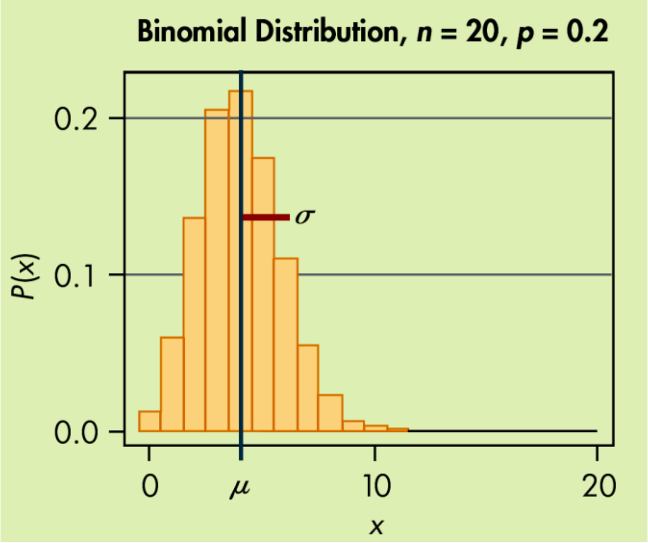
Histogram of Binomial Distribution $B(20, 0.2)$

Figure 5.5

EXAMPLE 11 – CALCULATING THE MEAN AND STANDARD DEVIATION OF A BINOMIAL DISTRIBUTION

- **Let's find the mean and the standard deviation of this distribution of x:**
- $\mu = np$
- $= (20)(0.2)$
- $= \mathbf{4.0}$

- $\sigma = \sqrt{npq}$
- $= \sqrt{20(0.2)(0.8)} = \sqrt{3.2}$
- $= \mathbf{1.79}$



Histogram of Binomial Distribution $B(20, 0.2)$

- **It is the expected standard deviation for the values of the random variable x that occur in samples of size 20 drawn from this same population**

QUESTIONS?

- **ANY QUESTION?**