

An Introduction to Biostatistics

Third Edition

Supplementary Problems

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Additional Problems for Chapter 1

1. (a) Complete a five-number summary for the data in Example 1.1.
 (b) Construct a box plot for these same data.
2. The first table below provides annual rainfall data (mm) for 118 consecutive years at Cowarie Station, South Australia from 1882 to 1999. The data have been rearranged in increasing order.

13	34	48	74	87	108	124	145	185	264
15	35	50	75	91	108	126	146	191	268
16	35	52	76	92	109	129	147	195	283
18	37	54	77	93	112	130	152	204	290
19	38	56	78	93	113	130	157	206	294
20	38	57	78	95	116	132	159	212	301
23	39	57	78	96	116	132	159	217	324
24	41	60	79	96	117	133	167	219	340
27	42	62	80	99	121	137	170	228	465
32	43	63	80	102	121	139	172	229	484
34	44	71	81	104	121	141	173	230	
34	44	73	85	107	122	143	183	248	

The second table provides annual rainfall data (mm) for 69 consecutive years at Mina, Nevada from 1928 to 1996. Again, the data have been rearranged in increasing order.

3	55	70	85	97	117	130	146	170	194
34	58	74	88	98	118	132	150	173	202
37	58	76	88	99	120	139	151	176	211
45	59	77	88	112	123	139	154	183	216
46	59	81	89	114	123	142	154	183	217
46	64	83	91	115	123	144	155	190	259
53	68	85	93	116	129	144	169	193	

The following basic summary statistics show that the two locations have very similar mean annual rainfalls.

	Cowarie Station	Mina, Nevada
n	118	69
\bar{X}	121.4 mm	117.0 mm
$\sum(X_i^2)$	2,642,765	1,135,331

- (a) For each data set, find the sample variance, standard deviation, and the standard error.
- (b) Create a histogram for each data set using 25 mm intervals. Comment on any differences.
- (c) Create five-number summaries for each.
- (d) Draw parallel box plots.
- (e) Interpret your results.

3. The reclusive sun bear, *Helarctos malayanus*, is the smallest member of the bear family and it lives in dense lowland forests of southeast Asia. It is now facing extinction because of deforestation and poaching. An isolated population was recently discovered in Indonesia. Listed below are the weights in pounds for a sample of 16 adult females from this population.

60	75	91	83	86	64	67	88
66	80	80	79	81	68	75	90

- (a) Find the mean, variance, standard deviation, and standard error for this sample.
 (b) Change the above descriptive statistics from pounds to kilograms.
4. Growing season is defined as the number of days between the last frost of the spring (before July 1) and the first frost of the fall (after July 1). A frost is defined as a minimum temperature below 32°F. The data in the lists below give the lengths of the growing seasons for 30 consecutive years (from 1970 to 1999) in Boston, MA and Lewiston, ME. The data have been rearranged in increasing order to facilitate analysis. Construct histograms of both data sets with classes of width 10 days. (Source: <http://neisa.unh.edu/Climate/IndicatorExcelFiles.zip>)

Boston, MA

191	192	194	195	195	195	196	197	202	205
205	209	210	213	213	216	217	219	222	223
223	224	225	226	229	229	232	235	236	247

Lewiston, ME

147	151	156	156	159	160	163	164	165	165
165	166	168	169	171	172	173	174	177	178
180	180	183	183	184	184	185	189	189	208

5. The gastropod *Conus geographus*, commonly known as the geographic cone, has a beautiful shell but possesses a deadly venom which is delivered by a small harpoon-shaped barb called a radula. The neurotoxin from the radula is similar to cobra venom and is usually fatal to humans who do not receive immediate medical care. Below are the long dimension measurements in mm of a sample of empty geographic cone shells collected at various sites along the Great Barrier Reef.

Length (mm)	Frequency
72	3
73	7
74	9
75	15
76	22
77	31
78	36
79	46
80	51
81	45
82	41
83	36
84	29
85	18
86	11
87	8
88	2
410	

- (a) Calculate the appropriate descriptive statistics for this sample using the frequency table formulas.
 (b) Discuss the 30–300 rule and its application to data such as this.

6. (a) Complete a five-number summary for the data in Example 1.2.
 (b) Construct a box plot for these same data.
7. Medical researchers are testing a new chemotherapy regime for colon cancer. A group of 100 male patients volunteer for the program. Of these, 50 are selected at random to receive the new therapy regime (experimental group) while the remaining 50 will receive the current standard regime (control group). The ages of the subjects are given below.

Control					Experimental				
20	41	48	53	59	28	43	49	54	61
23	42	48	53	59	30	43	49	54	62
24	42	48	53	60	32	44	49	55	62
25	42	48	53	60	33	44	50	55	63
27	43	49	54	61	35	44	50	55	64
36	45	50	56	65	39	46	51	56	73
37	45	50	56	67	40	47	52	57	75
38	45	51	56	68	40	47	52	58	76
38	46	51	57	70	41	47	52	59	78
39	46	51	57	72	41	47	52	59	80

- (a) Do both data sets satisfy the 30–300 rule?
 (b) Produce a five-number summary and a corresponding box plot for each group of data.
 (c) The researchers assumed that there were no significant differences in the ages of the subjects in the two groups. Do you agree? Justify your answer.
8. *Homo floresiensis* is an extinct species of hominin that lived on the Indonesian island of Flores between 74,000 and 18,000 years ago. The discovery in 2004 of a number of specimens led to the description of a new species considerably smaller than the previously known *Homo erectus* which had survived in parts of Asia until at least 100,000 years ago. Listed below are the brain case measurements in cubic centimeters for eight specimens of *H. floresiensis*. Calculate the mean, variance, and standard deviation for this sample.

384 365 385 380 341 377 382 395

According to Mark Collard, Assistant Professor of Biological Anthropology at the University of British Columbia, the anomalous nature of *Homo floresiensis* has been plausibly attributed to a process that evolutionary biologists call “island dwarfing.” According to this hypothesis, a population of *Homo erectus* became isolated on the island of Flores, and then experienced selection for smaller body size because the island was relatively poor in food resources. Eventually the population became so different from *Homo erectus* that its members formed a new species—the one we call *Homo floresiensis*.

9. Absolute pitch is thought by some to consist of two components: a relative common ability, *pitch memory*, and a more rare ability, *pitch labeling*. To investigate pitch memory, 46 undergraduates were asked to select one of 58 CDs which contained popular songs (that is, “Hotel California” by the Eagles and “Every Breath You Take” by the Police). Without listening to the song they selected, they were asked to reproduce (sing, whistle, hum) the tones of the song that they claimed to know very well. The subjects were recorded on digital audio tape and their reproductions were compared to the actual tones of the artists on the CD. Errors were measured in semitone deviations from the correct pitch. As is standard in such work, octave errors were not penalized (on the assumption that subjects with pitch memory may have a stronger representation for pitch class than pitch height). That is, an octave was added or subtracted, as necessary, to the tones produced until all tones fell within one-half octave (six semitones) on either side of the target tone. A summary of the data is given below. (Based on data from Daniel J. Levitin, 1994, “Absolute memory for musical pitch: Evidence from the production of learned melodies,” *Perception & Psychophysics*, 56(4): 414–423.)

Error (semitones)	Frequency
-6	1
-5	3
-4	4
-3	4
-2	4
-1	8
0	12
1	6
2	1
3	1
4	1
5	1
6	0
Total	46

- (a) Make a table of relative frequencies, cumulative frequencies, and relative cumulative frequencies for these data.
- (b) Make a relative frequency histogram of these data.
- (c) Compute the mean, variance, and standard deviation for these data.
- (d) Do these data exhibit the so-called “lounge singer effect” widely noted by vocal instructors, wherein amateur singers tend to undershoot tones and to sing flat? Justify your answer.
10. The Southern cavefish, *Typhlichthys subterraneus*, is found mostly in the dolomite aquifers of the Salem Plateau in the South Central Ozarks. A population of 17 individuals was recently discovered in a small cave in central Missouri. The length of each individual was measured (in cm) and is recorded below.

3.8 6.6 3.2 3.9 4.5 6.8
 4.0 2.8 3.0 3.5 3.8 3.9
 4.3 4.6 6.0 4.9 2.9

Find the population mean, the uncorrected sum of squares, the correction term, the corrected sum of squares, the population variance, and the population standard deviation.

11. Italian zoologist Francesco Rovero, documenting elusive forest animals deep in the Ndunlulu Forest of Tanzania’s Udzungwa Mountains, recently discovered a new species of elephant-shrew or sengi. The new species, which has been named the grey-faced sengi, *Rhynchocyon udzungwensis*, is thought to be larger than any other known sengi. Listed below are the weights in grams of 9 grey-faced sengi. Calculate the sample mean, variance, and standard error for these data.

645	650	705
717	685	760
709	730	700

12. From a site believed to be 30,000 years old in Irian Jaya near the border with Papua New Guinea archeologists recovered 12 adzes (double-edged stone blades for scythe-like tools). Given below are the lengths and diameters (in cm) at the base of the adzes.

Length	Diameter
20	8.0
23	7.5
19	10.3
26	9.9
25	10.1
28	11.0
29	11.3
20	11.2
22	10.0
24	9.8
19	9.5
24	11.0

Discuss these measurements in light of the 30–300 rule. Summarize the data appropriately. Do the data represent a sample or a population? Explain.

13. The smallmouth black bass, *Micropterus dolomieu*, is a very popular game fish throughout the temperate zones of North America. In a Bassmasters Tournament on the St. Lawrence River the following fish were caught and weighed to the nearest 10 grams.

1210	1610	1820
1470	1750	1920
1350	1540	1770
1300	1380	1450
1270	2110	2010

- (a) For this sample find the mean and standard deviation. Also determine the median and the range. Which pair of statistics above are more informative? Provide a rationale for your answer.
- (b) Construct a five-number summary for the data above.
- (c) Develop a box plot from the five-number summary. Are there any outliers?
14. Suppose the statistics in (a) of the previous problem were going to be reported in a newspaper article. The writer believes that the statistics would be more understandable in pounds rather than grams. What values should she report?
15. Listed below are the serum cholesterol levels for 1067 American males, aged 25 to 34 years old.

Cholesterol level (mg/100 ml)	Number of men
80–119	13
120–159	150
160–199	442
200–239	299
240–279	115
280–319	34
320–359	9
360–399	5

Determine the mean, variance and standard deviation for these data. What value will you give the first 13 men?

16. A researcher applied the carcinogenic compound benzo(a)pyrene to the skin of five mice and measured the concentration in the liver tissue after 48 hours. The results (nmoles/gm) are recorded below.

6 7 7 5 4

Calculate the mean, corrected sum of squares and standard deviation for these data.

17. The accompanying table gives the litter size (number of piglets surviving to 21 days) for each of 36 sows. Determine the median litter size and the range for this data set.

Litter size (Number of piglets)	Frequency (Number of sows)
5	1
6	0
7	2
8	3
9	3
10	9
11	8
12	5
13	3
14	2

18. Begin by reviewing the definition of an unbiased estimator of a population parameter. Then review why is $n - 1$ used in the formula for the sample variance.

Let a population consist of the following values:

4 6 8

- Calculate the population mean, the population variance, and standard deviation for the population data above.
 - List all samples of size *two* from the population above using sampling *with replacement*. There are nine different samples!
 - For each sample calculate \bar{X} and s^2 .
 - Average each of the statistics in (c) over all possible samples. Do these averages from (a) equal μ and σ^2 ?
 - For each sample, calculate an ‘incorrect’ s_n^2 using n instead of $n - 1$ in the denominator.
 - Average the new values of s_n^2 in (e) over all possible samples. Is this average equal to the original σ^2 ?
 - Use the calculations in (c) to argue that \bar{X} and s^2 are unbiased estimators of μ and σ^2 , but the calculations in (f) are not unbiased estimators of μ and σ^2 .
 - Can you now see why $n - 1$ and not n is used in the sample variance formula?
19. Listed below are the scoring averages for the top 195 players on PGA Tour for the year 2000. (Source: www.pgatour.com/stats/2000/r_120.html)
- Create a five-number summary of these data.
 - Create a box plot of these data.
 - Are there any outliers?

Player	Avg.	Player	Avg.	Player	Avg.	Player	Avg.
Tiger Woods	67.79	Tom Byrum	70.77	Jay Williamson	71.25	Perry Moss	71.83
Phil Mickelson	69.25	Shigeeki Maruyama	70.77	Dan Forsman	71.26	Jason Buha	71.84
Ernie Els	69.31	Fred Funk	70.79	Mark Brooks	71.27	Mathew Goggin	71.88
David Duval	69.41	Bob Estes	70.84	Billy Andrade	71.28	Ronnie Black	71.89
Paul Azinger	69.68	Stephen Ames	70.85	Jerry Smith	71.28	Bob Burns	71.89
Nick Price	69.75	Joel Edwards	70.85	Cameron Beckman	71.30	Mike Brisky	71.93
Stewart Cink	69.79	Skip Kendall	70.85	Jim Carter	71.30	Tom Purtzer	71.93
Steve Flesch	69.80	Carlos Franco	70.86	Robin Freeman	71.30	Jay Haas	71.94
Tom Lehman	69.84	Jean Van De Velde	70.86	Naomichi Joe Ozaki	71.31	Steve Gotsche	71.95
Loren Roberts	69.89	Len Mattiace	70.87	Rick Fehr	71.33	Barry Cheesman	71.96
Davis Love III	69.90	David Peoples	70.87	Pete Jordan	71.33	Dave Stockton, Jr.	71.96
Jesper Parnevik	69.94	Joe Durant	70.88	Woody Austin	71.37	Omar Uresti	71.97
Vijay Singh	70.01	Larry Mize	70.88	Brian Henninger	71.39	Casey Martin	71.98
Fred Couples	70.04	Blaine McCallister	70.89	Billy Mayfair	71.39	Craig Perks	72.00
Jim Furyk	70.06	Franklin Langham	70.90	Robert Gamez	71.40	Bart Bryant	72.04
John Huston	70.06	Brent Geiberger	70.91	Craig Stadler	71.41	John Maginnes	72.04
Hal Sutton	70.12	Brett Quigley	70.91	Brad Elder	71.42	Charles Raulerson	72.04
Justin Leonard	70.14	John Cook	70.92	Jimmy Green	71.43	Fulton Allem	72.05
David Toms	70.17	Greg Kraft	70.94	Shaun Micheel	71.43	Ted Tryba	72.05
Kirk Triplett	70.21	Harrison Frazar	70.96	Frank Nobile	71.43	P.H. Horgan III	72.06
Sergio Garcia	70.23	Brad Faxon	70.97	Glen Hnatiuk	71.44	Trevor Dodds	72.09
Chris Perry	70.25	Brandel Chamblee	70.98	Mark Wiebe	71.45	David Morland IV	72.11
Stuart Appleby	70.28	Paul Goydos	70.98	Peter Jacobsen	71.46	Bobby Cochran	72.13
Steve Lowery	70.29	Jeff Maggert	70.98	Tommy Armour III	71.50	Jay Delsing	72.13
Kenny Perry	70.30	Bill Glasson	70.99	Neal Lancaster	71.52	Brad Fabel	72.16
Bob May	70.32	Andrew Magee	70.99	Sean Murphy	71.52	Jeff Gove	72.17
Scott Verplank	70.32	Steve Pate	70.99	Dennis Paulson	71.52	Chip Beck	72.19
Mike Weir	70.36	Carl Paulson	71.02	Tom Pernice, Jr.	71.53	Rich Beem	72.21
Scott Dunlap	70.41	Tom Scherrer	71.02	K.J. Choi	71.54	Paul Curry	72.21
Scott Hoch	70.41	Mike Reid	71.06	Brandt Jobe	71.54	Kevin Wentworth	72.23
Kevin Sutherland	70.41	Glen Day	71.09	Steve Stricker	71.54	Kelly Gibson	72.27
Mark Calcavecchia	70.46	Steve Jones	71.10	Edward Fryatt	71.55	Dicky Pride	72.29
Grant Waite	70.49	Russ Cochran	71.11	David Sutherland	71.58	Craig A. Spence	72.30
Greg Chalmers	70.50	Craig Barlow	71.13	Rory Sabbatini	71.60	Gary Nicklaus	72.33
Robert Allenby	70.54	Brian Gay	71.14	Steve Elkington	71.61	Emlyn Aubrey	72.38
Duffy Waldorf	70.56	Olin Browne	71.15	Joey Sindelar	71.65	Bob Heintz	72.38
Lee Janzen	70.59	Esteban Toledo	71.16	Michael Bradley	71.69	Tommy Tolles	72.40
Craig Parry	70.62	Doug Barron	71.17	Brian Watts	71.69	Jason Caron	72.46
Jeff Sluman	70.62	Jim McGovern	71.17	Corey Pavin	71.70	John Rollins	72.46
Chris DiMarco	70.63	J.P. Hayes	71.19	Matt Gogel	71.71	Eric Booker	72.50
Tim Herron	70.64	Jay Don Blake	71.20	David Frost	71.72	Ryan Howison	72.50
Jonathan Kaye	70.65	Nick Faldo	71.22	Gabriel Hjertstedt	71.74	Steve Hart	72.64
Rocco Mediate	70.67	Mark O'Meara	71.22	Bradley Hughes	71.75	Keith Nolan	72.67
Dudley Hart	70.68	Joe Ogilvie	71.22	Bob Friend	71.76	Mike Hulbert	72.70
Frank Lickliter II	70.72	Robert Damron	71.23	Mike Springer	71.77	Aaron Bengoechea	72.80
Chris Riley	70.72	J.L. Lewis	71.23	Scott Gump	71.79	John Daly	72.91
Notah Begay III	70.73	Scott McCarron	71.23	Ben Bates	71.80	Nolan Henke	73.14
Paul Stankowski	70.74	Mike Sposa	71.23	Doug Dunakey	71.80	Craig Bowden	73.36
Jerry Kelly	70.76	Bob Tway	71.24	Michael Clark II	71.81		

Additional Problems for Chapter 2

- The Dalmatian is a popular breed of dog that has been plagued by a predisposition for deafness. In a large study to understand the basis of deafness and to investigate ways to reduce its incidence, the following facts were elucidated: eighty percent of the Dalmatians had brown eyes, the rest had blue eyes; fifteen percent of the Dalmatians were deaf, either unilaterally or bilaterally; ten percent of the Dalmatians had blue eyes and were deaf.
 - Draw a Venn diagram of the study and rewrite the above findings using set notation.
 - Are eye color and hearing level independent of each other?
 - What is the probability that a brown-eyed Dalmatian will be deaf?
 - What is the probability that a blue-eyed Dalmatian will be deaf?
 - How would you advise Dalmatian breeders to proceed in order to reduce the incidence of deafness?
- According to legend, Sic Bo has been played at the port of Shanghai for hundreds of years. It is played with three dice contained within a tumbler. The object of the game is to predict which numbers or combinations will turn up when the dice are rolled. Table 1 on the next page illustrates the payoffs for a variety of different outcomes for the game as it is played in one casino in Australia. Use the Sic Bo table provided to answer the following questions.
 - The payout for each triple is 180 for 1. What are the odds for each triple, i.e., what is the probability of rolling 3 ones for example?
 - The payout for any triple is 31 for 1. What are the odds of any triple?
 - Are the odds better in a) or b)? That is, are the payouts closer to the probabilities in (a) or (b)?
 - The payout for each double is 11 for 1. What are the odds for each double?
 - The total value payoff for a 4 is the same as a 17. Demonstrate why this is appropriate.
 - The total value payoff for a 4 is much higher than a 5. Show why this is logical.
 - For individual numbers, what is the probability of getting exactly one 1 on three dice; exactly two 1's on three dice; exactly three 1s on three dice. Comment on the payouts relative to these outcomes.
 - Based on your calculations above (a-g) is Sic Bo a fair game? What constitutes a fair game of chance?
- According to legend, Sic Bo has been played in the port of Shanghai for hundreds of years. It is played with three dice contained within a tumbler. The object of the game is to predict which numbers or combinations will turn up when the dice are rolled. The figure illustrates the pay offs for a variety of different outcomes for the game as it is played in one casino in Australia.
 - Choose three outcomes below and use your understanding of classical probability and combinatorics to calculate the odds of those outcomes.
 - (A) Specific Triple pays 180 to 1. Three specific matching numbers you nominate. Triple 1, 2, 3, 4, 5, or 6.
 - (B) Any Triple pays 31 to 1. Any three matching numbers.
 - (C) Specific Double pays 11 to 1. Two specific matching numbers you nominate Double 1, 2, 3, 4, 5, or 6.
 - (D) Total Value of 4 or 17 pays 62 to 1. Sum of three dice totals 4 or 17.

Table 1: Diagram of payout odds of the many different bets in Sic Bo as played at the Treasury Casino in Brisbane, Australia.

SMALL Numbers: 4 to 10 1 WINS 1 But Lose If Any Triple Appears		Each Double: 1 Wins 11						BIG Numbers: 11 to 17 1 WINS 1 But Lose If Any Triple Appears									
EACH Triple: 1 Wins 180																	
ANY Triple: 1 Wins 31																	
3 Dice Total PAYOFFS	4 1 wins 62	5 1 wins 31	6 1 wins 18	7 1 wins 12	8 1 wins 8	9 1 wins 7	10 1 wins 6	11 1 wins 6	12 1 wins 7	13 1 wins 8	14 1 wins 12	15 1 wins 18	16 1 wins 31	17 1 wins 62			
Each Combo: 1 and 2 1 Wins 6																	
INDIVIDUAL Numbers: 1 to 1 On ONE Die... 2 to 1 On TWO Dice... 12 to 1 On THREE Dice		ONE 		TWO 		THREE 		FOUR 		FIVE 		SIX 					

- (E) Total Value of 5 or 16 pays 31 to 1. Sum of three dice totals 5 or 16.
- (F) Total Value of 6 or 15 pays 18 to 1. Sum of three dice totals 6 or 15.
- (G) Total Value of 7 or 14 pays 12 to 1. Sum of three dice totals 7 or 14.
- (H) Total Value of 8 or 13 pays 8 to 1. Sum of three dice totals 8 or 13.
- (I) Total Value of 9 or 12 pays 7 to 1. Sum of three dice totals 9 or 12.
- (J) Total Value of 10 or 11 pays 6 to 1. Sum of three dice totals 10 or 11.
- (K) Two Dice Combinations pays 6 to 1. Specific combinations of two unmatched dice.
- (L) “Small” pays even money Sum of three dice totals between 4 and 10. Loses if any Triple appears.
- (M) “Big” pays even money Sum of three dice totals between 11 and 17. Loses if any Triple appears.
- (N) Specific Number A bet placed on a specific number being spun. The more dice featuring the nominated number, the higher the payout. On One Die pays even money On Two Dice pays 2 to 1. On Three Dice pays 12 to 1.
- (b) Are any outcomes and payouts “fair”? In other words, do the odds and payouts match? If not, which one has the best payout relative to its odds?
4. The gene causing Duchenne’s Muscular Dystrophy (DMD) is very large and contains 55 exons. Data from many studies indicate that there are 76 different point mutations, 114 different deletions, and 8 different duplications which cause DMD. Suppose these genetic defects occur equally frequently (they don’t really); find the following:
- (a) the probability a randomly chosen DMD patient has a point mutant.
- (b) the probability a randomly chosen DMD patient has a duplication or deletion.
- (c) the probability a randomly chosen DMD patient doesn’t have a deletion.
5. An amateur horticulturist has been growing tulips for many years. In one variety he notices that 40% have deep red flowers while the remainder are bright red. He also notes that 50% have fringed or crenulated petals, 20% have ruffled, curled petals referred to as parrot beak petals, and the rest have traditional, smooth petals. Half of the deep red flowers are fringed and 20% of them are parrot beaked.
- (a) Draw a Venn diagram of these characteristics for this variety. How many morphs are there? How many areas are there in your Venn diagram?
- (b) Are petal shape and color independent characteristics?
- (c) If a tulip is deep red, what is the probability that it is crenulate?
- (d) If a tulip is bright red, what is the probability that it is crenulate?
- (e) Comment on these last two calculations.
6. In a study on optimal foraging, an ichthyologist presents moon wrasses, *Thalassoma lunare*, with seven potential food items.
- (a) When the items are abundant, the wrasse tend to be selective, choosing only the two “most profitable” food items. How many diets of two different items are possible?
- (b) When food is less abundant, the wrasse widen their diet and select four different items (beggars can’t be choosers). How many such diets are possible?
- (c) How many different diet combinations are possible in the two experiments?
7. Consider the following blood type characteristics in a large population. Each characteristic (column) should be considered independent of the other two.

ABO blood group	Rh blood group	MN blood group
Type A 30%	Rh positive 85%	Type M 50%
Type O 40%	Rh negative 15%	Type N 30%
Type B 20%		Type MN 20%
Type AB 10%		

- (a) If these three blood groups are inherited independently, what is the probability that a randomly chosen individual will have type A, Rh positive, MN blood?
- (b) If someone is known to be type A, what is the probability they will be Rh positive?
- (c) In courts of law guilt must be determined beyond a reasonable doubt. If both the suspect and a blood stain at a crime scene are typed AB, Rh negative, MN, would this fact indicate that the suspect is guilty? Explain, including a probability argument.
8. In a newly developed chemotherapy treatment for acute pernicious leukemia, 4 different drugs are used on 4 consecutive days. To assess if the order of drugs is important, how many experimental protocols must be investigated?
9. An Australian ornithologist studying wedge-tailed eagles, *Aquila audax*, found that 40% of a population were males. Seventy-five percent of the population were reddish-brown while the rest were black. Twenty percent were reddish-brown males.
- (a) What percent of the population were black females?
- (b) If you can tell the color but not the sex at a long distance and you see a black eagle with your binoculars, what is the probability that it is a male? A female?
- (c) Are sex and color morph independent in wedge-tailed eagles? Explain.
10. The coastal taipan, *Oxyuranus scutellatus*, which can be found in the Greater Brisbane area, is the highest ranked species on Australia's "most likely to cause serious harm" list because of the efficiency of its bite, its temperament, and the extreme toxicity of its venom. Fortunately, the incidence of humans being bitten by this snake is rare. Suppose such bites prove fatal 30% of the time. If three Queenslanders are bitten during 1 year, what is the probability that all 3 will die? That exactly 2 will die? That at most 1 will die?
11. From previous studies reported in ecological journals, it is known that a particular population of peppered moths, *Biston betularia*, consists of two color morphs: 60% are black and 40% are mottled white. Fifty percent of the moths are male, but black males make up 20% of the total population.
- (a) If a moth is black, what is the probability that it is male?
- (b) If a moth is black, what is the probability that it is female?
- (c) Are sex and color morph independent? Explain.
- (d) What is the probability of trapping a random sample of 4 moths that are all mottled white?
12. In a study of development of American children, thousands of 17-year-old boys were evaluated. Twenty-one percent were found to be obese (defined as 30 lb or more over their ideal weight). Thirty-seven percent were reading below their grade level. Twelve percent were both obese and reading below grade level.
- (a) Generate an appropriate Venn diagram for this data set.
- (b) What percentage of the boys were either reading below grade level or obese?
- (c) What percentage of the boys were either reading below grade level or not obese?
- (d) What is the probability that an obese boy will be reading below grade level?
- (e) What is the probability that a boy who is not obese is reading below grade level?
- (f) Are body weight and reading level independent of each other? Explain.
- (g) What is the probability that an obese boy will be reading at or above grade level?
- (h) Assume that 10% of all the boys had respiratory problems and one-third of the obese boys had respiratory problems. What is the probability that a randomly selected boy will be obese and have respiratory problems?

13. In a large study of obesity 20 percent of the patients were found to have a mutation of a gene for a brain protein called melanocortin-4 receptor (*MC4R*). Thirty-five percent of the patients self reported binge eating at least twice a week. Seventy-five percent of the patients with *MC4R* mutations reported binge eating at least twice a week.
- Draw a Venn diagram representing the patients in this study.
 - What percentage are binge eaters and have the *MC4R* mutation?
 - What percentage are binge eaters or have the *MC4R* mutation?
 - What is the probability that a patient with a *MC4R* mutation is not a binge eater?
 - Is binge eating independent of the *MC4R* genotype?
14. In rats, the following genotypes of two independently assorting autosomal genes determine coat color:

$A_B_ = \text{grey}$
 $A_bb = \text{yellow}$
 $aaB_ = \text{black}$
 $aabb = \text{cream}$

A third gene pair on a separate autosome determines whether any color will be produced. The CC and Cc genotypes allow color according to the expression of the A and B alleles. However, the cc genotype results in albino rats regardless of the A and B alleles present. The cc genotype is said to be epistatic to the A and B gene loci. From the cross

$AaBbCc \times AaBbcc$

determine the expected phenotypes and their ratios assuming a large number of progeny.

15. In an article in the popular press on pregnancy (Ryan, M. Countdown to a baby. *The New Yorker*, July 1, 2002: 68), the author states that with *in vitro* fertilization “the odds for successful conception are better [than with intrauterine insemination]: one in three for each attempt in women thirty-five to thirty-seven. After three attempts, three out of five couples achieve pregnancy.” Comment on the probability calculation. In particular, does it appear successive attempts at fertilization are independent with this method?
16. In tomatoes, *Lycopersicon esculentum*, the alleles of one gene locus determine stem color with purple dominant to green that is, $G_ = \text{purple stems}$ and $gg = \text{green stems}$. A second independent gene locus controls fruit color with $Y_ = \text{red fruit}$ and $yy = \text{yellow fruit}$. A third independent locus controls leaf shape with $S_ = \text{cut leaves}$ and $ss = \text{smooth leaves}$. From the cross

female $GgYySs \times GgYyss$ male

find the probabilities of the following:

- The first offspring has a purple stem and yellow fruit;
- The first offspring has the same phenotype as the female parent;
- The first offspring is heterozygous for all three gene loci;
- An offspring with the same phenotype as the female parent is heterozygous for all three gene loci;
- The first two offspring have green stems.

17. The stone plant, *Lithops divergens*, is well-camouflaged and rather unpalatable. In a particular population 70% are grey-green and the remainder are brownish-green. Forty percent are oval shaped and the rest are round. Twenty percent are grey-green and oval shaped.
- Draw the appropriate Venn diagram for this population.
 - What percentage of the plants are grey-green or oval
 - Are color and shape independent of each other?
 - If a plant has brownish-green color, what is the probability it will be oval?
 - If thirty percent have some evidence of grazing damage and fifty percent of the brownish-green have grazing damage, what percentage of the grey-green plants will have grazing damage?
18. A chemist has taken 10 water samples from the wastewater of a paper factory. Unknown to the chemist, four samples are excessively acidic and can't be analyzed. In a random sample of 3 of the 10 samples, what is the probability that exactly two will have excess acid?
19. (a) A developmental geneticist studying gene expression theorizes that neural tube formation in the African clawed frog, *Xenopus laevis*, requires thirty gene products. If the genes are sequentially activated, how many ways can the process proceed?
- If the genes are not activated sequentially and 20 of the 30 are needed for development to continue, how many ways can activation occur?
 - From the example above do you feel that knowing the structure of a genome allows one to easily predict how it is utilized?
20. (a) Verify that $\binom{3}{0} + \binom{3}{1} + \binom{3}{2} + \binom{3}{3} = 2^3$.
- Verify that $\binom{4}{0} + \binom{4}{1} + \binom{4}{2} + \binom{4}{3} + \binom{4}{4} = 2^4$.
 - More generally, prove that

$$\sum_{i=0}^n \binom{n}{i} = 2^n.$$

Note the indices!

21. A restaurant in Québec City advertises:

Faites vous-même votre combinaison de pâtes, de sauces, d'accompagnements, et d'extra

that is, make your own combination of pastas, sauces, and extras. The selections offered are listed below. Patrons are free to choose as many items from each of the four categories as they wish.

Pâtes		Sauces	
Rotini	Fettucine épinard	Crème d'ail	Rosée
Spaghetti	Penne	Alfredo	Cari – Curry
Fusilli (tricolores)	Fettucine	Napolitaine	Carbonara
Tortellini	Linguine	Pesto – vert	Bolognaise
		Pesto – rouge	Californienne
Condiments			
Anchois	Champignons	Jambon	Ail
Crevettes	Jalapenos	Piments Rouges	Piments vert
Saumon fumé	Saucisses italiennes	Bacon	Poulet
Échalots	Escargots	Merguez	Olives
Fromages			
Mozzarella			Parmesan

- (a) The restaurant said there were more than 25,000 combinations. How many different meals are possible assuming that at least one pasta and one sauce must be selected? (The previous problem may help with your calculations.)
- (b) How many different meals are possible assuming only that at least one pasta must be selected?
- 22.** The poison dart frog, *Dendrobates auratus*, is aposematically colored with black patches on a background of either bright blue or green. Sixty-five percent have the blue background while the rest are green. They vary in the amounts of toxins sequestered in their skin. Forty percent have what are considered high levels of toxins. One quarter of the frogs are highly toxic and blue-skinned. Draw a Venn diagram of the poison dart frog population.
- (a) Find the probability that a randomly chosen frog is blue or highly toxic.
- (b) Find the probability that a randomly chosen blue frog is highly toxic.
- (c) Find the probability that a randomly chosen frog is green and highly toxic.
- (d) Find the probability that a randomly chosen green frog is highly toxic.
- (e) From (b) and (d) above would you say that color and toxicity level are independent? Explain your rationale.
- 23.** The principle pollutants of industrial waste water are heavy metals. Water samples taken from an industrial complex were tested for mercury and chromium. Seventy percent had high mercury levels and fifty percent had high chromium levels. Forty percent had high levels of both heavy metals.
- (a) Draw a Venn diagram representing these data.
- (b) Are the presence of the two heavy metals independent of each other?
- (c) What percentage of the waste water has low levels of both heavy metals?
- (d) If a sample has high mercury levels, what is the probability it won't have high chromium levels?
- (e) If a sample has high mercury levels, what is the probability it will have high chromium levels?
- 24.** In a population of recently discovered tree frogs, 40% of the individuals have orange-colored skin and the rest are green-colored. Seventy percent have black eyes while the remainder have gray eyes. Twenty percent have both orange skin and black eyes.
- (a) Are skin color and eye color independent?
- (b) What percentage of the frogs have orange skin or black eyes?
- (c) What percentage have green skin and gray eyes?
- (d) If a given frog has orange skin, what is the probability that it will have black eyes?
- (e) What is the probability that two randomly chosen frogs will both have orange skin and black eyes?
- 25.** In a large survey of West African village water sources, 30% of the sources contained eggs or larvae of the blood fluke *Schistosoma mansoni*. *Schistosoma* causes a human disease known as schistosomiasis. Twenty-five percent contained significant levels of coliform bacteria, especially *Escherichia coli*. Ten percent of the sources had high levels of both blood flukes and coliforms.
- (a) Draw a Venn diagram of this study.
- (b) Are the two contaminants independent of each other?
- (c) What percentage of the water sources were contaminated?
- (d) What percentage of the water sources were clean?
- (e) If a water source contained coliforms, what is the probability it also contains schistosoma eggs or larvae?
- (f) If a water source doesn't contain coliforms, what is the probability it will contain schistosoma eggs or larvae?

26. In 2007 the Danish Bacon and Food Council, the British subsidiary of a Danish pig producers' organization, attempted to determine what degree of crispiness and crunchiness made the perfect bacon sandwich, which is called a 'bacon butty' in Britain. The research combined four types of cooking (using grills, pans, and ovens in various ways), three kinds of oil, and four types of bacon (smoked, unsmoked, streaky, and thick cut) to establish the preferences of 50 tasters in such matters as the butty's tactile and aural crunchiness. The study also considered a broad range of condiments (like ketchup and brown sauce) and spreads. Let's assume that there were five different condiments. How many potential combinations of cooking type, oil, bacon type, and condiment (assuming at least one condiment/spread but not more than three per butty) were possible? (By the way, the study concluded that the best bacon butties were made with crisply grilled, not-too-fat bacon between thick slices of white bread. See Cowell, A. <http://www.nytimes.com/2007/04/11/world/europe/11bacon.html>)
27. The decorative backyard pond fish called koi are actually carp, *Cyprinus carpio*. They come in a bewildering array of colors and forms. A large koi pond at a local estate had the following:

65% yellow color (Y)
35% red color (R)

20% long-finned or butterfly (B)
80% traditional-finned (T)

10% red, butterfly koi

- (a) Are the fin type and color independent characteristics?
- (b) What percentage are traditional finned, yellow-colored koi?
- (c) What percentage are yellow butterflies?
- (d) Shining scales called Kin Gin Rin occur in 15% of the fish; 3% of fish are Kin Gin Rin butterflies; 5.25% are red Kin Gin Rin fish. Is Kin Gin Rin independent of fin type and color?
- (e) What is the probability that a randomly chosen fish will be a yellow, Kin Gin Rin butterfly?
28. An environmental chemist analyzes seawater samples for two heavy metals: lead and mercury. She finds that 38% of the samples taken in a particular river delta contain toxic levels of lead or mercury that is, $P(Pb \cup Hg) = 0.38$ and 32% contain toxic levels of lead. Ten percent of her samples contain toxic levels of both metals.
- (a) Draw and label an appropriate Venn diagram for this study.
- (b) What percent of the samples contain only toxic levels of lead?
- (c) What percent of the samples contain only toxic levels of mercury?
- (d) What percent of the samples didn't have high levels of either containment?
29. The hyrax, or dassie, is an odd mammal that superficially resembles a guinea pig and is about the size of a rabbit. It is neither, however, but is more closely related to elephants, manatees, and aardvarks. Hyraxes are found in Africa and along the Red Sea on the Arabian Peninsula. A particular colony of rock hyrax, *Procapra capensis*, was found to consist of 70% females and 30% males. Forty percent had brownish gray fur while the rest had yellowish fur with a white underbelly. One in ten was a brownish gray male.
- (a) Draw a Venn diagram for color and gender for the colony. Write out the characteristics using set notation.
- (b) What percentage of the hyraxes were yellow or male?
- (c) Are color and gender independent characteristics?
- (d) What is the probability that a female hyrax will be yellowish?
- (e) What is the probability that a randomly captured member of this colony is a yellowish female?

30. While bearded irises are one of the more popular perennial flowers grown in the Northeastern U.S., they have a number of serious pests. The most serious of these is a small moth called the iris borer, *Macronoctua onusta*.

A commercial breeder of bearded irises had a crop that consisted of 60% purple-flowered plants and 40% yellow-flowered plants. He found that 20% were infected with iris borer and 25% of the yellow-flowered were infected.

- What percent of his crop were yellow and infected?
 - Are flower color and infection independent of each other?
 - Find the probability that a randomly chosen plant is purple-flowered and infected.
 - Find the probability that a purple-flowered plant is infected.
31. Suppose the economic climate requires that a large urban hospital reduce its emergency room staff from 32 physicians to 28. The CEO of the hospital claims that the four physicians chosen for termination were chosen completely at random. If the four chosen are the four oldest and highest paid, find the probability of this occurring if the process really were random. Does this probability suggest age discrimination?
32. Recent studies have demonstrated that hospitalizations of heavy children aged 2 to 19 have sky-rocketed in the past decade. Nationwide the obesity related diseases asthma, diabetes, and gall bladder dysfunction had the following percentages in the hospitalized children:

10%	Asthma
35%	Diabetes
15%	Gall Bladder Dysfunction
5%	Had both Asthma and Diabetes
4%	Had both Diabetes and Gall Bladder Dysfunction
2%	Had both Asthma and Gall Bladder Dysfunction
1%	Had all three maladies

- Draw a Venn diagram of this population and label each area represented including its percentage.
 - What percent had at least one of the three maladies?
 - What percent had none of the maladies?
 - If a patient has diabetes, what is the probability he will also have asthma?
 - Are diabetes and asthma independent maladies?
 - What percentage suffered only from asthma?
33. A fair 6-sided die is rolled twice. If X is the discrete random variable X representing the maximum of the two numbers obtained on the rolls, determine the density function of this variable.
34. Mars, Inc., the candy giant that makes M&M's[®], Snickers[®], etc., has a large pool of tasters who test new products. This pool is made up of 40 people of different ages and ethnic backgrounds. Suppose a new candy bar under development has an ingredient that causes severe allergic reactions in some people. If 5 of the 40 tasters have this allergy and 20 of the 40 are assigned to taste the new bar, determine the probability that none of those chosen will have an allergic reaction to the new bar.
35. Twenty-five federal prisoners volunteered to test a new antimalarial drug. Only fifteen will be given the drug. If, unknown to the pharmacologist running the trials, five of the prisoners have a hypersensitivity to the new drug, find the following:
- there will be no allergic reactions among those taking the drug.
 - there will be exactly 2 allergic reactions among those taking the drug.

- 36.** An ethnobotanist working in Kazakhstan found a new species of apple tree, *Malus sp.* She noted that 30% of the trees have red fruit while the rest have yellow fruit. Forty-five percent of the trees are dwarfed while the rest are standard size. Ten percent of the trees are both red-fruited and dwarf.
- (a) What percentage of the trees are either red or dwarf?
 - (b) What percentage of the trees are both red and standard size?
 - (c) Are size and fruit color independent?
 - (d) If a tree has standard size, what is the probability that it will have red fruit?

Additional Problems for Chapter 3

- Suppose that you have read that the leopard frog, *Rana pipiens*, has a sex ratio in most populations of 60% females and 40% males. If this is true, what is the probability that
 - in a random sample of 20 individuals collected from Odell's Pond fewer than 10 will be female?
 - in a random sample of 13 exactly 8 will be female?
- A certain population is normally distributed.
 - What proportion of the population lies within ± 0.5 standard deviations of the mean?
 - What proportion of the population lies within ± 1.5 standard deviations of the mean?
 - What proportion of the population lies within ± 2.5 standard deviations of the mean?
- Assume that tree diameters of sugar maples, *Acer saccharum*, from some defined forest area are normally distributed with a mean of 50 cm and a standard deviation of 10 cm. Find the probability that
 - a randomly chosen tree has a diameter less than 60 cm;
 - a randomly chosen tree has a diameter between 35 cm and 60 cm.
- Assume that the mean number of calls being made to a computer help center is 2 per minute. How many minutes each hour would you expect there to be no calls made to the center?
- A large nutrition study has found that the total carbohydrates intake of 12- to 14-year-old male Americans is normally distributed with a mean of 124 g/1000 cal and a standard deviation of 20 g/1000 cal.
 - What is the probability that a randomly selected boy from this age group will have an intake of less than 140 g/1000 cal?
 - What is the probability that a randomly selected boy from this age group will have an intake greater than or equal to 130 g/1000 cal?
 - If a normal total carbohydrate intake is considered to be between 94 g/1000 cal and 154 g/1000 cal, what percentage of the population would be considered normal?
 - If you randomly selected 3 boys and they all have values less than 104 g/1000 cal, would you be concerned about your sampling technique? Explain.
- In an area of heavy infestation, gypsy moths lay egg clusters on trees with a mean number of clusters per tree equal to 3. Calculate the probability that a randomly chosen tree has
 - no egg clusters;
 - at least 1 egg cluster.
- Childhood lead poisoning is a public health concern in most urban areas of the United States. In a certain population, 1 child in 10 has a high blood-lead level (defined as 30 $\mu\text{g}/\text{dl}$ or more). In a randomly chosen group of 16 children from this population, what is the probability that:
 - None has high blood lead.
 - 3 or fewer have high blood lead.
 - More than 4 have high blood lead.
 - What is the expected number that will have high blood lead?

8. The number of typographical errors per page in a statistics textbook has a Poisson distribution. Suppose that 90.4% of the pages have no errors.
- What is the expected number of errors per page?
 - What is the probability that a page will have at least 2 errors?
9. In its Current Population Survey of 1998, the Census Bureau found that 23.4% of U.S. families were headed by a single parent.
- If 80 families are chosen at random, find the probability that no more than 21 are headed by a single parent.
 - Find the probability that at least 12 are headed by a single parent.
10. The National Communication System is the government agency charged with coordinating emergency preparedness communications for the Federal Government. In one of their reports, Poisson distributions are used to estimate the probability of the number of annual occurrences of significant natural hazards within the boundaries of each regional Bell operating company area, with the mean annual occurrence derived from historical data. [Based on data from: Natural and technological disaster threats to national security and emergency preparedness (NS/EP) telecommunications. www.ncs.gov/n5_hp/Information_Assurance/NAT96-3.htm, August 2000.]
- For the five Mid-Atlantic states floods are seen as the greatest threat. If μ is estimated to be 1.423 floods per year, find the probability that: (i) there will be no floods in a single year; (ii) there will be at least 1 flood in the region in a single year; (iii) there will be more than 1 flood in the region in a single year.
 - In the Midwest, tornadoes are seen as the second-ranked threat. If the probability that there were no tornadoes in a single year is estimated to be 0.206, what is μ ? What is the probability that there will be exactly 1 tornado?
11. The transformation of bacterial cells by the uptake of plasmids from their environment is a rare event. With a standard protocol only 1 in 500 cells is successfully transformed ($p=0.002$). If 2000 cells are treated with this protocol, find
- the probability that 3 or fewer cells become transformed;
 - the probability that at least 5 cells become transformed.
12. One of Earth's oddest plants is *Welwitschia mirabilis* of southwestern Africa. It was first described by plant collectors in Namibia and Angola in the early 1860s. The stem of the adult plant looks like an upside-down traffic cone and has just two long, strap-like leaves that never fall off. The individual plants can live for 1500 years and the desert winds thrash the leaves into strips that get quite tangled over time. These ancient specimens have been described as looking like giant spiders creeping through the desert. In the Mossâmedes Desert the adult plants are Poissonally distributed with an average of 3 plants per hectare. Determine the following probabilities.
- A randomly chosen hectare will have more than 3 plants.
 - A randomly chosen hectare will have between 1 and 4 plants (inclusive).
 - A randomly chosen hectare will have less than 3 plants.
 - If you come across a hectare with 9 adult plants would you consider the claim of a poisson distribution with a mean of 3 to be suspect? Explain.
13. Reconsider the tomatoes, *Lycopersicon esculentum*, in Supplementary Problem 2.16. From the cross
- $$\text{female } GgYySs \times GgYyss \text{ male}$$
- find the probabilities of the following:
- Exactly two of the first five offspring have green stems;
 - At least 4 of the first 10 have green stems;
 - More than 4 of the first 10 have green stems.

14. The director of a plant germplasm repository travels to Uzbekistan to collect apple seed from wild land races that she hopes will be resistant to fire blight, a bacterial disease of commercial apples. It is thought that 10% of the wild apples in one area have natural resistance to fire blight.

(a) How many trees must she sample to be 95% confident that she has collected at least some seeds that are resistant?

Suppose she collects from 15 trees, find the probabilities that:

- (b) None of seeds will be resistant;
- (c) Seeds from at least three trees will be resistant;
- (d) Seeds from 2 or 3 trees will be resistant;
- (e) At most seeds from 4 trees will be resistant.
15. Suppose that you buy an old house with a large number of water pipes that have a great many connections and joints. Over time these connections and joints occasionally fail. In Bob Vilas' *Home Again* magazine you read that water system joints in houses like yours fail Poissonally at a rate of 1 every two years. You plan to go on a six-month cruise and leave the house vacant. What is the probability that the water system will not spring a leak while you are gone?
16. It has been documented that 70% of those envenomated by *Conus geographus* (see page 2 of this document) will experience respiratory failure. If 10 people are admitted to hospitals in Northeastern Australia with *C. geographus* wounds, find the following probabilities:
- (a) Less than 7 will have respiratory failure;
- (b) Seven will have respiratory failure;
- (c) More than 7 will have respiratory failure.
- (d) If only 2 have respiratory failure, would that be considered unusual?
17. In the Sea of Cortez the yellowfin tuna, *Thunnus albacares* average about 70 pounds. The weights are normally distributed with a standard deviation of 30 pounds.
- (a) What percentage of the fish are above 70 pounds in weight?
- (b) What percentage of the fish are above 115 pounds in weight?
- (c) What percentage are between 85 and 115 pounds in weight?
- (d) What is the probability that the first two fish caught both weigh over 85 pounds?
- (e) On a recent vacation to Los Cabos my wife (mostly) and I landed a 180 pound yellowfin. The crew was very excited because of the rarity of fish that size. What percentage of the population are as large or larger than our fish?
18. Suppose the survival time (in weeks) after first diagnosis for untreated patients with acute myelogenous leukemia is normally distributed with $\mu = 40$ and $\sigma = 15$.
- (a) How long can a patient expect to live if untreated?
- (b) What is the probability that he will live less than 35 weeks?
- (c) What is the probability that he will live longer than 60 weeks?
- (d) Treatment is devised and a sample of 9 treated patients live an average of 55 weeks. Using probability arguments would you say the treatment significantly lengthens survival time?

19. Radioactive waste generated by America's massive weapons programs after World War II remains an environmental problem of enormous proportion. One storage site in Washington State has about 200,000 cubic meters of highly radioactive liquid waste stored in 177 specially constructed underground tanks designed to last 10 to 20 years. It is theorized that these tanks are now failing Poissonally with a mean of 0.5 per year. Assuming this theory is correct, find the probability that in the next year:
- No tanks will fail;
 - Two tanks will fail;
 - More than two tanks will fail.
 - What is the probability of at least one failure in the next 5 years?
20. If the water coming from the municipal water supply has an average chromium level of $2.6 \mu\text{g/L}$ with a standard deviation of $0.5 \mu\text{g/L}$, would you say that water coming from a well tested at $4.0 \mu\text{g/L}$ of chromium has a significantly higher level of chromium than the municipal water? Use the normal distribution and probability arguments here.
21. If a large population poison dart frogs, *Dendrobates auratus*, has 40% of the individuals that are highly toxic, find the following:
- The probability of less than 7 in a random sample of 15 will be highly toxic.
 - The probability that more than 7 in a random sample of 15 will be highly toxic.
 - The probability that exactly 7 in a random sample of 15 will be highly toxic.
 - How many highly toxic individuals do you expect in a random sample of 15?
22. Suppose the *Dendrobates auratus* frogs, are Poissonally distributed along a stream with a mean of 2 frogs per 100 meters.
- What is the probability that a given 100 m stretch has less than 2 frogs?
 - More than 2 frogs?
 - Exactly 2 frogs?
23. According to the extensive records kept by the Golden Kennel Club, the number of live births to golden retriever bitches during their first pregnancy has the following probability density function.

x (live pups)	3	4	5	6	7	8	9	10
$f(x)$	0.05	0.07	0.10	0.15	0.25	0.20	0.05	

- Complete the pdf above and construct the cumulative distribution function, $F(x)$, for the number of live births per litter.
 - Find the probability that $X \leq 6$.
 - Find the probability that a litter has greater than 7 live puppies.
 - Find the mean number of live puppies per first litter.
24. Suppose the number of category 5 hurricanes reaching landfall in the United States per decade has the following probability density function.

X	0	1	2	3	4	5 or more
$f(X)$	0.70	0.20	0.05	0.03	0.01	0.01

- Construct the cumulative distribution function for X .
- From the CDF find the probability of less than 3 storms/decade.
- Find the expected value of X .
- Find the mean number of storms per decade.

25. Assume that since records have been kept, the North American East Coast has experienced an average of one hurricane of category 3 or higher per hurricane season. If hurricanes of this magnitude have a Poisson distribution over time, find the following:
- The probability of no category 3–5 hurricanes in a season.
 - The probability of at least 2 of these hurricanes in a season.
 - The probability of less than 6 but more than 1 in a season.
 - The expected number of category 3 or greater hurricanes per year.
26. In 2004, a survey found that in Nebraska 23% of all children under 18 were living in families headed by a single parent. If 100 children are chosen at random, how many would be expected to be living in families headed by a single parent? Find the probability that less than 20 are living in families headed by a single parent. (Based on data reported by: The Annie E. Casey Foundation. KIDS COUNT 2006. See www.aecf.org/kidscount/sld/profile.jsp.)
27. If *Rafflesia arnoldii* is distributed Poissonally with an average of 2 plants per hectare in the deep rainforest. Find the following probabilities:
- A random hectare has no plants.
 - A random hectare has less than three plants.
 - A random hectare has between 5 and 1 plants inclusive.
 - How many plants would you expect in a randomly chosen hectare?
28. (a) Of the 100 members of the U.S. Senate at the start of 2001, 50 were members of the Republican Party and 50 were members of the Democratic Party. Twelve senators had been elected to the national academic honor society Phi Beta Kappa as undergraduates in college. Four of the 12 were Republicans. *If we assume that membership in Phi Beta Kappa and political affiliation are independent events*, determine the probability that: (i) exactly 4 of the 12 are Republicans; (ii) at most 4 are Republicans. [Based on data provided by Priscilla Taylor. 2001. Personal communication. Also see *The Key Reporter*, **66**(2): p. 4.]
- (b) Of the 435 members of the U.S. House of Representatives at the start of 2001, 221 were Republicans. Twenty-six Representatives were members of Phi Beta Kappa as undergraduates, and of these 8 were Republicans. *If we assume that membership in Phi Beta Kappa and political affiliation are independent events*, determine the probability that: (i) exactly 8 of the 26 are Republicans; (ii) at most 8 are Republicans.
29. A population has a normal distribution with mean $\mu = 50$ and standard deviation $\sigma = 12$.
- Calculate the probability that X is greater than 54.
 - Calculate the probability that X is less than 32.
 - Calculate the probability that X is greater than 50 but less than 77.
 - Calculate the probability that X is less than 50 but greater than 28.
 - Calculate the probability that X is less than 76.
 - Calculate the probability that X is greater than 33.
 - Calculate the probability that X is not between 40 and 60.
 - Calculate the probability that X is between 35 and 65.
 - Calculate the probability that X is between 32 and 57.
 - Calculate the probability that X is not between 27 and 72.
30. (a) A flower of genotype Aa is self-fertilized. What is the probability that of 10 seeds it produces, 3 or less will have an aa genotype?
- (b) What is the probability that exactly 3 of the 10 will have the aa genotype

- 31.** Two persons are on a reducing diet. The first person weighs 178 lb and belongs to an age and height group for which the mean weight is 144 lb with a standard deviation of 12 lb. The second person weighs 194 lb and belongs to an age and height group for which the mean weight is 160 lb with a standard deviation of 16 lb. Assuming weight to be normally distributed within each age and height group, use the Z distribution to determine which person is most overweight. Explain your rationale.
- 32.** A number of articles in both the scientific and popular press have been written about the income and social advantages enjoyed by those who are taller. According to Wikipedia, for the 46 U.S. presidential elections in which the heights of both candidates are known, the taller candidate won 27 times, the shorter candidate won 17 times, and the candidates were the same height 2 times. (See http://en.wikipedia.org/wiki/List_of_heights_of_United_States_presidential_candidates.)
- (a) Is there evidence that the taller candidate has a statistically greater probability than chance of defeating the shorter candidate?
- (b) But wait, there's more! In three of the cases in which the shorter candidate won, the taller candidate actually received more popular votes but lost in the Electoral College. This happened in 1824, 1888, and 2000 (the other time that the electoral vote winner was not the popular vote winner was in 1876, for which we do not know the height of the loser). So, of the 46 cases for which we have data, the taller candidate has won the popular vote 30 times, and the shorter candidate 14 times, and the candidates were the same height 2 times. Is there evidence that the taller candidate has a statistically greater probability than chance of defeating the shorter candidate in the popular vote?
- 33.** Largemouth bass, *Micropterus salmoides*, as three-year olds have lengths that are normally distributed with $\mu = 32$ cm and a standard deviation of 5 cm. Given this distribution find the following:
- (a) The probability that a fish is over 40 cm in length.
- (b) The probability that a fish is less than 31.5 cm in length.
- (c) The probability that a fish is between 36 and 28 cm in length.
- (d) The probability that the first five fish caught are all less than 30 cm.
- (e) If you caught five fish and none were as large as the claimed mean, how would you interpret your experience relative to the claim of normalcy?
- 34.** The following table shows the density for random variable X , the number of adult females in a band of howler monkeys:

X (Females)	1	2	3	4	5
$f(x)$	0.10	0.15	0.50	0.15	0.10

- (a) Construct the cumulative distribution function, $F(x)$, for $f(x)$.
- (b) Calculate $E(X)$ and μ for this variable.
- (c) Calculate σ^2 knowing that $E(X^2) = 10.1$.
- 35.** It has long been hypothesized that cardiac mortality is higher at Christmas and New Year's than during other days in December. Suppose for a large population the number of deaths per day in December averages 500 with a standard deviation of 50 and the data is normally distributed. (Adapted from: Phillips, David P. et al. 2004. Cardiac mortality is higher around Christmas and New Year's than at any other time: The holidays as a risk factor for death. *Circulation*. **110**: 3781–3788.)
- (a) On a particular Christmas 650 cardiac deaths occur. Was 650 on Christmas a rare event?
- (b) That same year 595 cardiac deaths occurred on New Year's Day. How rare is this number of deaths given the overall distribution?
- (c) How many days a year would you expect to have as many as 595 deaths?

36. A breeder of labrador retrievers understands that the AKC only recognizes black, chocolate, and yellow coat colors. Black and chocolate coats are caused by alleles of the same gene with the black allele dominant to the chocolate allele. According to Mendelian genetics two dogs heterozygous (Bb) for these two alleles will produce puppies in a 3 black (B₋) to 1 chocolate (bb) ratio.
- Assume that two heterozygotes (Bb) are mated together and produce a litter of 14 puppies. Find the following probabilities:
- There will be at least 5 chocolate-coated puppies.
 - There will be more than 5 chocolate-coated puppies.
 - There will be 5 chocolate-coated puppies.
 - What is the expected number of chocolate-coated puppies in such a litter?
37. A microbiologist plates aliquots of 1 million *E. coli* bacteria on individual petri dishes containing nutrient agar plus streptomycin, an antibiotic that normally kills *E. coli*. If the *E. coli* average one mutation to streptomycin resistance per million cells, determine the following:
- A petri dish will have no resistant colonies.
 - A petri dish will have one resistant colony.
 - A petri dish will have more than 2 resistant colonies.
 - The expected average number of resistant colonies per petri dish.
38. One year you decide to enter the famous Lake Trout Fishing Derby held each Memorial Day weekend on Seneca Lake. You also decide to fish the south end of the lake and will only register (at the north end) a fish that has a reasonable chance of winning. The DEC has determined that the weights of lake trout in Seneca Lake are normally distributed with a mean of 4.1 lbs and a standard deviation of 2.2 lbs.
- Your plan is to register a fish only if it is in the 90th percentile or higher. How big must a fish be to be worthy of registering?
 - Also what percentage of the lake trout will be between 3 and 6 pounds?
39. Osteoporosis is a debilitating disease characterized by low bone mineral density (BMD) and deterioration of the microarchitecture that weakens the bone and increases risk of fracture. BMD scores are assumed to be normally distributed and are usually reported as z scores. Osteoporosis is defined as a z score of -2.5 or less, while low bone mass, termed osteopenia, is defined as a z score in the range of -1.1 to -2.5 .
- What percentage of the population would be diagnosed with osteoporosis?
 - What percentage of the population would be diagnosed with osteopenia?
 - What percentage of the population would be considered to have normal or higher than normal BMDs?
40. Suppose two subspecies of a particular mouse are very similar looking, but subspecies A has a mean overall body length of 10.3 cm and subspecies B has a mean overall body length of 12.4 cm. Both subspecies have standard deviations for their lengths of 2.1 cm.
- If you capture a mouse that is 11.0 cm in length, what is the probability that it is subspecies A? Subspecies B?
 - Suppose the captured mouse was 12.0 cm in length, how do the probabilities for each subspecies change?
41. (a) Taxonomists use Latin binomials to designate individual species. Likewise, people consistently use two-word epithets to designate specific organisms within a larger group of organisms, despite there being an infinitude of potentially more logical methods. It is so familiar that it is hard to notice. In English, among the oaks, we distinguish the pin oak, black oak, or white oak, among bears, grizzly bears, black bears, and polar bears. When Mayan Indians, familiar with the wild piglike creature known as peccaries, encountered Spaniards' pigs, they dubbed them "village peccaries." We use two-part names for ourselves as well: Sally Smith or Li Wen.

There appears to be such profound unconscious agreement that people will even concur on which exact words make the best names for particular organisms. Brent Berlin, an ethnobiologist at the University of Georgia, discovered this when he read 50 pairs of names, each consisting of one bird and one fish name, to a group of 100 undergraduates, and asked them to identify which was which. The names had been randomly chosen from the language of Peru's Huambisa people, to which the students had had no previous exposure. With such a large sample size—there were 5,000 choices being made—the students' expected score is, of course, 50 percent if they were guessing randomly. Instead, they identified the bird and fish names correctly 58 percent of the time. Is this *significantly* more often than expected for random guessing? Were the students able to intuit the names' birdiness or fishiness? (Source: Yoon, C. K. 2009. Reviving the lost art of naming the world. www.nytimes.com/2009/08/11/science/11naming.html)

- (b) Fish or fowl? Take part of the quiz yourself. In each (a)–(b) pair, select the bird. (Source: Berlin, B. 2009. www.nytimes.com//interactive/2009/08/11/science/20090811-NAMING-QUIZ.html)

	a	Pronunciation	b	Pronunciation
1	chunchuikit	choon-chew-EE-keet	máuts	MAW-oots
2	áau	OW	tsapáum	tsa-POWM
3	chichikía	chee-chee-KEE-ah	katán	kah-TAHN
4	tsárur	TSA-roor	wáuk	WOW-ook
5	terés	tah-RUSS	takáikit	tah-KAY-keet
6	iyáchi	ee-YA-chee	ápup	A-poop
7	yawarách	yah-wah-RAHTCH	tuícha	too-EEK-cha
8	yákukua	YA-ka-kwah	kasháikunim	ka-SHAY-koo-neem
9	wáikia	WAY-kee-ah	kanúskin	kah-NOOS-keen
10	wahák	wa-HAHK	hápatar	HA-pa-tar

42. *Melaleuca quinquenervia*, the bottlebrush tree, is native to Australia but is an invasive species in Florida. In southern Florida wetlands it's thought to be distributed Poissonally with a mean of 5 trees per hectare. If the distribution is correct:
- What is the probability of a hectare having less than 5 bottlebrush trees?
 - What is the probability of a random hectare having exactly 5 bottlebrush trees?
 - What is the probability of a random hectare having more than 5 bottlebrush trees?
 - How many are expected per hectare?
 - What is the expected variance in number of bottlebrushes per hectare?
43. Many of the game fish in Lake Ontario have significant levels of DDT and PCB's. Recently high levels of polybrominated diethyl ethers (PBDE's) used as flame retardants in the plastics used in electronics, furniture foam, textiles, etc. have been reported. It has been determined that salmon with more than 5 ppm PBDE should not be eaten more than once a month and fish with more than 8 ppm should never be eaten.
- If PBDE levels are normally distributed with a mean of 4 ppm and a standard deviation of 2 ppm, find the following probabilities:
- A randomly chosen salmon has a PBDE level of 8 or more ppm and, therefore, should not be eaten.
 - A randomly chosen salmon falls in the restricted eating class (5 to 8 ppm).
 - A random sample of 16 salmon have a mean PBDE level of 5 or more ppm.
 - If a random sample of 25 salmon have a mean PBDE level of 6 ppm with a standard deviation of 2.5 ppm, would you say that the claim of a mean of 4 ppm is too low? Analyze as a test of hypothesis.

44. In spite of a public awareness campaign, it is thought that only 30% of fishermen on Lake Ontario understand that there is a health risk from eating Chinook and Coho salmon from Lake Ontario. An investigative reporter decides to test this claim. She surveys 19 fishermen about the risks of eating Ontario salmon.
- How many would she expect to know that risk exists?
 - Assuming the 30% claim is correct, what is the probability that 4 or fewer know of the risk?
 - Suppose she surveys 100 fishermen and finds 15 are aware of the risk, would you say the 30% value is too low? Use a normal approximation of the binomial distribution to develop a probability argument to support your position here.
45. LDL-cholesterol levels in men in industrialized societies tend to be normally distributed with a mean of 150 mg/dl and a standard deviation of 25 mg/dl. Individuals with Familial Hypercholesterolemia (FH), a dominant autosomal trait, have LDL-cholesterol levels that are normally distributed with a mean of 350 mg/dl and a standard deviation of 50 mg/dl. A patient is examined and found to have an LDL-cholesterol level of 225 mg/dl. What is the probability of a level at least this high given a normal genotype? What is the probability of a level no higher than this given the patient has FH? Do you think the patient has FH? Discuss. (Consider FH is a rare disease.)
46. A particular strain of inbred mice has a form of muscular dystrophy that has a genetic basis. In this strain the probability of the appearance of muscular dystrophy (MD) in any one mouse born to specified parents is 0.25. If 16 offspring are raised from these parents, find the following:
- The expected number that will have muscular dystrophy.
 - The probability that less than 4 will have MD.
 - The probability that 4 will have MD.
 - The probability that more than 4 will have MD.
47. Suppose that the Public Health Department in a large eastern city claims that the mean number of rats per city block is 4 and is Poissonally distributed.
- What is the expected number of rats per city block?
 - What is the probability of finding 2 or less rats in a randomly chosen city block?
 - What is the probability of finding 2 rats in a city block?
 - If you found a city block with 7 rats, would you say there is a significant rodent problem on that block? Use a probability argument.
48. The following is the probability density function for the number of live puppies produced by purebred standard French poodle dogs in their first litters.

X	2	3	4	5	6
$f(X)$	0.05	0.15	0.25	0.35	0.20

- Construct the cumulative distribution function for X .
 - Find $P(X = 5)$.
 - Find $F(5)$.
 - Determine $E(X)$ and $E(X^2)$
 - Find the mean and the variance of X .
49. In an aerial survey of an African savannah it was determined that a rare species of *Acacia* trees average five per hectare. Assuming that these trees are Poissonally distributed, find the following:
- a randomly chosen hectare has less than 3 *Acacia* trees.
 - a randomly chosen hectare has exactly 3 *Acacia* trees.
 - a randomly chosen hectare has more than 3 *Acacia* trees.

50. Assume that male and female rat pups are equally likely to be born to breeding females in the laboratories of a large biological supply company. Using the normal curve approximation of the binomial, determine the probability that of 1000 animals born 650 or less will be female.
51. An architect designing a men's gymnasium wants to make the interior doors high enough so that 95% of the men using them will have at least a one-foot clearance. Assuming that the heights will be normally distributed, with a mean of 70 in and a standard deviation of 3 in, how high must the architect make the doors?
52. Suppose it is known that in a certain area of a large city the average number of rats per quarter block is five. Assuming that the number of rats is Poissonally distributed, find the probability that in a randomly selected quarter block:
- (a) There are exactly five rats.
 - (b) There are more than five rats.
 - (c) There are fewer than five rats.
 - (d) There are between five and seven rats, inclusive.
53. A certain strain of *Diplococcus pneumoniae* mutates to penicillin resistance at a rate of 1 per 10,000,000 cells. If petri dishes are plated with about one million bacteria each, find the probability that a randomly chosen petri dish will contain exactly 2 resistant colonies.
54. By far the most widely prescribed medicine in the U.S. is the tranquilizer with the brand name "Valium". The published mean lethal dose (LD_{50} kills 50% of mice) of the drug is 720 mg/kg in mice. The standard deviation is 40 mg/kg. If it is assumed that the lethal dose is normally distributed, what dose will kill about 90% of the mice (LD_{90})?

Additional Problems for Chapter 4

1. An apiculturist investigating nutritional causes of differences in bee morphology weighed 16 worker bee pupae from a commercial hive. She found their average weight to be 530 mg with a standard deviation of 36 mg. Construct the 90% confidence interval for the population mean (μ) and the population variance (σ^2) of worker bee pupal weights.
2. As part of a review of Irish healthcare web sites, researchers examined 60 different web sites. Of these, 46 contained service information intended for the general public. The Department of Health in Ireland recommends a reading age at or below 12 to 14 years for health information leaflets aimed at the general public. The following table provides the frequency and reading age for the 46 sites with service information. (Based on data reported in: O'Mahony, B. 1999. Irish health care web sites: a review. *Irish Medical Journal*, **92**(4): 334–336.)

Reading age	Web sites
8	1
9	0
10	1
11	2
12	1
13	4
14	2
15	7
16	4
17	24

- (a) Find the mean reading age and standard deviation for these data.
 - (b) Make a bar graph of these data.
 - (c) From your bar graph, does it appear to you that the reading age for these web sites is at or below 14 years of age?
 - (d) Find a 95% confidence interval for the reading age. Does the confidence interval support your impression from part (c) above?
3. A 2007 telephone survey of 1,213 people in Sydney, Australia revealed that 40% of the respondents thought that global warming was a greater threat to security than terrorism. The poll indicated that there was a margin of error of no more than $m = 3\%$. However the confidence level $1 - \alpha$ was not given. Determine this level. (Source: *The New York Times*, www.nytimes.com/2007/10/04/world/asia/04australia.html)
4. The Deepwater Horizon oil spill impacted many species of aquatic wildlife, some well known like the iconic Brown Pelican. A recently discovered species of pancake batfish named *Halieutichthys intermedius* is also in grave danger.

With craggy faces, stumpy fins for “walking on the seafloor, and an excreted fluid that lures in prey, these bottom dwellers might be terrifying were it not for their dainty size. Small enough to fit in the palm of your hand, the pancake-flat fish feed on tiny invertebrates in the waters of the southern U.S. coastline from Louisiana to North Carolina.

Because *H. intermedius* is a newly described species we need to estimate its population parameters from the sample collected. Below are the summary statistics for lengths of the 16 specimens so far collected.

$$\bar{X} = 6.5 \text{ cm} \quad s^2 = 4.10 \text{ cm}^2$$

From these data, calculate 95% confidence intervals for the mean μ , variance σ^2 , and standard deviation σ of lengths of this new species.

5. Hepatitis C is a very difficult disease to cure. A recent study utilized a new antiviral drug telaprevir in conjunction with the standard drugs ribavirin and peginterferon. The success rate in clearing the virus with the new combination was 69% in a study involving 250 hepatitis C patients. Was the clear rate significantly higher than the rate of 41% with ribavirin or peginterferon alone?
6. A Clovis point is a particular kind of spear point used by Paleo-Indians, the first inhabitants of North America, to hunt large game such as mastodons and mammoths. The point was made of stone and had a leaf-like shape, fluted edges, lengthwise channels on both sides and a long, slender point. The points are named for Clovis, New Mexico where the first examples were unearthed by archeologists in 1929. Below are measurements of the lengths (in cm) of nine spear points recovered from the Gault site in Texas.

23.6 18.3 22.5 25.0 19.1 24.8 17.9 28.3 24.0

- (a) For this sample find the mean and variance for the lengths.
- (b) For each statistic calculate the 95% confidence interval for its parameter.
7. Recently on the *Today Show* a guest expert claimed that generic drugs are often dangerous because they don't contain the same amount of active ingredient as the brand-name drugs. The expert claimed that according to the FDA, generics should contain between 100 and 125% of the claimed active ingredient amount as determined by a 90% confidence interval. Suppose the epilepsy drug Tegretol is dispensed as chewable, 100 mg tablets. The generic form of this drug is called carbamazepine. A sample of 25 tablets of carbamazepine produced abroad had a mean of 132.3 mg and a standard deviation of 15.0 mg. Does the foreign generic conform to the FDA standards?
8. A recent year-long study conducted by researchers from the University of Iowa found unexpectedly high levels of polychlorinated biphenyls (PCBs), particularly PCB11 (3,3'-dichlorobiphenyl) in Chicago's urban air.

PCB production ceased in the 1970s due to the high toxicity of most PCB congeners and mixtures. PCBs are classified as persistent organic pollutants which bioaccumulate in animals. While the University of Iowa study found PCB11 in 91% of 184 sample sites, the concentrations were not uniform. At one site near a large elementary school air sampling produced the following data

$$n = 12 \quad \bar{X} = 24 \text{ pg/m}^3 \quad s = 20 \text{ pg/m}^3$$

Calculate 99% confidence intervals for μ , σ^2 , and σ from these data. Interpret these calculations in everyday vernacular.

9. In New York State one of the most common amphibians is the red-backed salamander, *Plethodon cimeveus*. This species lives in the leaf litter of deciduous forests. A sample from an isolated population found on a very remote forest reserve in the Adirondack Mountains had the following statistics for their total lengths in centimeters:

$$n = 25 \quad \bar{X} = 11.1 \text{ cm} \quad s^2 = 1.44 \text{ cm}^2$$

- (a) Calculate a 95% confidence interval for the mean of this sample.
- (b) Calculate a 95% confidence interval for the variance of this sample.
- (c) A much larger and less remote population has a mean length of 10.0 cm. Utilizing earlier calculations would you say that the remote population has a significantly longer average length?

Additional Problems for Chapter 6

1. The data below represent the systolic blood pressures (in mmHg) of 14 patients undergoing drug therapy for hypertension. Assuming symmetry of systolic blood pressures, on the basis of these data can you conclude that the median is significantly less than 165 mmHg?

183	152	178	157	194	163	144
193	160	114	177	155	118	158

2. In one population of patients, the mean hemoglobin level is 13.5 g/100 ml of whole blood. The standard deviation of this variable is 1.4 g/100 ml of whole blood. A series of nine tests on a patient revealed a sample standard deviation of 2.1 g/100 ml of whole blood. Is the hemoglobin level in this patient significantly more variable than normal?
3. A geneticist, studying flower color in *Mirabilis jalapa*, the four-o'clock flower, crossed pink and white individuals together and predicted 50% white-flowered offspring and 50% pink-flowered offspring. Of the 100 seeds collected and germinated, 60 resulted in pink-flowered plants and 40 resulted in white-flowered plants. Was this result significantly different from the expectation? (Use a normal approximation here.)
4. Suppose that for years an investigator has used a stock of inbred rats whose weights have $\sigma = 30$ g. He is considering switching to a cheaper source of supply of rats, except he suspects that the new rats will show greater variability in weight. Measurement of a random sample of 20 rats from the cheaper source yielded a corrected sum of squares of 30,400 and a standard deviation of 40 g. Statistically confirm or refute the investigator's suspicions.
5. The following measurements of wind velocities (in km/hr) during 20 consecutive 15 minute intervals (starting at 1430) were monitored during a thunderstorm on 9 July 2000 in Geneva, NY. Test whether the median wind velocity significantly exceeded 30 km/hr. (Based on data from Robert Seem, New York State Agricultural Experiment Station, August 2000. Personal communication.)

24.6	27.5	39.6	42.5	41.8	47.2	52.3	44.7	37.3	42.5
38.5	36.7	34.4	33.3	33.3	36.7	33.3	29.3	28.6	24.1

6. A machine used to produce individual serving packages of ketchup is normally run at 75 units/minute and at that speed the $\sigma = 0.12$ g. The production manager is considering raising the production speed to the maximum of 100 units/minute, but believes the servings will be more variable at that production rate. Measurement of a random sample of 25 serving packages produced at the higher rate yielded a standard deviation of 0.15 g. Statistically confirm or refute the production manager's suspicions.
7. According to a new labeling law, for a product to claim it is an *excellent* source of choline it must contain 15% of the recommended daily intake per serving or 80 mg. A new brand of honey cracked wheat bread is tested for choline content with the following data collected in milligrams of choline per slice.

73	73	82	84	81	75	70	81
84	78	82	82	87	80	83	77

Do the data support the claim that the new honey cracked wheat bread is an excellent source of choline?

8. At a factory that processes fresh vegetables into canned vegetables, the procedure to wash tomatoes before they are rendered for canning leaves behind an average of 21 insect eggs per 100 kg with a standard deviation of 10.7 eggs/100 kg. The eggs are identified by carefully surveying the washed tomatoes with a black light. Insect eggs show up as brightly glowing specks under a standard black light. A modified washing process leaves behind an average of 20 eggs/100 kg with a standard deviation of 4.8 eggs/100 kg.

If the data for the modified washing process is based on 20 samples, can you say the modified washing method is significantly more uniform than the original method?

9. A commonly used taxonomic key claims that “water pennies” of the species *Psephenus herricki* are 8 mm in length. Assuming that lengths are normally distributed, use the data in Problem 5 of Chapter 1 to test whether the sample mean is significantly different from the claimed value.
10. A psychologist, using a standard IQ test, determined the IQ’s of 41 fifth grade children and found their mean IQ score to be 100 and the standard deviation of their scores to be 15. The test originator claims the test scores will have a mean of 100 and a standard deviation of 10. Is the variance of the test scores greater than claimed by the originator?
11. In an extensive census of deep ocean ecosystems a bottom-dwelling fish named *Aphyonius gelatinosus* was possibly rediscovered. This fish first described in 1878 has rarely been seen since its initial description. It has a white jelly-like body and tiny eyes. The dorsal and anal fins are continuous with the caudal fin. It lacks scales and a swim bladder.

The original paper claimed this species averaged 15 cm in length with a nose-to-gill cover length of 4 cm. The standard deviations for the original specimens collected were 3.0 cm for the overall length and 0.7 cm for the nose-to-gill cover length. The recently censored individuals had the following statistics:

$$n = 36, \quad \bar{X}_L = 18 \text{ cm}, \quad s_L = 4 \text{ cm}, \quad \bar{X}_{NG} = 3 \text{ cm}, \quad s_{NG} = 0.5 \text{ cm}.$$

Numerical taxonomists often use characteristics such as these to assign individuals to species. Do you feel the newly censored individuals are the same species as the earlier described *Aphyonius gelatinosus*?

12. On page 3 of this document, we examined the pitch errors students made in trying to reproduce familiar songs and the so-called “lounge singer effect” wherein amateur singers tend to undershoot tones and sing flat. We now consider this question again in the context of hypothesis testing. (Based on data from Daniel J. Levitin, 1994, “Absolute memory for musical pitch: Evidence from the production of learned melodies,” *Perception & Psychophysics*, 56(4): 414–423.)

Error (semitones)	Frequency
-6	1
-5	3
-4	4
-3	4
-2	4
-1	8
0	12
1	6
2	1
3	1
4	1
5	1
6	0
Total	46

- (a) Rewrite the research hypothesis, “The students sing flat” as a hypothesis about the mean pitch error. Also state the null hypothesis in terms of the mean pitch error.

- (b) Use a t test to answer this question.
- (c) Suppose that you had used a sign test. Would your answer have been the same?
- (d) Suppose that you had used a Wilcoxon signed-rank test. What would your conclusion be?
- (e) Under what circumstances would each of the tests carried out be most appropriate? Which test do you think is most appropriate? You may wish to review your answer to Problem 2 of this chapter.
- 13.** Frank Perdue, the former C.E.O. of Perdue Farms, was obsessive about his chickens. He grew his company from a small family farm into a giant chicken processor that employed 20,000 people and had sales over 2 billion dollars annually. He was known for his attention to all details regarding chickens.
- He realized that consumers wanted more white meat so he crossed Cornish males with White Plymouth Rock females to create a meaty-breasted Perdue pedigree. His goal was to produce individual chicken breasts that averaged 5.0 oz and were quite uniform in size (standard deviation of less than 0.5 oz).
- A sample of 30 processed chicken breasts from his experimental flock had a mean of 4.8 oz and a standard deviation of 0.6 oz. Does this sample indicate that Frank has met his standards for size and uniformity of chicken breasts?
- 14.** Diflunisal is a drug used to treat mild to moderate pain in patients with osteoarthritis or rheumatoid arthritis. Diflunisal's ocular effects had not been investigated until a study was conducted on its effects on intraocular pressure in glaucoma patients who were already receiving the standard maximum therapy for glaucoma. Glaucoma is an eye disease characterized by abnormally high intraocular fluid pressure often leading to damage of the optic disk and loss of vision.
- Suppose the change in ocular pressure after administration of diflunisal (follow-up baseline) among 10 patients whose standard treatment was topical glaucoma medications and methazolamide was -1.6 ± 15 mmHg. Did the diflunisal change the ocular pressure significantly?
- 15.** A horticultural scientist is interested in developing a new variety of daisy that could be used in cut-flower arrangements. Normally daisies are one of the best flowers in terms of longevity in cut flower bouquets lasting an average of nine days in tap water. To test the longevity of the new variety 25 blooming stems were cut and placed individually in tap water. The length of time until necrosis or obvious senescence was recorded for each stem. The summary statistics for these recordings are $\bar{X} = 10.3$ days and $s = 3.1$ days. Does the new variety live significantly longer than average for daisies?
- 16.** A breeder of golden retrievers has bred dogs for many years and produced dogs that were quite uniform in size. His females had a standard deviation in height at the shoulder at one year of age of 2.5 cm.
- A good friend of the breeder raised standard poodles that were also very uniform in height with a standard deviation of 3.1 cm.
- Because of the growing popularity of cross breeds, the two breeders decided to produce golden doodles, the offspring of golden retriever bitches and poodle sires. To their surprise the golden doodles were also very uniform in height, yielding a standard deviation of 2.9 cm. A pair of golden doodles were allowed to produce a litter and the offspring seemed less uniform with a standard deviation of 4.5 cm in height for the 12 puppies.
- (a) Was the variability in this litter significantly greater than that of golden doodle hybrids?
- (b) Use your knowledge of genetics to explain this increase in variance in the F_2 .
- 17.** For several years my wife has grown paperwhite narcissus flowers from bulbs throughout the winter months. These narcissus plants, while beautiful and fragrant, always grew quite tall, averaging 26 inches at bloom. One day my wife read an article in a gardening magazine stating that if you add vodka to the growing media the paperwhites will be significantly shorter at bloom. She then set nine bulbs and gave each a shot of my Grey Goose® vodka! Two weeks later she measured the heights of the plants at bloom. Her data in inches are compiled below.

18.7 20.3 25.9 19.0 21.1 22.6 24.0 27.3 23.5

Do the data from her experiment indicate that the vodka treatment significantly reduced the height at bloom of the paperwhites?

18. A number of studies have linked intellectual impairment in children to blood lead concentrations. Recently the Centers for Disease Control (CDC) set the level of concern for lead at $10 \mu\text{g}/\text{dl}$. Suppose a study of children with lead concentrations between 10 and $20 \mu\text{g}/\text{dl}$ generated the following scores on a standardized IQ test:

97	95	101	105	84	99	110
90	92	89	106	107	87	100
92	94	96	88	105	90	91

For these data:

- (a) Find the mean, variance and standard deviation for the data above.
- (b) If the national average on the standardized test is 100, does this group have a significantly lower mean?
- (c) If the national standard deviation on this standardized test is 10, is the group above significantly different in terms of variability?
19. An experiment was done to see if chewing sugarless gum can curb consumption and craving of sweets and make people feel more energetic and alert through the afternoon doldrums. In a pilot study 15 people were asked to rate their level of alertness at 3:00 PM with and without chewing sugarless gum. Below are their responses, with a + meaning more alert with gum, – meaning less alert and 0 meaning no real difference. Do the data support the claim that chewing sugarless gum increases afternoon alertness?

+ + + - - + 0 + - + + + + + -

20. It is well known that while the French have a relatively high-fat diet, they exhibit a low incidence of heart disease. These facts are known as the “French Paradox.” The French habit of consuming large amounts of red wine has long thought to contribute to the paradox. Recently, resveratrol (trans-3,5,4'-trihydroxystilbene) has been isolated from skins of red grapes. This compound may be the causative agent in the French Paradox.

Some researchers believe that resveratrol regulates a conserved family of genes that produce NAD-dependent protein deacetylases which act as antioxidants which inhibit free radical activity, mutations, coronary heart disease, atherosclerosis, etc.

- (a) The first experimental tests of the effectiveness of resveratrol were completed on the yeast, *Saccharomyces cerevisiae*. Cells of this species normally have a post-reproductive lifespan of 10.2 days. Twenty-five yeast cells grown on a resveratrol-enriched medium lived 26.5 days on average and had a standard error of 7.2 days. From this result would you say that resveratrol significantly lengthened the post-reproductive life spans of yeast cells? Use a critical value to assess significance.
- (b) A second experiment was conducted on the round worm, *Caenorhabditis elegans*, which normally lives 20 days under optimal conditions. Fifty worms raised on resveratrol-laced media lived 28.5 days on average with a standard deviation of 9.3 days. Do *C. elegans* benefit in the form of increased lifespan from resveratrol in their media? Use a P value to determine statistical significance.
21. Tim Coulson, a professor at Imperial College London, has documented what he believes is a concrete effect of global warming on the size of wild soay sheep on Hirta Island, an uninhabited British island in the St. Kilda archipelago off the coast of Scotland. Soay sheep are one of the world’s oldest breeds of domestic sheep. Studying the 2000 soay sheep on Hirta for the past 20 years, Coulson claims the sheep have decreased in weight by 5% during that time.

Warmer winters and longer summers mean weaker, smaller soay lambs are surviving to breed and, in turn, produce smaller offspring. In the past, only the big healthy sheep and large lambs that had piled on weight in their first summer could survive the harsh winters of Hirta.

Twenty years ago adult soay ewes weighed an average of 66 lb. To test Coulson’s claim a random sample of 25 adult ewes on Hirta were captured and weighed yielding the summary statistics $\bar{X} = 61$ lb and $s = 8$ lb. Is his claim of a 5% decrease in weight supported by these data?

22. A manufacturer of pipettors claims that the latest model of the 0.5–10 pipettor is more consistent than earlier models. The earlier model set at $5 \mu\text{l}$ had a standard deviation for aliquots of $0.81 \mu\text{l}$.

A sample of 16 new model pipettors set at $5 \mu\text{l}$ had a standard deviation for aliquots of $0.63 \mu\text{l}$. Are the new pipettors significantly less variable at the $5 \mu\text{l}$ setting?

23. Recently energy drinks containing guarana have become increasingly popular in the U.S. Guarana is a creeping shrub native to Venezuela and northern Brazil. The fruit are small, bright red and contain black seeds. Guarana seeds are rich in caffeine and contain about four times more than coffee beans. They are also rich in tannins and xanthine alkaloids.

Guarana is reputed to be a stimulant and increase mental alertness, fight fatigue, and increase stamina and physical endurance. To test guaranas effect on memory, a standard computer test of memory was utilized. This test has a mean score of 90 for the thousands of people who have taken it on line.

A random sample of 25 college sophomores were given 12 oz drinks of Kuat, a drink produced by the Coca-Cola Company for the Brazilian market. Kuat has high levels of guarana and 82 calories per 200 ml serving.

The students waited 30 minutes, then took the computerized memory test. The results were: $\bar{X} = 93.5$ points and $s^2 = 36$ points. Did the Kuat significantly increase memory scores?

24. A paleobotanist studying the fossils of a community of early land plants in the Rhynie Chert of Scotland found 19 well-preserved specimens believed to be the species, *Aglaophyton major*. These specimens were about 18 cm long and branched dichotomously. Dichotomous branching in plants results when the growing point (apical bud) divides into two equal growing points which, in turn, divide in a similar manner after a period of time, and so on. The angles of these branch points are recorded below.

87°	75°	78°	66°	66°	68°	73°	69°	71°	83°
80°	67°	67°	75°	88°	84°	65°	65°	69°	

If the median branching angle of other well-known populations of *A. major* is 78° , can you assume that the newly found specimens have the same median branching angle? Analyze with the sign test.

Additional Problems for Chapter 7

1. The mitral valve is the heart valve between the left atrium and left ventricle and it has two flaps. In patients with mitral valve prolapse, one or both valve flaps are enlarged. When the heart pumps (contracts), part of one or both flaps collapses backward into the left atrium permitting a small amount of blood to leak backward through the valve and cause a heart murmur. Patients with mitral valve prolapse are at higher risk for infection during dental procedures. Consequently, a single large dose of an antibiotic is usually prescribed for such patients to be taken one hour before any dental work is done. In a pilot study of antibiotics, penicillin was administered to six volunteers and in a later trial the same dose of amoxicillin was given to the same people. The table below gives the concentration of each drug in the bloodstream 1 hour after administration. The measurements are in $\mu\text{g}/\text{ml}$ and are assumed to be normally distributed. Is the bloodstream concentration of penicillin significantly different from that of amoxicillin?

Person	Penicillin	Amoxicillin
1	42	36
2	34	44
3	57	61
4	40	35
5	28	35
6	48	50

2. Aposematic coloration acts as a signal to warn predators of potentially dangerous or unpleasant features. It is believed that individuals which possess color patterns resembling those of aposematic species gain a defensive advantage because predators have learned to avoid animals with these patterns through encounters with aposematic species. A series of experiments tested this hypothesis using the aposematic marine flatworm, *Phrikoceros baibaiye*, and a potential predator, *Thalassoma lunare* (moon wrasse). Each of seven wrasses was presented separately with two different models of flatworms. One was an accurately colored model of *P. baibaiye* and the other was a colorless control model. Both models were made from brine shrimp and agar and should have been palatable for the wrasses. X_i denotes the number of times the i th wrasse attacked the model of *P. baibaiye* and Y_i the number of times it attacked the colorless model during the experimental period. (Based on data reported in Ang, H. and L. Newman. 1996. Warning colouration in pseudocerotid flatworms Platyhelminthes, polycladida. Personal communication.)
- (a) Use the data below to test the aposematic hypothesis $H_0: M_{X-Y} \geq 0$, the model of *P. baibaiye* is attacked at least as frequently as the colorless model, versus $H_a: M_{X-Y} < 0$, the model of *P. baibaiye* is attacked less frequently than the colorless model.

Fish	X: <i>P. baibaiye</i> model	Y: Colorless model
1	1	9
2	5	9
3	7	5
4	6	9
5	1	9
6	5	9
7	7	9

(b) Comment on the sample-size aspect of the design of this experiment.

3. Two plots of the same species of trees were planted at the same time, one on a hillside, the other a control group on level ground. Diameter at breast height (DBH) for trees in both plots was measured (in cm) several years later. We are interested in testing whether a hillside habitat is stressful on the trees and stunts their growth. Carry out an appropriate test of this assertion assuming that DBHs are symmetrically distributed.

Control	46	52	44	42	
Hillside	29	39	45	36	38

4. In 1985–1986, a study on tree-diameter growth was conducted at the Hubbard Brook Experimental Forest located in the White Mountain National Forest, near Woodstock, New Hampshire. Two cores were taken from each of 145 trees using an increment borer (0.5 cm in diameter). To reduce the variability due to slope, they were taken from two directions perpendicular to slope at the height of 1.0–1.2 m above ground. In coring, efforts were made to pass through the pith of stem. The data below are for the two cores from a 92-year-old American beech tree, *Fagus grandifolia*, whose diameter was 36.4 cm. For ease of plotting, the widths of the annual rings from the two cores are given in decimillimeters (tenths of a millimeter). (Based on data reported in: Kim, Eunshik. 1988. Radial Growth Patterns of Tree Species in Relation to Environmental Factors. Yale University, Ph.D. Thesis.)

Year	Core 1	Core 2
1985	10.2	17.7
1984	14.4	17.5
1983	12.8	15.9
1982	15.1	20.1
1981	13.2	13.0
1980	20.8	21.8
1979	19.5	21.5
1978	22.8	21.8
1977	22.7	21.8
1976	12.5	20.0
1975	9.2	25.3
1974	8.8	19.4
1973	5.0	10.9
1972	7.7	18.5
1971	7.0	17.5

Find a 95% confidence interval for the difference in tree ring size using sign test methods. Interpret your answer.

5. Some species of fish are more active at night than during the day. To test this hypothesis for mullet, *Mugil cephalus*, seining was done at high tide in both day and night for one week at Polka Point. The data are the number of mullet caught. Is there evidence for increased night activity? Assume symmetry.

Day	1	2	3	4	5	6	7
Daylight	23	67	34	48	24	51	26
Night	80	53	73	84	42	49	47

6. Mullet were captured in day and night seining exercises at North Stradbroke Island during consecutive high tides and their lengths (in cm) were recorded. Determine whether there was a significant difference in their lengths depending on the time of capture. Analyze using the Wilcoxon rank-sum test.

Night	18	18	20	20	20	21	21	22	23	25
Day	16	17	17	18	18	19	19	19		

7. Estrus is a phase of increased female sexual receptivity, proceptivity, selectivity and attractiveness. It is common across all mammalian species including primates and is thought to function to obtain mates of superior genetic quality. Many scientists believe human female estrus has become lost over evolutionary time perhaps to promote male provisioning and paternal care in long-term pair-bonded relationships.

Contrary to this lost-estrus view a number of studies show that women near the most fertile point of their cycle (just before ovulation) are more attractive to males in a variety of ways from increased body scent to higher verbal creativity and fluency.

One study photographed 30 young women who were in steady relationships and not using the pill. Each woman was filmed twice wearing their self-chosen clothing, once during estrus (as confirmed by hormonal assay) and once during the lower fertility luteal phase of her cycle. With the women's faces obscured leaving only body and clothing cues, 42 mixed-sex raters made a forced-choice judgment ("In which photo is the person trying to look more attractive?") The raters chose the woman in estrus 60% of the time. Is this a significant deviation from random choice? Hint: Adapt the sign test for paired data.

8. These data give the mandible lengths (in mm) for 10 male and 10 female golden jackals, *Canis aureus*, in the collection of the British Museum of Natural History. Is there evidence that the median mandible length differs between sexes in this species? Test using the Wilcoxon rank-sum test. (*HSDS*, #51)

Males	120	107	110	116	114	111	113	117	114	112
Females	110	111	107	108	110	105	107	106	111	111

9. In order for *Banksia serrata* to germinate, fire is required to open its seed cones. In order to understand the effect of fire on these trees, two neighboring sites were surveyed. Site A has been burned frequently during the last 80 years, while fire at Site B has been infrequent during this period. It is hypothesized that the different frequency of fire will result in larger median DBH for *B. serrata* (in cm) at location B than at location A. State the null and alternative hypotheses and analyze the data utilizing the Wilcoxon rank-sum test. Interpret your result.

Site A	12	16	20	26	30	32	36	46
Site B	28	34	44	48	48	50		

10. (a) The data below show how responsive different female white-crowned sparrows, *Zonotrichia leucophrys*, were to the recorded courtship songs of male sparrows of two species that had been raised in the laboratory. Responses to their own species are in the top row and responses to a related species (song sparrow) are in the bottom row. Animal communication must follow predictable patterns for it to be effective, so we might expect a greater response by female sparrows to appropriate (same species) male songs than to inappropriate (different species) male courtship songs. Carry out a test of this hypothesis at the 0.05 significance level using the sign test. Interpret the result. (Based on data reported in: Spittle-Nabors, K. and M. Baker. 1987. Sexual display response of female white-crowned sparrows to normal, isolate, and modified conspecific songs. *Animal Behaviour*, **35**: 380–386.)

Female	a	b	c	d	e	f	g	h	i	j	k	l	m
WCS	1	4	10	1	4	20	1	1	1	7	14	1	3
SS	2	0	10	0	0	14	27	0	0	0	10	0	4

- (b) Find a 95% confidence interval for the median difference in numbers of song patterns.

11. These data are from Charles Darwin's study of cross- and self-fertilization. Pairs of seedlings of the same age, one produced by cross-fertilization and the other by self-fertilization, were grown together so that members of each pair were reared under nearly identical conditions. The aim was to demonstrate the greater vigor of the cross-fertilized plants. The data given in pairs are the heights of each plant (in inches) after a fixed period of time. (*HSDS*, #3)

Cross	23.5	12.0	21.0	22.0	19.1	21.5	22.1	20.4	18.3	21.6	23.3	21.0	22.1	23.0	12.0
Self	17.4	20.4	20.0	20.0	18.4	18.6	18.6	15.3	16.5	18.0	16.3	18.0	12.8	15.5	18.0

- (a) State the appropriate one-sided hypotheses and carry out a test at the $\alpha = 0.05$ level (assume no information on the way heights are distributed).
- (b) Find a 95% confidence interval for the median difference in heights.
12. These data show winter energy consumption (in MWhr) in 10 homes near Bristol, England, before and after the installation of cavity-wall insulation. How much energy does the insulation save? Use a confidence interval and do not assume symmetry. (*HSDS*, #86)

Before	12.1	11.0	14.1	13.8	15.5	12.2	12.8	9.9	10.8	12.7
After	12.0	10.6	13.4	11.2	15.3	13.6	12.6	8.8	9.6	12.4

13. (a) A taxonomist suspects that a significant difference in bill length exists between an eastern population of a certain bird species and a western population of the same species. She hopes to use this difference, if significant, as part of a general morphological picture on which to base a claim of subspeciation. A total of 11 specimens were collected from each population. The bill length of each specimen was measured to the nearest millimeter resulting in the following data. Analyze the data below with the appropriate statistical methods assuming normality.

Eastern	Western
$n_E = 11$	$n_W = 11$
$\bar{X}_E = 88.0$	$\bar{X}_W = 80.0$
$s_E = 10.0$	$s_W = 15.0$

- (b) Calculate a 95% confidence interval for σ_E^2 .
- (c) Calculate a 95% confidence interval for μ_E .
14. The article "Maternal attachment: The importance of the first post-partum days" that appeared in *The New England Journal of Medicine* in 1972 was influential in changing the way hospitals approach the care of newborns. This and subsequent studies made the issue of maternal bonding in the first few days after birth an important consideration in maternity wards. The study was based on a small sample using control and experimental groups consisting of just 14 mothers each (the mean age, socioeconomic and marital status, ethnicity, premedication, sex of the infant, and days hospitalized in both groups were nearly identical).

The mothers in the control group had what was then traditional contact with their infants: a glimpse of the baby shortly after birth, brief contact and identification at 6 to 12 hours, and then visits every 4 hours for bottle feedings. In addition to this routine contact, the mothers in the extended contact group were given their nude babies, with a heat panel overhead, for 1 hour within the first three hours after delivery, and five extra hours of contact each afternoon of the 3 days after delivery. These were the *only* differences in routine between the two groups.

To determine if this short additional time with the infant early in life changed later behavior, the mothers were asked to return to the hospital a month after the delivery to complete a questionnaire regarding their interaction with their newborns and to be observed interacting (or not) with their newborns.

- (a) The total score on the questionnaires could range from 0 to 6, with higher scores indicating higher levels of maternal interaction. Let H_0 be the hypothesis that there is no difference between the scores of the mothers from the Control and Extended Contact groups and H_a the hypothesis that the Extended Contact mothers' scores are higher. The researchers used the Wilcoxon rank-sum test to analyze the data below. Test with $\alpha = 0.025$. What did they conclude? (Based on data reported in Klaus, M. et al. 1972. Maternal attachment: The importance of the first post-partum days. *The New England Journal of Medicine*, **286**(9): 460–463.)

X: Control group 0 0 0 0 0 1 3 4 4 4 4 5 5 6
 Y: Extended contact 2 3 4 4 4 4 4 5 5 5 5 5 6 6

- (b) Each mother was then observed with their child and scored (again, 0 to 6) according to the level of interaction with their child. Test the same hypotheses as in part (a). What was the researchers' conclusion?

X: Control group 1 2 2 2 2 3 3 3 4 4 5 5 6 6
 Y: Extended contact 3 4 5 5 5 6 6 6 6 6 6 6 6 6

- (c) The combined scores from the interview and the observation were examined. Test the same hypotheses as in part (a). What was the researchers' conclusion?

X: Control group 2 2 3 3 4 5 6 8 8 8 9 10 10 10
 Y: Extended contact 7 8 8 9 10 10 10 10 10 11 11 11 12 12

- (d) How might you have used the results of this study if you were a public health official?

15. In a small pilot study of antibiotics, a standard dose of the broad-spectrum antibiotic, gentamicin was administered to six volunteers and in a later trial the same quantity of erythromycin was given to the same people. The results below show the concentration of each drug in the bloodstream one hour after administration. The measurements are in $\mu\text{g}/\text{ml}$ and are assumed to be normally distributed. Is the bloodstream concentration of gentamicin significantly different from that of erythromycin?

Person	Gentamicin	Erythromycin
1	28	31
2	58	67
3	43	42
4	38	36
5	35	29
6	40	43

16. Children diagnosed with attention-deficit hyperactivity disorder (ADHD) lack concentration, patience, and organizational skills. In a study to investigate anatomical differences between ADHD children and the general population, the brain volumes of random samples of children from each group were measured using magnetic resonance imaging (MRI). All the children were male and eight to ten years old. Brain sizes were adjusted for height and weight. From earlier studies it was thought that ADHD children would have significantly smaller brain volumes. Do the data support this contention?

Brain Volume (cm^3)	
ADHD	General Population
$\bar{X} = 1270$	$\bar{X} = 1310$
$s = 40$	$s = 45$
$n = 16$	$n = 25$

17. Do people find hairy spiders scarier than nonhairy spiders? In order to find out, 20 people were randomly assigned to two groups of 10 each. One group viewed a hairy spider and the other group viewed a very similar but nonhairy spider. Each person was asked to rate the spider that they viewed on a scariness scale from 1 to 10 (10 being most scary). These were the results:

Hairy	10	8	7	9	9	10	9	9	5	8
Nonhairy	7	6	8	6	1	5	4	5	6	3

What may we conclude from this experiment? Analyze using the Wilcoxon rank-sum test.

18. In a second experiment to analyze the strength of people's phobias regarding spiders, 20 people were asked to rank both a hairy spider and a similar but nonhairy spider on a scale from 1 to 10 with 10 being the most frightening.

Hairy	Nonhairy	Hairy	Nonhairy
10	9	10	7
7	5	7	3
10	8	5	1
9	9	10	9
7	5	9	7
8	9	10	3
10	8	7	10
10	5	8	5
9	4	8	4
10	10	8	1

- (a) Analyze the data above with the sign test for paired data.
- (b) Is this experiment design better than the one presented in the previous problem? Explain.
19. It has been known for some time that males of some animal species have evolved beautiful coloration and ornamentation through sexual selection. More recent studies have been conducted to determine whether male choice for female "showiness" also occurs. A study by Amundsen and Forsgren examined the mating behavior of the two-spotted goby, *Gobiusculus flavescens*, a small (4–5 cm) fish which inhabits shallow waters along rocky shores. Observations of natural populations indicate that the sex-ratio of these fish changes from an initial male bias at the start of the mating season to a strong female bias by the end of the season when a male may be surrounded by several females courting him at the same time. Female two-spotted gobies develop colorful yellow-orange bellies during breeding. The surplus of females late in the season provides the opportunity for males to be selective for more conspicuously colored females. (Source: Amundsen, T. and Forsgren, E. "Male mate choice selects for female coloration in a fish." *Proceedings of the National Academy of Sciences U.S.A.* 2001, **98**: 13155–13160.)
- (a) Fifteen mate preference trials were conducted in a three-compartment aquarium. In each trial, one male and two females of similar length but different coloration (conspicuous and drab) were introduced to the aquarium. The male was placed in the center compartment and each female was placed in an end compartment. Once acclimated to the aquarium, the time the male spent within a 5 cm zone of each female compartment was recorded. Thirteen of 15 males spent more time near the colorful females than the drab. Carry out an appropriate test to determine whether these data support the hypotheses of male selectivity.
- (b) To ensure that the size of the females would not be a confounding factor in the selection by males, the researchers attempted to use pairs of females that were closely matched by length. The mean difference (Conspicuous – Drab) in length of the pairs was $\mu_d = 0.1$ mm with a standard deviation of 1.2 mm. Carry out an appropriate analysis to verify that there was no significant difference in the length between pairs of the conspicuous and drab females.

- (c) However, the researchers noted that the more conspicuous females had rounder bellies. Female belly coloration is mainly caused by pigmented eggs being visible through the skin, though it is also caused by orange-red pigment spots in the abdominal skin, itself. Consequently, they measured the body masses of the females. The mean difference (Conspicuous – Drab) in mass of the pairs was $\mu_d = 0.12$ g with a standard deviation of 0.08 g. Carry out an appropriate analysis to determine whether there was a significant difference in the mass between pairs of conspicuous and drab females.
- (d) Because the more colorful female gobies are rounder and have a larger mass than drab females of a similar length, a second set of trials was conducted to control for this potentially confounding factor. Sixteen pairs of females of medium coloration and of similar length and body mass were selected. One member of each pair was randomly assigned to a color-enhancement treatment by means of an apricot-colored permanent marker. The other member of each pair acted as a control and was treated with a colorless marker. The data for the differences (Color-enhanced – Control) in mass and length are given in the table below.

	Mass (g)	Length (mm)
μ_d	0.01	0.4
s_d	0.03	0.7

Carry out an appropriate analysis with $\alpha = 0.05$ to determine whether there was a significant difference in the mass between pairs of the color-enhanced and control females. What about for length?

- (e) From the data supplied, what level of precision was used in measuring goby length? Given this fact and the results of the tests in the previous part, do you feel that the pairs are well-matched?
- (f) When the second set of trials were actually carried out, 14 of 16 males spent more time with the color-enhanced females in the trials. Analyze these results. Do they support the hypothesis that male two-spotted gobies are selective for coloration in female mates?
- (g) As a final check on possible confounding factors, the researchers recorded the amount of time each female spent within 5 cm of the male tank and calculated the signed-ranks of the difference in these times for each pair. For the (Conspicuous – Drab) pairs, they obtained a value of $W_- = 56$. For the (Color-enhanced – Control) pairs, $W_- = 62$. Carefully state the hypotheses for the tests and interpret the results. Is there cause for concern? Remember, the sample sizes are different for the two trials.
20. The American Kennel Club periodically issues warnings against buying dogs from “puppy mills. The AKC claims these dogs are inbred and poorly maintained. They also claim that the breeding bitches are abused and malnourished. To test this claim an animal protection officer weighed Labrador Retriever breeding bitches who have just whelped their second litter at a large so-called puppy mill and at several sanctioned AKC breeders. The weights are given below in kilograms.

Weight (kg)	
Puppy Mill	AKC Breeders
20.3	22.3
21.7	26.0
23.8	25.2
19.9	20.8
22.0	24.5
22.9	25.0

- (a) Are there significantly lower weights for the puppy mill bitches?
- (b) What factors other than nutrition might affect a dog’s weight at whelping? How would you design the experiment to take these factors into account?

21. In order to study the effects of cooperative behaviors within groups of the arid land mongoose, *Suricata suricatta*, commonly known as the meerkat, pups were taken from various groups and placed in cooperative groups consisting of between 2 and 30 adults centered around one breeding pair. The pups were weighed upon capture and again 30 days after being placed in foster groups. The average weight gain in grams is recorded below for two groups: Those with less than 10 cooperating nonbreeding adults and those with more than 20 cooperating nonbreeding adults.

Less than 10	More than 20
$n_L = 15$	$n_M = 12$
$\bar{X}_L = 6.2$ gm	$\bar{X}_M = 8.1$ gm
$s_L = 1.5$ gm	$s_M = 1.3$ gm

Do pups with higher numbers of cooperating nonbreeding adults in their group gain significantly more weight?

22. In a study of the effects of environment on brain development in the Norway rat, *Rattus norvegicus*, a group of twenty two-week old rats was randomly divided into two groups. The 12 animals in the highly stimulated group were caged together in a large enclosure furnished with a variety of toys and climbing apparatus that were changed around on a daily basis. The eight animals in the control group lived in isolation without toys or climbing apparatus. After six months the rats were sacrificed and their cortex weights recorded in milligrams.

Stimulated rats (mg)	Control rats (mg)
708	670
743	650
745	655
650	625
675	667
676	680
690	698
695	690
712	
696	
703	
700	

Did the highly stimulated group have significantly heavier cortexes than the control group? Analyze these data using an unpaired t test and the Wilcoxon rank-sum test. Which do you feel is more appropriate? Explain.

23. A study was conducted to compare the indoor air quality in public bars where smoking is permitted with the air quality in bars where smoking is banned. Measurements of the carbon monoxide levels (in ppm) were taken at 10 PM in 40 bars where smoking was permitted and 40 bars where it was banned. The data generated the following statistical summaries.

	Smoking	Non-smoking
\bar{X}	11.6 ppm	6.9 ppm
s	7.3 ppm	2.7 ppm

Are the CO levels significantly lower in the non-smoking bars?

24. The herb *Ginkgo biloba* is currently being touted as an enhancer of memory and intellect. In a study to test this claim, psychologists developed a set of tasks that involved remembering and manipulating new information. The scores from this set of tasks appear to be normally distributed when administered to any large group. Below are the scores for 12 fifty-five year old men who were tested prior to using the Ginkgo extract and then again after three months of using a recommended daily supplement.

Subject	Control	<i>G. biloba</i>
1	18	21
2	25	23
3	23	25
4	17	19
5	29	29
6	30	32
7	32	33
8	19	20
9	33	31
10	28	27
11	27	29
12	24	30

25. Assume that two independent samples have the same size n and that their variances are similar. Show that the formula for the pooled variance in this case reduces to the average of the two sample variances.
26. In a study of the long term effects of low birth weight on cognitive and social development, forty babies who were on average born 7 weeks premature and weighed 1.18 kg at birth were compared to a control group of forty babies who were born full term and who averaged 3.28 kg at birth. All babies were born in the late 1970s and had similar socioeconomic status. Below are the summary statistics for scores on an IQ test administered to both groups at age twenty.

Premature	Control
$\bar{X}_P = 102.7$	$\bar{X}_C = 107.2$
$s_P^2 = 64.32$	$s_C^2 = 60.78$

Assuming that scores on this particular test are approximately normally distributed, do the results indicate significantly lower achievement in the low birth weight group?

27. Ten female pups with one adjacent male and one adjacent female litter mate in utero were also measured for the anogenital distance. The females are designated 1m females while females with two adjacent males are designated 2m females. The data are below.

1m Females	1.00	1.01	0.99	0.99	1.01	0.95	0.97	0.99	1.02	1.00
2m Females	1.05	1.00	1.03	0.99	1.01	1.07	1.03	1.05	1.08	1.06

Are there significant differences between the 1m females and the 2m females?

28. (a) The home ranges in the field (in square meters) of 2m females and 0m females (no adjacent males, see the previous problem) was monitored for 25 animals in each group generating the following summary statistics.

2m Females	0m Females
$\bar{X} = 220$	$\bar{X} = 110$
$s = 60$	$s = 40$

Are the home ranges of 2m females significantly more variable than those of 0m females?

- (b) Do 2m females have significantly larger home ranges than 0m females?

Note: The previous two problems are adapted from: Vandenberg, J. G. 2003. Prenatal hormone exposure and sexual variation. *American Scientist*, **91**: 218–225.

29. Good nutrition has previously been shown to lower blood pressure. A diet high in fruits, vegetables, and low-fat dairy (the so-called DASH diet) was tested for its efficacy in lowering blood pressure. Fifteen volunteers were tested before beginning the DASH diet and again after three weeks on the diet. The data below are their systolic blood pressures in mmHg.

Before	After
160	152
142	140
130	130
156	150
140	130
144	138
168	156
170	160
152	154
128	126
146	140
180	160
160	144
158	150
156	144

Did the DASH diet significantly lower the systolic blood pressure?

30. Do lost pet ads predict earthquakes? There is considerable anecdotal evidence that some animals are presciently aware of impending earthquakes and volcanoes. In particular, there are numerous reports of anxious activity by pets, including running away, in the period before a quake. Dan Ross, USGS Volunteer for Science, age 10 and Andrew Michael, USGS tested this idea for a science fair project. They selected ten dates between 1983 and 1993 when an earthquake of magnitude of 4.5 or greater occurred within 50 km of San Jose, CA. They also selected ten dates at random during this same time period, carefully avoiding dates at least one month before and after the quakes. For each date, the local newspaper was examined and the number of missing pet ads was recorded. Their data are presented in the table below.

Earthquake Dates	Magnitude	Missing Pet Ads	Control Dates	Missing Pet Ads
Mar. 23, 1991	4.5	17	Dec. 09, 1985	13
Apr. 02, 1989	4.6	22	Oct. 07, 1986	14
Aug. 11, 1993	4.6	27	Nov. 29, 1992	17
Nov. 09, 1988	4.8	22	Dec. 23, 1984	18
Aug. 07, 1989	4.9	19	Dec. 01, 1985	18
Jun. 27, 1988	5.1	21	Feb. 01, 1993	19
Jun. 12, 1988	5.2	20	Jun. 10, 1991	23
Mar. 30, 1986	5.6	21	Feb. 27, 1993	25
Apr. 24, 1984	6.1	22	Dec. 10, 1991	26
Oct. 17, 1989	7.1	28	Aug. 14, 1991	29

Formulate and test an appropriate hypothesis. Do not assume that lost pet ads are normally distributed.

31. As part of a larger study of nutrition and obesity in America, an experiment was conducted to test the effect of portion size on consumption. The test subjects were nine-year old, middle-income Caucasian children. They were served a macaroni-and-cheese entrée one of two ways: either an age appropriate serving or twice the age appropriate serving amount. Thirty randomly chosen children were divided equally between the two groups. The amount of macaroni-and-cheese eaten (in grams) was determined for each child. Do the data below indicate that larger servings contribute to overeating?

	AAS	Double AAS
\bar{X}	120 gm	135 gm
s^2	49 gm ²	64 gm ²

Assume consumed amounts are normally distributed. Analyze fully.

32. The Kuna people of the Caribbean traditionally have very low incidence of stroke, brain infarction, or transient ischemic attack. When these people move to the mainland of North or South America the incidence of these maladies increases dramatically. A researcher felt that a change of diet may be the cause of this increase. On the islands the Kuna drink unrefined cocoa which is rich in flavonoids. To test the effects of flavonoids on blood flow to the brain, she measured blood flow through the carotid artery in twelve middle-aged volunteers who normally don't drink flavonoid-containing beverages. The same individuals were evaluated again, after consuming 1 liter of unrefined cocoa drink per day for a week. Did the cocoa significantly increase the blood flow to the brain? Units are milliliters/1000 grams of brain/minute.

No Cocoa	50	55	47	50	57	55	52	60	72	50	45	50
Cocoa	54	56	47	55	58	61	59	63	70	62	50	52

Analyze assuming only symmetry in the data.

33. As part of a larger study on the effects of various air pollutants on human birth weight, researchers found that children born to women living in counties with low carbon monoxide levels (25% lower) had babies that averaged 3250 g with a standard deviation of 70 g ($n = 25$). Children born to mothers living in counties with high carbon monoxide levels (75% levels) had babies that averaged 3200 g with a standard deviation of 60 g ($n = 36$). Are the babies significantly smaller in the CO polluted counties?
34. In a study of serum creatinine levels in thyroid cancer patients, patients were divided into two groups: Means of creatinine levels in the euthyroid ($n = 56$) and mild hypothyroid ($n = 18$) states were judged not significantly different (69.9 and 67.1 $\mu\text{mol/l}$, respectively). Assuming that (1) the variances were similar for the two populations and (2) the researchers carried out an unpaired t test with $\alpha = 0.05$, what is the smallest possible value of the pooled variance s_p^2 ?

35. The biological activity of insulin, like any protein, is affected if stored at extremes of temperature. Manufacturers recommend storing insulin under cool (15–30°C), shaded conditions. Neither condition is possible in the desert, where temperatures frequently exceed 40°C, thus constituting a major problem for diabetic patients. A small study was conducted to demonstrate the possible effect on the bioactivity of insulin following storage in a *zeer*, a semi-porous clay pot containing water, in desert conditions. The small amounts of water that slowly seep through the walls of the *zeer* evaporate, using up heat, thereby cooling the remaining water. This principle is widely used in the Middle East to cool drinking water in such containers.

For the study, after intravenous injection of a standardized dose of insulin, blood was taken every 5 minutes for a period of 30 minutes. The slope of the fall in plasma glucose level (in mmol/l/min) was determined for each subject. (Based on data reported in Khiriah Al Shaibi et al. Storing insulin in a clay pot in the desert causes no loss of activity: A preliminary report, *Annals of Saudi Medicine*, 1999, 19(6): www.kfshrc.edu.sa/annals/196/98-243.PDF.)

- (a) In one phase of the experiment (subjects 1–4), the efficacy of insulin that had yet to be stored was compared to insulin which was stored in a *zeer* over a six week period. Given the concern that insulin stored at higher temperatures may be less effective in lowering glucose levels, carry out an appropriate test on the first group to determine whether there is evidence for such differences.

Subject	Before storage	After storage in refrigerator	After storage in zeer
1	0.258		0.254
2	0.216		0.180
3	0.176		0.129
4	0.139		0.176
5		0.300	0.250
6		0.198	0.179
7		0.186	0.146
8		0.230	0.220

- (b) In a second phase of the experiment (subjects 5–8), the efficacy of insulin that was stored in a refrigerator (4°C) was compared to insulin which was stored in a *zeer* (mean temperature 26.7°C). Carry out an appropriate test to determine whether there is evidence for a decrease in efficacy of *zeer*-stored insulin.
36. Suppose a researcher wishes to test the efficacy of a new drug for migraine headache relief. The subjects in the study took the drug or a placebo for two consecutive migraine headaches with the order of treatment randomized. Data for the number of minutes until the patient was free of nausea and vomiting are listed below.

Drug	Placebo	d_i
12	21	–9
9	16	–7
11	8	3
21	36	–15
17	28	–11
22	20	2
18	29	–11
11	22	–11

Analyze these data parametrically with a t test and nonparametrically with a Wilcoxon signed-rank test and then a sign test. Comment on the results.

37. Metabolic syndrome is a condition that occurs in older adults who eat high-calorie diets. People with metabolic syndrome have high blood sugar levels and high blood pressure, among other health problems. It was thought that niacin-bound chromium (NBC) might stave off the life-shortening effects of metabolic syndrome. Using a strain of rats with a strong tendency to develop metabolic syndrome, researchers tested the effect of NBC on the blood sugar levels of these rats. The NBC group received a chromium supplement in their food for 30 days while the control group received an inert placebo.

	Control	NBC
n	25	28
\bar{X}	121	110
s	11	28

Data were recorded in mg/100 cc of blood and were normally distributed. Did the NBC significantly decrease blood sugar in this strain of rats?

38. Since about 2001 an obscure hallucinogen drug called ibogaine has been used as an unsanctioned treatment for the symptoms of opiate addiction withdrawal. Derived from the root bark of the West African shrub *Tabernanthe iboga*, ibogaine transports many users on an often-unpleasant 24- to 36-hour “trip” in which they see visions or relive past events. (This was the drug used to treat Nicholas Brody after Saul Berenson brought him back from Venezuela in Season 3 of *Homeland*.)

To test the efficacy of ibogaine for this use, twenty heroin addicts were detoxed without the ibogaine for three days. All returned to their addiction. Each was given ibogaine and detoxed again for three days. Reported below are the discomfort levels reported by the addicts on the third day of each detox (the higher the number the greater the discomfort). Analyze appropriately.

Before Ibogaine	After Ibogaine
10	9
9	5
8	7
10	10
10	9
7	8
10	9
10	7
10	6
9	10
9	7
10	7
8	5
5	2
10	10
10	8
9	5
10	9
8	8
10	9

39. The New York Public Library (NYPL) possesses a number of Dutch books. Some were deteriorated to such an extent, that it was decided to include them in a microfilming program during the 1960s. The original books were to be destroyed but, through contacts at the Koninklijke Bibliotheek (KB, National Library of the Netherlands) in The Hague, the Dutch books were returned to their land of origin. In this way the KB obtained possession of a few hundred Dutch books, which had been stored in New York.

At the end of the 1980s these books were rediscovered in the KB and submitted to some pilot tests. The study focused on the differences between six New York books and the identical editions that came

from the KB collection. The NYPL books had been stored in depots without climate control before they were microfilmed. After the filming they were transferred to the former KB building (also no climate control). In 1982 the KB moved into a new building, and the books were then stored in an office room with a temperature of about 20°C and 50% relative humidity (RH). The KB copies were situated in the KB depots until the moment of investigation, first until 1982 in a depot without air conditioning, and subsequently in a storage room at 18°C and 50% RH. The investigation showed remarkable differences between the NYPL and the KB copies: The paper in the NYPL copies was more acid (especially at the margins), was more discolored and less strong. The much greater fluctuations in climate in New York compared to The Hague were suggested as a possible cause of the differences. A second possibility was the large difference in air pollution between the two locations: The higher concentrations of gasses like SO₂, NO, and NO₂ in New York might lead to a greater absorption of these gasses into the books. This would explain the lower pH in the margins.

In 1994 the KB continued the investigation to characterize the differences between the NYPL and the KB copies of identical editions. Ninety-two identical titles (of the same edition) were located and compared. Among the data recorded were the differences in pH in the following table. (Derived from data reported in Sophia Pauk and Henk Porck, 1996, “A study on identical books, stored under two different conditions,” www.kb.nl/kb/resources/frameset_kb.html?/kb/sbo/cons/101/rappned.html.)

Differences in pH: KB–NYPL		
Location	Margin	Center
n	92	92
\bar{X}_d	1.23	−0.16
s_d	0.37	0.26

- (a) Do these data support the results of the earlier pilot study? Test the hypothesis that the NYPL volumes have a lower pH (higher acidity) at the margins of the text. ($H_0 : \mu_d \leq 0$ versus $H_a : \mu_d > 0$.)
- (b) Test the hypothesis that the NYPL volumes have a lower pH at the center of the text.
40. Social psychologists and neuroeconomists have been studying the effect of oxytocin, a hormone released by the brain in response to social stimuli, on generosity. They gave 50 male college students ten dollars and randomly paired them with a second student via computer. Each ten dollar recipient had to decide how much of the ten dollars to give to his computer partner. If the partner rejected the offer, both of them got nothing. The ten-dollar recipients were randomly divided into two groups. One group received a dose of oxytocin immediately before making the money-splitting decision. The other group received a placebo. Below are the data for this study. Did the group given oxytocin give significantly more money to their computer partners?

	Oxytocin	Placebo
n	25	25
\bar{X}	\$4.86	\$4.06
s^2	0.1225	0.1681

41. One of the most annoying and persistent symptoms of menopause is hot flashes. Many menopausal women take hormone replacement therapy to ameliorate this symptom. This therapy has several side effects including an increased risk of certain cancers. These side effects have caused researchers to look for more benign remedies. A soy extract called Agly Max is chemically related to human estrogen but lacks the negative effects. Fifteen menopausal women 45 to 55 years old were asked to rate the intensity of their hot flashes on a 10 to 1 scale with 10 being the worst. They were then given a standard dose of Agly Max for three weeks and again asked to rate the intensity of their hot flashes.

Without making any assumptions regarding the distribution of their ratings, analyze the data below for the efficacy of Agly Max.

Before	After
10	7
9	5
8	8
10	4
10	8
8	6
7	8
5	6
10	8
10	4
9	7
9	6
8	9
10	7
9	3

42. Laureysens et al. (2004) measured metal content in the wood of 13 poplar clones growing in a polluted area, once in August and once in November. Concentrations of aluminum (in micrograms of Al per gram of wood) are shown below.

Clone	August	November
Balsam Spire	8.1	11.2
Beaupre	10.0	16.3
Hazendans	16.5	15.3
Hoogvorst	13.6	15.6
Raspalje	9.5	10.5
Unal	8.3	15.5
Columbia River	18.3	12.7
Fritzi Pauley	13.3	11.1
Trichobel	7.9	19.9
Gaver	8.1	20.4
Gibecq	8.9	14.2
Primo	12.6	12.7
Woltersen	13.4	36.8

There are two nominal variables: time of year (August or November) and poplar clone (Balsam Spire, Beaupre, etc.), and one measurement variable (micrograms of aluminum per gram of wood). There are not enough observations to confidently test whether the differences between August and November are normally distributed, but they look like they might be a bit skewed; the Woltersen clone, in particular, has a much larger difference than any other clone.

To be conservative the authors analyzed the data using a Wilcoxon signed-rank test. Using this test would you say that the median change from August to November (3.1 micrograms Al/g wood is significantly different from zero? (Source: Laureysens, I. et al. 2004. Clonal variation in heavy metal accumulation and biomass production in a poplar coppice culture. I. Seasonal variation in leaf, wood and bark concentrations. *Environ. Pollution*. **131**: 485–494.

43. To test the efficacy of St. John's Wort (an OTC herbal supplement) for the treatment of attention deficit hyperactivity disorder (ADHD, 54 children with moderate ADHD were assigned randomly and equally to either 3 capsules of St. John's Wort daily or 3 placebo capsules daily. The changes on a standardized evaluation test for ADHD (higher scores indicate improvement in function) are summarized below.

	St. John's Wort	Placebo
\bar{X}	3.0	2.0
s	2.5	3.0

Was the St. John's Wort significantly more effective than the placebo in raising test scores? Assume normality of the data.

44. Skin from cadavers can be used to provide temporary skin grafts for severely burned patients. The longer such a graft survives before its inevitable rejection by the immune system, the more the patient benefits. A medical team investigated the usefulness of matching graft to patient with respect to the HL-A antigen system. Each patient received two grafts, one with close HL-A compatibility, and the other with poor compatibility. The survival times (in days) of the skin grafts are shown in the accompanying table.

Patient	HL-A compatibility	
	Close	Poor
1	37	29
2	19	13
3	57	47
4	16	11
5	23	18
6	63	43
7	50	50
8	60	45
9	29	18
10	16	13
11	20	15

- (a) Does matching the graft to the patient significantly increase graft survival times?
 (b) What type of error could you have made here? Why?
45. As part of a larger study on hypertension the effect of various dietary supplements were investigated utilizing a spontaneously hypertensive rat strain (SHRs). One supplement investigated was cinnamon. The researchers chose this popular spice because prior research had established that certain water-soluble polyphenolic compounds in cinnamon, called procyanidins (type A), act as insulin mimetics, that is, they mimic the physiological actions of insulin.

Two groups of SHRs were fed a high starch diet for 25 days with the experimental group having 8% whole cinnamon powder by weight added to their diet. The data below are the weight gains in grams for the two groups.

	- Cinnamon	+ Cinnamon
\bar{X}	214 g	190 g
s	20 g	17 g
n	16	25

Did the cinnamon supplement significantly decrease the weight gain in SHRs?

46. A geneticist interested in the effects of inbreeding of purebred dogs decided to study longevity in purebred and mixed-bred retrievers. She recorded the life spans of 25 purebred labrador and golden retrievers. She also recorded the life spans of 25 cross-bred labrador/golden hybrids. From the data below would you say that the hybrids lived significantly longer than the purebreds?

	Purebreds	Hybrids
\bar{X}	10 yr	11 yr
s	2.1 yr	1.5 yr

47. Personal trainers have long noted that women vary greatly in their physiological and anatomical responses to weight training. A study aimed at understanding the causes of these differences investigated the responses of two groups of women to 10 weeks of intense resistance training. The women taking oral contraceptives gained an average of 2.1% muscle mass, while the women not taking oral contraceptives gained 3.5% muscle mass.

It was hypothesized that the women taking oral contraceptives had dramatically lower levels of natural muscle-building hormones and higher levels of cortisol, a hormone associated with breakdown of muscle. Below are the data for blood cortisol levels in the two groups of women. Units are micrograms per deciliter (mcg/dL).

	+OC	-OC
n	15	20
\bar{X}	25.1	20.4
s	3.0	3.0

Do the data indicate elevated cortisol levels in the women taking oral contraceptives?

48. It has long been thought that lizards and other poikilotherms bask in the sun to increase their body temperature. A recent study at Texas Christian University looked at the importance of basking as a way to modify a vitamin D precursor found in the skin. The researchers hypothesized that chameleons fed a diet low in vitamin D would bask significantly longer in order to attain sufficient vitamin D.

	Vitamin D deficient diet	Normal diet
\bar{X}	6.8 hr	5.3 hr
s	2.1 hr	2.4 hr
n	25	16

The data above are summaries for the number of hours spent basking per day for two groups of panther chameleons. Did the chameleons fed on vitamin D deficient diet bask significantly longer? What are the implications of these findings for zoo curators and reptilian pet owners?

49. Polychlorinated biphenyls (PCBs) are worldwide environmental contaminants of industrial origin that are related to DDT. They are being phased out in the United States, but they will remain in the environment for many years. An experiment is run to study the effects of PCB on the reproductive ability of screech owls. The purpose is to compare the shell thickness of eggs produced by birds exposed to PCB with that of birds not exposed to the contaminant. It is thought that shells of the former group will be thinner than those of the latter. Do these data support this research hypothesis? Explain.

Shell thickness (mm)			
Exposed to PCB		Free of PCB	
0.21	0.226	0.22	0.27
0.223	0.215	0.265	0.18
0.25	0.24	0.217	0.187
0.19	0.136	0.20	0.256
0.20		0.23	

50. Sickle-cell anemia is a disease associated with impaired urinary potassium excretion. A study is run to compare the responses of subjects with normal hemoglobin and sickle cell disease to an oral potassium chloride (KCl) load (0.75 meq/kg body weight). Before patients receive the KCl load, no differences in urine pH were detected. The data below were obtained at the end of the study. Do they indicate that there is a difference in the way that these groups respond to an oral KCl load relative to the variable urine pH?

Urine pH			
Normal		Sickle cell	
6.6	5.9	5.7	5.2
6.1	5.4	5.6	5.6
6.2	5.7	5.3	5.9
5.8	4.7	5.4	6.0
		4.8	

51. Some aquaculturists believe that fresh water algae of the genus *Chlorella* produce “natural estrogens” which speed the sexual maturity of female carp and tilapia. To test this theory female carp that were immature and eighteen months old were divided into two groups. One group was raised in a holding pond seeded with *Chlorella* algae; the second group was raised in a holding pond that was maintained algae-free. Each fish in each group was tested every day for sexual maturity. The data (days to eggs release) for the two groups are presented below.

	Chlorella +	Chlorella –
n	25	25
\bar{X}	95 days	110 days
s	15 days	17 days

- (a) Did the female fish raised with chlorella mature significantly faster than those without chlorella?
 (b) This same alga is thought to inhibit testes development. Male carp were raised using the protocol above with the following results. Data are again days to sexual maturity.

	Chlorella +	Chlorella –
n	20	15
\bar{X}	125 days	90 days
s	12 days	15 days

52. Recent educational studies have indicated a positive link between musical training and performance of certain math skills. A high school geometry teacher decided to investigate this relationship. For her tenth-grade students in the plane geometry class she devised a test of spatial relationships and reasoning. After administering the test she divided the students into two groups: those who had studied a musical instrument for three or more years and those who hadn't.

Music training	No music training
$\bar{X} = 85$	$\bar{X} = 83$
$s = 5$	$s = 4$
$n = 16$	$n = 22$

Did the musically trained students do significantly better on the test?

53. The Dinka people live in the southern part of Sudan. Cattle are particularly important in Dinka culture with ownership of livestock serving as one factor in social standing. The Dinka use cattle for other social purposes. For example, cattle serve as the primary means of settling a negotiated ‘bride price’ which the groom’s family pays to the bride’s family. There are several factors which may affect this price (see http://www.gurtong.org/resourcecenter/people/profile_tribe.asp). Chief’s daughters fetch more cattle in the same way a chief’s son is expected to pay more cattle for his wife. University graduates fetch higher bride prices, a factor that may positively affect enrollment of girls in schools. On page 164 of *The Tall Book* journalist Arianne Cohen suggests that, among the Dinka, women over six feet tall fetch 80 to 100 cows on the marriage market while shorter women bring only 50 to 70, a premium of roughly 30 cattle in such negotiations for taller women.

An anthropologist conducts a small survey of eleven elders in a Dinka village. Based on their experience and knowledge, she asks each to suggest an average bride price for women taller than six feet and for women shorter than six feet; see the table below. The researcher has no basis to assume that the data are normally distributed. Determine a 95% confidence interval for the median difference between the two estimates. Interpret your answer in relation to the claim of a 30 cattle premium for taller women.

Elder	Greater than 6 ft	Less than 6 ft
1	57	49
2	63	51
3	94	74
4	82	61
5	89	68
6	85	63
7	88	65
8	77	52
9	80	55
10	109	75
11	116	79

54. To test the “Eat less, live longer” hypothesis that had previously been tested on fruit flies and round worms, ten pairs of full sib male rhesus monkeys were randomly assigned to one of two diets. Half were assigned the normal captive monkey diet of vitamin-enriched chow plus some fruit treats. Half were assigned a reduced-calorie diet, cutting their daily intake by 30%, but ensuring what they did eat was properly nourishing. The data below are the life spans in years for the participant monkeys.

Normal diet	Reduced diet
26.0	27.0
24.5	26.5
28.1	29.0
27.3	27.3
28.0	30.0
29.0	29.3
27.7	28.4
25.5	24.7
28.5	28.7
30.0	30.1

First analyze the data above nonparametrically and then assuming normality.

55. Cryptic coloration is often thought to be one of the most compelling examples of evolution by natural selection. Much of the research on crypsis has focused on predator-prey systems despite the fact that it may occur in other groups, such as parasites.

Ectoparasites live on their host's exterior. The principle defense of most hosts against ectoparasites is grooming behavior, which has a visual component. Consequently cryptically colored ectoparasites may be better able to avoid host grooming. Bush, et al studied this hypothesis in the following clever way.

Avian feather lice are permanent ectoparasites that spend their entire life cycle on the body of the host bird. Feather lice feed on feathers and dead skin; the feather damage they cause leads to reduced survival and mating success.

Bush, et al used pairs of closely related bird species to test whether avian feather lice have evolved background-matching coloration to avoid preening. Each pair consisted of one dark- and one light-colored bird species. The lice on each bird pair were divided into two types: 'typical' lice and 'head' lice. Typical lice are not restricted to any particular microhabitat on the body of the bird. In contrast, head lice are plump, slow-moving lice that are specialized for the head and neck feathers. Because they reside on birds' head, the birds can neither see nor preen head lice. Head lice are controlled largely by foot scratching, which does not have a visual component. However, birds can see and preen the typical lice that reside elsewhere on their bodies. One suspects that the ability of typical lice to blend in with the background would be important to their survival. In short, the researchers predicted that typical lice would be under selection for background-matching coloration, whereas head lice would not be under such color selection pressure.

The researchers created 'luminosity' scores for each pair of birds and their corresponding lice as follows. Differences in luminosity were calculated by subtracting the score of the louse species on the dark-colored bird from the score of the louse species on the light-colored bird within each pair of bird species. A positive score indicates that the lighter, more luminous louse resides on the lighter bird and the darker louse of the pair resides on the darker bird. Negative values are cases of conspicuous coloration in which the lighter louse was on the darker host and vice versa.

- (a) The researchers used a two-sided Wilcoxon signed-rank test with the scores for typical lice on 16 bird-species pairs in the table below. Was there a significant difference in luminosity between the typical lice on dark and on light-colored birds? Clearly state the hypotheses.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
47.1	-4.7	-15.9	20.0	-50.0	36.5	7.1	31.8	10.6	30.0	40.6	44.7	27.1	30.6	1.2	8.2

- (b) The again researchers used a two-sided Wilcoxon signed-rank test with the scores for head lice on 10 bird-species pairs in the table below. Did they find a significant difference in luminosity between the head lice on dark and on light-colored birds. Clearly state the hypotheses.

Q	R	S	T	U	V	W	X	Y	Z
-13.5	3.8	-1.6	-11.0	15.1	-8.0	-0.8	4.1	3.7	10.8

- (c) Did their findings support their evolutionary hypothesis? Explain.
56. As part of a larger study on the ability of dental cements to hold single crowns, two cements were each tested on 21 different tooth casts. The amount of force in foot-pounds required to pull each cemented crown from the casting was recorded. Assume that the data for each cement are normally distributed. Is cement 1 significantly stronger than cement 2?

$$\begin{array}{ll}
 \text{Cement 1} & \text{Cement 2} \\
 \bar{X}_1 = 45 \text{ ft-lb} & \bar{X}_2 = 42 \text{ ft-lb} \\
 s_1^2 = 36 \text{ (ft-lb)}^2 & s_2^2 = 25 \text{ (ft-lb)}^2
 \end{array}$$

57. Mulberry, *Morus* spp., is increasingly being used as forage plant because of its high protein content and high digestibility. However, its cultivation management is not yet defined when destined to be used for domestic farm animals. In Brazil, mulberry is known as a forage plant for the silkworm, *Bombyx mori* L. where it is cut close to the ground (low-cut) at intervals of 13 weeks. The management of mulberry like a shrub or a tree (high-trunk) has been encouraged by some in Europe and Japan with the advantages of the system being: greater production, better exploitation of soil, better leaf quality, greater longevity. In a field trial, clones of 12 different mulberry species that are typically grown using the low-cut technique were grown using two different high-trunk methods: cutting every 9 weeks and cutting every 13 weeks. (Based on data reported in José Eduardo de Almeida and Tamara Canto Fonseca. “A contribution to the introduction of the high-trunk mulberry system in tropical climates,” www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP/FRG/Mulberry/Posters/HTML/Almeida2.htm)

Clone	Cutting frequency			
	9 weeks (4 cuts per year)		13 weeks (3 cuts per year)	
	1997/98 kg/plant	1998/99 kg/plant	1997/98 kg/plant	1998/99 kg/plant
IZ 1/16	7.19	6.67	6.44	9.06
IZ 3/2	5.58	3.91	5.33	7.45
IZ 6/7	5.15	5.55	4.32	6.05
IZ 10/1	5.49	4.73	5.98	9.20
IZ 10/4	5.97	5.03	7.01	8.61
IZ 10/8	6.46	5.72	5.55	9.32
IZ 11/9	4.59	3.26	5.90	4.92
IZ 13/6	6.48	6.42	6.59	9.03
IZ 56/4	7.01	4.73	4.72	8.00
IZ 57/2	5.54	3.57	6.03	6.67
IZ 40	6.62	7.26	6.80	9.33
KORIN	6.81	5.36	6.62	9.43

- (a) The researchers used a sign test to determine whether there were significant differences in the production levels for the two high-trunk methods for the initial year (1997/98) of the field trial. What did they find?
- (b) Having given the plants a year to adapt to the new cultivation methods, the researchers tested the hypotheses H_0 : There is no increase in production from the first year to the second year, versus H_a : There is an increase in production during the second year. Carry out two paired sign tests, one for each cultivation method and interpret the results.
- (c) Finally carry out a sign test to compare the production results for the two cultivation methods during the second year of the trial. Interpret your results.
58. Cathartic swearing may occur in painful situations such as hitting one’s thumb with a hammer or stubbing one’s toe. Given that the experience of pain can be affected by various psychological and emotional states, researchers devised an experiment to test whether swearing affects one’s ability to endure pain.

Eleven male college students were recruited to participate. Each was asked to list “five words you might say after hitting your thumb with a hammer” and the first swear word listed for each was used in the experiment. As a control, participants selected “five words that describe a table” and the word whose position corresponded with the swear word was used.

Participants first submerged their non-dominant hand in a 25°C water bath (room temperature) for 3 min. Then the participants submerged the same hand in the cold water (5°C) for as long as they could stand it (with an upper limit of 5 min). This was carried out twice with each person. While his hand was submerged, the student repeated either the swear word or the control word (the order in which the two trials took place was randomized). After each trial participants were asked to measure their pain on the Perceived Pain Scale (0 to 10). The following data were collected.

Control	Swearing
5.0	5.5
2.5	0.0
3.5	2.5
5.5	1.5
4.0	3.5
5.5	3.0
6.5	3.0
1.0	5.0
5.0	3.5
7.5	3.5
4.0	2.0

Carry out a hypothesis test to decide whether swearing lowers the perception of pain. Assume only that pain scores are symmetrically distributed. (Based on Stephens, R. et al. 2009. Swearing as a response to pain. *NeuroReport*. **20**: 1056–1060.)

Additional Problems for Chapter 8

1. Girths (in cm) of *Callitris* trees were sampled by students at three locations at Brown Lake on North Stradbroke Island: on a slope, at a hilltop, and in a valley. Determine whether there was a significant difference in median girths for the various locations. Use a Kruskal-Wallis test.

Slope	Rank	Hilltop	Rank	Valley	Rank
17	1	24	3	29	7
19	2	28	5.5	58	15
26	4	38	11	64	16
28	5.5	41	12.5	78	17
30	8	41	12.5	80	18
31	9	45	14	82	19
33	10			98	20
Sum	39.5	Sum	58.5	Sum	112

2. The silver content (%Ag) of a number of Byzantium coins discovered in Cyprus was determined. Nine came from the first coinage of the reign of King Manuel I, Comnenus (1143–1180); seven came from a second coinage minted several years later; four from a third coinage; and another seven from a fourth coinage. The question is whether there were significant differences in the silver content of the coins minted at different times during King Manuel's reign. (*HSDS*, #149)

I	Rank	II	Rank	III	Rank	IV	Rank
5.9		6.6		4.5		5.1	
6.2		6.9		4.6		5.3	
6.4		8.1		4.9		5.5	
6.6		8.6		5.5		5.6	
6.8		9.0				5.8	
6.9		9.2				5.8	
7.0		9.3				6.2	
7.2							
7.7							

- (a) State the appropriate null and alternative hypotheses for these data.
- (b) Rank all the observations (use midranks when necessary) and compute the sums of the sample ranks R_i .
- (c) Compute the Kruskal-Wallis test statistic H for these data and determine whether H_0 should be rejected.
- (d) If necessary, carry out paired comparisons.

3. In order for *Banksia serrata* to germinate, fire is required to open its seed cones. The frequency and severity of fire at a hillside site at Brown Lake on North Stradbroke Island varies by location on the hill. In order to determine the relative densities of *B. serrata* at various positions, a small study was conducted. At the hilltop, along the east-facing slope, and in a level control area, several 100-m transects were laid out. Every 10 m along these transects, the species of the nearest tree in each quarter was recorded and the number of *B. serrata* along each transect was determined. These data are given in the first three columns in the following table. The median girths (in cm) of the *B. serrata* were also determined for each transect. These data appear in the last three columns of the table

Number of trees			Median girth (cm)		
Hilltop	Slope	Control	Hilltop	Slope	Control
10	13	4	39	33	44
11	14	6	45	37	56
12	15	7	51	41	65
12	16	7	54	46	67
14	19	11	57	47	77
14	21	12	59	58	81
		15			102

- (a) Determine whether there is a significant difference in the median numbers of trees at the three locations. If appropriate, carry out a set of paired comparisons.
- (b) Determine whether there is a significant difference in the median girths of trees at the three locations. If appropriate, carry out a set of paired comparisons.
4. An instructor in a second-term calculus course wishes to determine whether the year in college has any effect on the performance of his students on their final exam. The table below lists the exam grade (out of 150) for students categorized by year. Are there significant differences in performance among years? Analyze with ANOVA and Bonferroni t tests, if necessary.

First year	Sophomore	Junior
122	117	72
111	97	91
104	113	71
118	123	72
113	130	96
98		121
129		
111		
127		

5. (a) In 1909 the Danish botanist Wilhelm Johannsen did a number of studies of the inheritance of seed weight in the bean *Phaseolus vulgaris*. Below is the data from one of these experiments in which Johannsen compared the weights of the parent seed to that of the progeny within pure breeding line #13. The parental seeds were classified as 27.5, 37.5, 47.5 and 57.5 cg in weight. In each class all individual parents' weights were within 2 cg of the class value. From the information given, do different sized parent seeds lead to different average sizes for the offspring? Analyze the data with a one-way ANOVA. Use $\sum_i \sum_j X_{ij}^2 = 830,562.5$ and the other summary data provided. What do the results indicate about the cause of the variability in the parent sizes and the progeny sizes? Remember all individuals are from the genetically pure line #13.

Parental weight (cg)	Number of progeny of beans of weight (cg)									Summary	
	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	n_i	T_i
27.5		1	5	6	11	4	8	5		40	1780
37.5	1	2	6	27	43	45	27	11	2	164	7425
47.5		5	9	18	28	19	21	3		103	4473
57.5		1	7	17	16	26	17	8	3	95	4348

Note: Beans in the 22.5 cg class include all beans between 20 and 25 cg; those in the 27.5 cg class include all beans between 25 and 30 cg and so on.

- (b) In a second experiment he compared the weights of different size parents to their offsprings' weights among various pure lines. Comment on the variability within and between the lines. What do you think is the cause of the differences in the means among the lines? What is the cause of the differences among parents within each line?

Mean weights of beans from Johanssen's different pure lines						
Parental seed (cg)	Mean weight (cg) of line number					
	19	18	13	7	2	1
20		41.0		45.9		
30	35.8	40.7	47.5			
40	34.8	40.8	45.0	49.5	57.2	
50			45.1		54.9	
60			45.8	48.2	56.5	63.1
70					55.5	64.9
Line mean (cg)	35.1	40.8	45.4	49.2	55.8	64.2

From these and similar studies Johanssen differentiated between genetic and environmental causes of variability. He later coined the terms gene, genotype and phenotype.

6. In a study on brain development in the Norway rat various diets were compared for their effects on cortex weight. Diet one consisted of commercial lab rat chow. Diet two was the commercial rat chow augmented with vitamins and minerals. Diet three consisted of fresh grains and vegetables. Diet four was similar to three except a 2% alcohol solution replaced the normal drinking water. Twenty two-week old rats were randomly assigned to one of the diets; all other conditions remained the same. After four months the rats were sacrificed and their cortex weights recorded in milligrams.

Cortex weight (mg)			
Diet I	Diet II	Diet III	Diet IV
650	660	700	675
670	700	710	700
665	680	690	660
680	690	725	685
685	695	715	675

- (a) Did diet affect the cortex weights? Analyze with one-way ANOVA. Comment on the experimental design.
- (b) Is a Kruskal-Wallis Test appropriate here? Explain.

7. For many years practitioners of traditional Chinese medicine have advocated oolong tea consumption for weight control. Researchers worked with a strain of adult female rats that spontaneously become obese on a normal diet. For 10 weeks, the researchers let the animals eat all they wanted but laced the chow of some with a dried extract of brewed oolong tea. All the animals ate about the same amount of food. Group I got 2% of their food as tea extract by weight. Group II got 4% of their food as tea extract by weight. Group III didn't have any tea extract in their chow. Data are weight gains in grams with 15 rats per group.

Group	I	II	III
\bar{X}_i	40	20	120
CSS_i	1400	1120	1890

Analyze the data with ANOVA techniques.

8. To test the effect on zinc on the common cold, 32 volunteers were subjected to rhinovirus type 39 administered through nasal drops. The 32 volunteers were randomly assigned to four treatment regimes that included three different zinc preparations: zinc acetate lozenges (5 mg or 11.5 mg), zinc gluconate lozenges (13.3 mg), and placebo lozenges. Illness severity was assessed by using symptom scores that were recorded daily for five days after virus was administered. At each evaluation, subjects judged the maximum severity of eight symptoms: sneezing, rhinorrhea, nasal obstruction, sore throat, cough, headache, malaise, and chilliness during the preceding 24 hours. Each symptom was assigned a severity score of 0–4: “absent,” “mild,” “moderate,” “severe,” or “very severe.” At the end of five days, all of the symptom scores for each volunteer were summed to yield their total symptom score (TSS), as reported below.

Placebo	Zn gluconate	Zn acetate 5 mg	Zn acetate 11.5 mg
35	25	27	25
39	29	32	29
43	33	38	35
42	32	37	34
31	21	23	20
83	73	88	85
71	61	73	70
38	28	32	29

Are there significant differences in the TSS's among the treatments? It is appropriate to analyze nonparametrically.

9. To compare four different sunblock formulations (treatments), each sunblock was applied in to the backs of 3 subjects assigned randomly from a group of 12 volunteers. At the end of a 4-hour exposure to bright sunlight, each strip was evaluated for sunburn damage and ranked, with rank #1 indicating the least damage and rank #12 indicating the most damage. The ranked data are summarized below. Carry out an appropriate test to determine whether there were differences among the treatments, and if so, locate the treatments that are different.

Treatment	I	II	III	IV
n_i	3	3	3	3
Mean rank $\frac{R_i}{n_i}$	5.33	10.83	2.33	7.5

10. Current fitness industry trends include a growing interest in non-competitive boxing programs. A study was conducted to examine the physiological responses of punching at various tempos. Using commercially available boxing equipment, twelve male boxing-trained subjects performed straight left and right punches at four different tempos (60, 80, 100, and 120 punches per minute). Each trial lasted two minutes, similar to that of traditional boxing-round training. Oxygen consumption (ml/kg/min), and heart rate (bpm) were monitored continuously during each round using open circuit spirometry and telemetry. Summary data are recorded below. (Based on concepts in Kravitz L. et al., Metabolic effect of punching tempo, www.unm.edu/~lkravitz/Research%20Abstrs/punchingtempo.html.)
- (a) Use ANOVA to determine whether there is a difference in oxygen consumption among the various tempos. If so, which pairs are different? Use Bonferroni-Holm t tests if mean comparisons are required.

Punches/min	60	80	100	120	Total
n_i	12	12	12	12	48
\bar{X}_i	25.2	28.0	28.3	29.9	
s_i	3.2	3.4	3.0	3.1	
T_i	302.4	336	339.6	358.8	1336.8

- (b) Determine whether there is a difference in heart rates among the various tempos. If so, which pairs are different?

Bpm	60	80	100	120	Total
n_i	12	12	12	12	48
\bar{X}_i	164.7	173.3	176.3	182.1	
s_i	13.1	11.9	11.1	9.9	
T_i	1976.4	2079.6	2115.6	2185.2	8356.8

11. The popular drugs, Zetia and Vytorin are designed to lower cholesterol. It is hoped that lower cholesterol levels will lead to a reduction in heart attacks and strokes caused by atherosclerosis. The progression of heart disease in humans can be tracked by measurement of the intima-media thickness (IMT) of artery walls by various ultrasound techniques.

In the study below the IMT was measured in the far wall of both common carotid arteries (CCA) using an automatic detection system. Each patient was measured after 90 days of treatment. The data below are the final lumen diameters (in mm) derived from these measurements.

	Treatment		
	Control	Zetia	Vytorin
\bar{X}	0.707	0.756	0.797
s	0.127	0.130	0.141
n	50	45	55

Assume the data are normally distributed and test whether the lumen diameters are significantly different among the three treatments. Carefully summarize your results relating the efficacy of the drugs to the control group and to each other. Use the Tukey test, if mean for any mean comparisons.

12. A social psychologist wants to determine if type of music has any effect on the number of beers consumed by people in a tavern. Four taverns are selected that have different musical formats. Five people are randomly sampled in each tavern and their beer consumption monitored for three hours. Complete the following one-factor ANOVA summary table using $\alpha = 0.05$. State the hypotheses of the test and interpret the results.

Source of variation	Sum of squares	df	MS	F	c.v.
Treatment			7.52	5.01	
Error					
Total					

13. A psychologist would like to know whether the season (fall, winter, spring, summer) has any consistent effect on people's sexual activity. In the middle of each season the psychologist selects a random sample of $n = 25$ students. Each individual is given a sexual activity questionnaire. A one-factor ANOVA was used to analyze these data. Complete the following ANOVA summary table using $\alpha = 0.05$.

Source of variation	Sum of squares	df	MS	F	c.v.
Treatment				5.00	
Error	960				
Total					

14. The so-called “Napoleon complex” is a height-related bias that may influence one's evaluation of others where relatively shorter males (or females) exhibit aggressive behavior towards taller males (or females). Gift and Rodenberg tested for such height bias by examining the behavior of professional referees in the National Basketball Association and the number of fouls they called on players during the games of the 2008–2009 through 2011–2012 seasons.

Referee crews were divided into three categories according to the crews' average height: (i) 6 ft and under; (ii) between 6 ft and 6 ft, 3 in; and (iii) 6 ft, 3 in and above. The mean number of fouls per player per game (weighted by minutes played) for the three crew heights were recorded.

	6 ft and under	6 ft to 6 ft, 3 in	6 ft, 3 in and above
\bar{X}_i	4.13	4.09	4.03
n_i	11,925	64,989	13,475
$\sum \sum (X_{ij}^2) =$	2,664,892		$SS_{\text{Error}} = 855,503$

Are there significant differences in the mean number of fouls called by referee crews of different heights? Use the Bonferroni-Holm test for mean separation, if necessary. (Based on data in: Gift, Paul and Ryan M. Rodenberg. 2014. Napoleon Complex: Height Bias Among National Basketball Association Referees. *Journal of Sports Economics*. <http://jse.sagepub.com/content/15/5/541>)

15. Twelve young Merino lambs all born during the same week were randomly assigned to one of three diets. The table below shows the weight gains in pounds after two weeks for each lamb. Are there significant differences in the weight gains among diets? Analyze with ANOVA and Bonferroni-Holmi t tests, if necessary.

Diet 1	Diet 2	Diet 3
8	9	15
16	16	10
9	21	17
	11	6
	18	

16. Measurements on cumulative radiation dosage were made on workers at a nuclear weapons plant over a six-month period. The table below presents data in REM's for workers whose dosage was assessed at three different locations. Determine if there was a significant difference in the mean dosage level among the three locations. Analyze via ANOVA and an appropriate mean separation technique, if necessary.

	Location		
	A	B	C
	1.1	2.9	1.7
	2.7	2.1	3.1
	1.9	1.9	2.2
	2.1	1.9	2.8
	3.1	2.4	1.5
	1.4	1.5	2.8
	2.8	2.6	1.5
	2.2	3.4	2.9
	1.8	1.2	2.1
	1.0	2.3	2.2
$T_{i.}$	20.1	22.2	22.8
CSS_i	4.61	3.82	3.20
s_i	0.72	0.61	0.60

$$\sum_i \sum_j X_{ij}^2 = 153.29, \quad T_{..} = 65.1, \quad SS_{\text{Total}} = 12.02$$

Additional Problems for Chapter 9

1. The following table shows the aggression scores of 30 laboratory rats reared under three different conditions. One animal from each of 10 litters was randomly assigned to each of the three rearing conditions. Assume the scores are normally distributed.

Litter	I: Extremely Crowded	II: Moderately Crowded	III: Not Crowded
1	30	20	10
2	30	10	20
3	30	20	10
4	25	15	10
5	35	25	20
6	30	20	10
7	20	20	10
8	30	30	10
9	25	25	10
10	30	20	20
\bar{X}	28.5	20.5	13.0

Source of variation	Sum of squares	df	MS	<i>F</i>	c.v.
Treatment	1201.7				
Litters	253.3		28.14		
Error					
Total	1836.7	29			

Write all appropriate hypotheses for this experiment, complete the ANOVA table and clearly state your findings.

2. Aposematic coloration acts as a signal to warn predators of potentially dangerous or unpleasant features possessed by a prey species. It is believed that individuals that possess color patterns resembling those of aposematic species gain a defensive advantage, known as Batesian mimicry, because predators have learned to avoid animals with these patterns through encounters with aposematic species. An experiment was conducted to test this hypothesis using three aposematic marine flatworms, *Pseudoceros paralaticlavus*, *Pseudobiceros stellae*, and *Phrikoceros baibaiye*. The predators were moon wrasse, *Thalassoma lunare*. In seven separate trials, three different species of flatworms, colored models of each species, and a colorless control model were placed randomly in a tank with 14 moon wrasse. All models were made from brine shrimp and agar and should have been palatable to the wrasses. The aposematic (that is, alternative) hypothesis is that the colored flatworm models will gain a defensive advantage that the control model will not have. Attack values corresponding to the number and intensity of the attacks on the flatworms and models were calculated for each 9-hour trial. Was there a significant difference in the attack values for live flatworms and control models? (Based on data reported by Ang, H. and L. Newman. 1996. Warning colouration in pseudocerotid flatworms Platyhelminthes, polycladida. Personal communication.)

<i>Pseudoceros paralaticlavus</i>		<i>Pseudobiceros stellae</i>		<i>Phrikoceros baibaiye</i>		Control
Real	Model	Real	Model	Real	Model	Model
0	1	1	1	0	1	9
0	1	1	0	1	5	9
0	2	0	1	2	7	9
0	0	1	2	4	6	9
0	0	0	0	0	1	9
0	0	0	2	9	5	9
0	0	7	5	9	7	9

- Modify the argument in Appendix A.5 to show that the two ways of computing the test statistic T for the Friedman test give the same result.
- Each of six garter snakes, *Thamnophis radix*, was observed during the presentation of petri dishes containing solutions of different chemical stimuli. The number of tongue flicks during a 5-minute interval of exposure was recorded. The three petri dishes were presented to the snakes in random order.

Snake	Stimulus		
	Fish mucus	Worm mucus	dH ₂ O
1	13	18	8
2	9	19	12
3	17	12	10
4	10	16	11
5	13	17	12
6	11	14	12

Do the snakes respond differently to these stimuli? Use a Tukey test if mean comparisons are required.

- A pharmaceutical company developing new capsules for the delivery of medicines to treat heart attacks formulated three new capsule types. On three consecutive days volunteers were given a different type of capsule containing a standard medical dose of a popular heart attack medicine. Four hours after taking the capsule with 8 ounces of water, the level of the drug (mg/L) was determined in a blood sample taken from a brachial artery.

Volunteer	Capsule Type			$T_{.j}$
	A	B	C	
1	9	10	8	27
2	9	9	8	26
3	8	10	10	28
4	13	17	13	43
5	12	17	14	43
6	15	16	15	46
7	9	10	8	27
8	15	17	13	45
9	7	9	7	23
10	11	15	12	38
$T_{i.}$	108	130	108	$T_{..} = 346$

- Are there significant differences in the drug levels delivered by the three capsule types? Assume the data are normally distributed and analyze with a randomized complete block design ANOVA.
- Did blocking by volunteer improve the analysis? Explain.

6. As a hermit crab grows and becomes crowded within its shell, it will exchange its shell for a larger empty one. Where shell resources are limited, there is often competition among crabs for such shells. Researchers are able to measure shell crowding by counting the total number of exposed appendages (excluding the major chela which is used to block the aperture of the shell) once the crab is fully retracted into its shell.

A field study on Carrie Bow Cay off the coast of Belize was conducted on the behavior of *Coenobita clypeatus*, a terrestrial hermit crab. Researchers first divided the hermit crabs into three size classes: small, medium, and large. They then measured a sample of 85 crabs in each size class and recorded how crowded each was in its shell. Next, the researchers introduced empty shells of each size class into the environment in proportion to the distribution of size classes of the crab population on the cay. Six months later the crabs were again sampled and the amount of crowding was recorded. Several summary statistics are given below.

Time	Size			
	Small	Medium	Large	
Initial	$T_{11.} = 422$ $\bar{X}_{11.} = 4.97$ $n = 85$	$T_{21.} = 830$ $\bar{X}_{21.} = 9.77$ $n = 85$	$T_{31.} = 802$ $\bar{X}_{31.} = 9.43$ $n = 85$	$T_{.1.} = 2054$ $\bar{X}_{.1.} = 8.05$ $n = 255$
After 6 months	$T_{12.} = 277$ $\bar{X}_{12.} = 3.26$ $n = 85$	$T_{22.} = 671$ $\bar{X}_{22.} = 7.89$ $n = 85$	$T_{32.} = 728$ $\bar{X}_{32.} = 8.57$ $n = 85$	$T_{.2.} = 1676$ $\bar{X}_{.2.} = 6.57$ $n = 255$
	$T_{1..} = 699$ $\bar{X}_{1..} = 4.11$ $n = 170$	$T_{2..} = 1501$ $\bar{X}_{2..} = 8.83$ $n = 170$	$T_{3..} = 1530$ $\bar{X}_{3..} = 9.00$ $n = 170$	$T_{..} = 3730$ $N = 510$
	$\sum_i \sum_j \sum_k X_{ijk}^2 = 35,447$			

Analyze the data as a factorial design two-way ANOVA. Include mean separation techniques if appropriate. (Based on: Lewis, S. and Randi Rotjan. 2009. Vacancy chains provide aggregate benefits to *Coenobita clypeatus* hermit crab. *Ethology*, **115**: 356–365.)

7. An experiment was performed to test the photoreactivation phenomenon found in bacteria that have been exposed to ultraviolet light. Photoreactivation is the repair of DNA damaged by ultraviolet radiation by the DNA repair enzyme, photolyase which requires the presence of visible light. A plate of bacteria was exposed to ultraviolet for five minutes. A sample was taken from the exposed plate, plated, exposed to visible light for five minutes, then incubated. A second sample was exposed to visible light for a ten-minute period before incubation. A third sample was incubated without prior exposure to visible light. The procedure above was carried out for five different strains of bacteria. After a specific incubation time, the colonies were counted.

	Strain					$T_{.j}$
	A	B	C	D	E	
No exposure	45	40	10	23	32	150
5 min exposure	72	81	53	55	48	309
10 min exposure	90	100	75	70	64	399
$T_{.i}$	207	221	138	148	144	858

Were there significant differences in colony numbers among the light treatments?

8. Apple firmness is used as a measure of ripeness and condition of the fruit. Firmness is tested by using a device called a penetrometer, which measures the pressure (in pounds) required to insert a 7/16-inch plunger head into the apple. Each apple is not of uniform firmness. Typically, the blush side is firmer than the green side so often (as in the data below) both the blush and the green sides are measured. The skin of the apple distorts the pressure test readings, so it must be removed from the area to be tested. The apple is tested at a point half way between the stem and calyx ends of the fruit. The data below were collected on 2, 9, and 11 September 2014 by Jay Freer, a fruit technician at Cornell University's Geneva Agricultural Experiment Station. The apples tested were McIntosh Reds from a single orchard in Geneva, NY. Analyze the data as a factorial design ANOVA to determine whether mean firmness varies significantly by date and whether the fruit from outside and inside the canopy differ significantly.

Canopy Location	Sept 2, 2014	Sept 8, 2014	Sept 11, 2014
Outside	21.2	17.0	16.4
	19.2	17.1	17.4
	20.9	19.3	14.7
	18.0	16.2	16.4
	16.5	17.3	18.0
	18.5	16.2	15.8
	18.5	16.0	17.6
	16.2	13.7	14.9
	16.7	15.0	16.1
	19.5	14.3	15.6
Inside	18.5	12.5	15.7
	16.6	15.8	16.2
	16.4	15.8	15.8
	17.9	15.5	15.1
	16.8	14.7	15.7
	18.4	15.4	14.2
	15.3	15.3	16.4
	15.0	17.3	15.1
	15.7	17.7	15.6
	15.7	17.5	16.2

9. The amount of light in a forest varies by height-zone. Photon flux density (measured in micromoles/m²/s) was recorded at Simpson's Falls in Brisbane Forest Park at three different height-zones along a transect. The measurements at each point were made within a second of each other to minimize the effects of extraneous conditions such as changes in cloud cover. Is there a significant difference in photon flux density among the height-zones? Clearly state the null and alternative hypotheses. If appropriate, carry out a set of paired comparisons at the $\alpha' = 0.05$ -level.

Location	Canopy	Grass	Ground
1	66	47	10
2	75	54	21
3	82	49	11
4	319	140	17
5	105	35	8
6	65	28	23
7	82	91	89

10. With the advent of computerized speech recognition, automatic speaker recognition has become a problem of interest. Automatic speaker recognition (SR) is comprised of speaker identification (SI) and speaker verification (SV). SV is the process of verifying whether a speaker is who he claims to be by using a given recorded speech, whereas SI is the determination of the identity of the person most likely to have spoken a given passage (from among a known population). In a recent study, a model reflecting

40 acoustic features of speech were extracted from tape recordings of each of 14 males. Subsequently, six different methods (CBD: City block distance; ED: Euclidean distance; WED: Weighted Euclidean distance; MD: Mahalanobis distance; GP: Gaussian probability density estimation; and KLT: probability estimation after Karhunen-Loeve transformation) were used to compare the reference models to new test recordings of these same 14 males. For each speaker the number of matches (out of 40) is listed below for each of the six methods. The researchers used the Friedman test to determine whether there were differences in accuracy among the methods. What did they find? Use paired comparisons, if appropriate. (Based on data reported in Sherman Ong and Cheng-Hong Yang, "A comparative study of text-independent speaker identification using statistical features," *International Journal of Computer Engineering and Management*, 1998, 6(1): www.journal.au.edu/ijcem/jan98/article5.html.)

Speaker	Method					
	CBD	ED	WED	MD	GP	KLT
1	37	33	38	35	34	38
2	39	39	40	40	40	40
3	33	26	35	39	29	35
4	33	26	39	37	38	38
5	38	37	40	37	38	39
6	28	31	33	36	35	36
7	36	37	37	39	39	38
8	30	24	33	36	36	38
9	39	38	40	33	33	38
10	32	32	34	38	38	39
11	28	26	27	32	33	33
12	27	23	29	39	39	37
13	39	39	39	39	40	39
14	40	40	40	40	40	40

Additional Problems for Chapter 10

1. *Beneckea natriegens*, a halophilic bacterium that grows very rapidly in optimal conditions, was observed over a period of seven hours. The number of cell counts per cubic centimeter in successive samples during its growth was recorded.

Incubation time (min)	20	40	60	90	120	180	240	300	360	420
Bacterial count	47	62	73	103	220	537	1580	4500	9200	12800

- (a) Plot the incubation time against the bacterial count and on a separate graph plot the incubation time against the natural logarithm of the bacterial count. Which of these two do you consider to be closest to a linear relationship?
- (b) For the graph you selected, calculate the best straight line approximation by the method of least squares. Test the significance of b and find the 95% confidence interval for β .
2. A plant physiologist grew 13 individually potted soybean seedlings in a greenhouse. The table gives measurements of the total leaf area (cm^2) and total plant dry weight (gm) for each plant after 16 days of growth. Calculate the correlation coefficient for these data. Test its significance via a t test. Interpret the result.

Plant	Leaf area, X	Dry weight, Y
1	411	2.00
2	550	2.46
3	471	2.11
4	393	1.89
5	427	2.05
6	431	2.30
7	492	2.46
8	371	2.06
9	470	2.25
10	419	2.07
11	407	2.17
12	489	2.32
13	439	2.12

$SS_X = 28,465.7$	$SS_Y = 0.363708$
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$\sum(X_i - \bar{X})(Y_i - \bar{Y}) = 82.977$

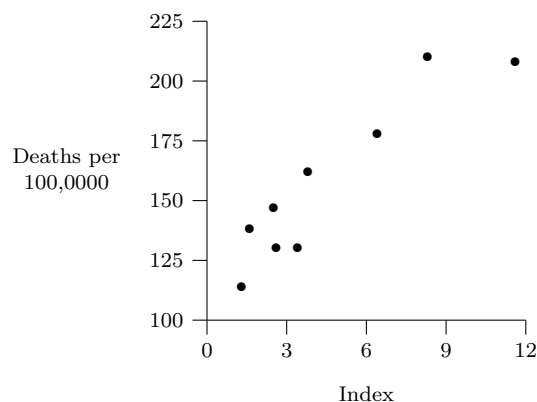
3. Some geysers such as Old Faithful in Yellowstone National Park are remarkably consistent in the periodicity of their eruption. For example, in 1988, 6,900 timed intervals between eruptions for Old Faithful averaged 76.17 minutes, with the shortest observed interval 41 minutes and the longest 114 minutes. In the past 120 years Old Faithful's yearly average interval has always been between 60 and 79 minutes. It is also well known that the relationship between the length of the eruption and the length of the subsequent interval duration is a positive one. Suppose the following data were collected over a several day period.

Eruption Time (min)	Interval Duration (min)
1.5	50
2.1	56
2.4	65
3.2	71
2.9	70
2.5	66
2.2	57
3.5	76
3.0	69
3.5	76
4.1	82
2.0	57
4.6	89
2.8	70
5.0	95
3.6	75
4.0	80
2.4	67
3.5	77
4.9	94

Test for the relationship between these variables. Is this a correlation or regression situation? Discuss your rationale here.

4. The Hanford Atomic Energy Plant in Washington has been a plutonium production facility since World War II, and some of the wastes have been stored in pits in the same area. Radioactive waste has been seeping into the Columbia River since that time, and eight Oregon counties and the city of Portland have been exposed to radioactive contamination. The table below lists the number of cancer deaths per 100,000 residents for Portland and these counties. It also lists an index of exposure that measures the proximity of the residents to the contamination. The index assumes that exposure is directly proportional to river frontage and inversely proportional both to the distance from Hanford and to the square of the county's (or city's) average depth away from the river. The accompanying figure is a scatter plot of the index versus deaths data. Are deaths and the index correlated? (Source: Fadeley, R. 1965. Oregon malignancy pattern physiographically related to Hanford Washington radioisotope storage. *Journal of Environmental Health*, **27**: 883–897.)

County/City	Index	Deaths
Umatilla	2.5	147
Morrow	2.6	130
Gilliam	3.4	130
Sherman	1.3	114
Wasco	1.6	138
Hood River	3.8	162
Portland	11.6	208
Columbia	6.4	178
Clatsop	8.3	210



5. Last summer my wife and I acquired a golden retriever puppy named Sydney. She was eight weeks old when we brought her home. We immediately took her to the vet for an initial checkup. During the checkup he mentioned that golden retriever puppies should gain weight linearly for the first six months of their lives. Since our previous golden “Hoover” had a serious weight problem, my wife and I decided to carefully monitor Sydney’s development. Each Tuesday we weighed her to the nearest half-pound. The data are below.

Week	Weight
8	7.5
9	9.0
10	12.0
11	15.5
12	16.5
13	19.0
14	22.5
15	25.0
16	26.5
17	31.0
18	33.0
19	34.5
20	37.0
21	39.0
22	41.0

- (a) Did Sydney gain weight linearly? Graph the data and calculate the regression equation for her weight.
- (b) What would you expect her weight to be at 15.5 weeks? At 150 weeks?
- (c) Calculate the 95% confidence interval for β
6. The following water quality data were collected on the seven central Finger Lakes in Central New York in two consecutive years. The analyzed parameters included total coliform and *E. coli* bacteria, total phosphate, dissolved nutrient content, and plankton concentrations which were combined in a single water quality index (lower is better). Determine and interpret Kendall's correlation coefficient for these data. (Source: *The Finger Lakes Institute*, Summer 2007.)

Lake	2005	2006
Honeoye	6.1	7.0
Canandaigua	1.4	3.1
Keuka	3.0	3.3
Seneca	7.0	3.2
Cayuga	4.4	5.9
Owasco	6.7	5.6
Skaneateles	1.0	1.0

7. Dissolved silicon in seawater is required by many primary producers, studies have linked the depletion of this substance with decreased productivity in marine ecosystems. A study was conducted to gain further insight into the behavior of dissolved silicon. The two variables studied were X , the distance in kilometers from shore, and Y , the silicon concentration in micrograms per liter ($\mu\text{g}/\text{liter}$) of seawater. These measurements, taken over the northwest African shelf, are presented below.

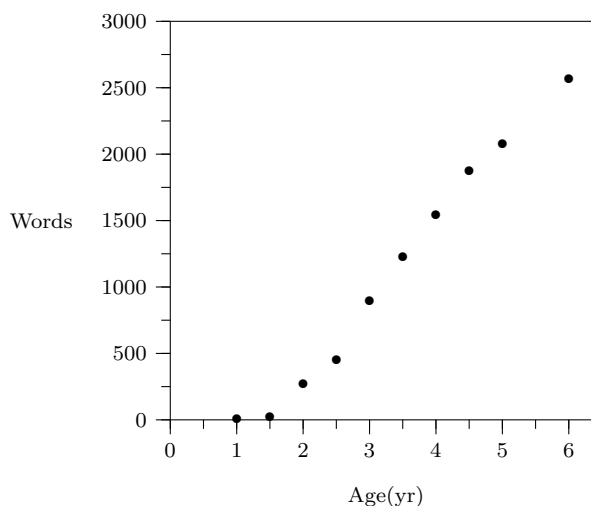
X	Y	X	Y	X	Y
5	6.1	25	3.7	42	3.4
5	6.2	25	3.7	42	3.6
5	6.1	25	3.8	42	3.5
5	6.0	25	3.9	42	3.2
15	5.2	32	3.9	55	3.7
15	5.0	32	3.8	55	3.9
15	4.9	32	3.9	55	3.6
15	5.1	32	3.7	55	3.8

$\sum X = 696$	$\sum Y = 103.7$	
$\sum X^2 = 26,752$	$\sum XY = 2692.5$	$\sum Y^2 = 469.81$
$\bar{X} = 29.0$	$\bar{Y} = 4.32$	
$SS_X = 6568$	$SS_{XY} = -314.8$	$SS_Y = 21.74$

Calculate the regression equation for this data. Test its significance with ANOVA. Predict the silicon concentration at 37 kilometers from shore and calculate the 95% confidence interval for this prediction. Calculate b to four decimals and the sums of squares and mean squares to two decimals.

8. (a) The average oral vocabulary size of children at various ages is given in the table below. The scatterplot shows a clear relationship, but is it linear? If so, describe it with a mathematical model, that is, a regression line equation. Use analysis of variance to test $H_0 : \beta = 0$. Also calculate a 95% confidence interval for β , if appropriate. (*HSDS*, #346)
- (b) Calculate $\hat{\mu}_{Y|5.5}$ and its 95% confidence interval. Would you say a five-and-one-half year-old with a vocabulary of 2000 words is in the normal range? Explain.

Age (yr)	Words
1.0	3
1.5	22
2.0	272
2.5	446
3.0	896
3.5	1222
4.0	1540
4.5	1870
5.0	2072
6.0	2562
$\bar{X} = 3.30$	$\bar{Y} = 1090.5$
$SS_X = 23.10$	$SS_Y = 7,403,118$
$SS_{XY} = 12,980.50$	



Source of variation	Sum of squares	df	MS	F	c.v.
Regression	7,294,080	1	7,294,080	535.15	5.32
Error	109,038	8	13,630		
Total	7,403,118	9			

Since $F = 535.15 \gg 5.32$, reject H_0 . The slope is significantly different from 0. For a 95% confidence interval for β ,

$$s_b = \sqrt{\frac{MS_{\text{Error}}}{SS_X}} = \sqrt{\frac{13,630}{23.10}} = 24.29,$$

so

$$L_1 = 561.926 - 2.306(24.29) = 505.91$$

$$L_2 = 561.926 + 2.306(24.29) = 617.94.$$

9. Data from a random sample of 11 gravid female iguanas, including their postpartum weights and the number of eggs each produced, were collected. Test whether there is a significant correlation between the females mass and the number of eggs she produces?

Specimen	Mass (kg)	Number of Eggs
1	0.90	33
2	1.55	50
3	1.30	46
4	1.00	33
5	1.55	53
6	1.80	57
7	1.50	44
8	1.05	31
9	1.70	60
10	1.20	40
11	1.45	50

10. Because adult male African elephants, *Loxodonta africana*, continue to grow in height and weight, it is thought that older males are generally more dominant to younger ones. Mature males have sexually active musth periods and inactive non-musth periods. During musth, males “announce” their sexually aggressive state with infrasonic calls, temporal gland secretions, and urine dribbling. As part of a study to examine how male elephants use these signals to assess other males, 28 males born between 1935 and 1962 were ranked by dominance. (Based on data reported in Joyce H. Poole, “Signals and assessment in African elephants: evidence from playback experiments,” *Animal Behaviour*, 1999, 58(1): 185–193.)

Dominance rank	Year of birth
1	1935
2	1939
3	1940
4	1935
5	1945
6	1945
7	1945
8	1947
9	1945
10	1945
11	1946
12	1950
13	1952
14	1950
15	1948
16	1953
17	1953
18	1951
19	1953
20	1953
21	1953
22	1956
23	1956
24	1957
25	1957
26	1960
27	1961
28	1962

- (a) Determine the strength of the correlation between dominance and age in male African elephants by calculating Kendall’s τ for these data.

(b) Test the hypothesis $H_a : \tau > 0$ and interpret the result.

11. The temperature of an object depends on how fast the atoms and molecules of the object vibrate. As an object is cooled, the oscillations of its atoms and molecules slow. In any material, a temperature is eventually reached where oscillations are as slow as they can possibly be. The temperature at which this occurs is called *absolute zero*. Note that the oscillations never come to a complete stop, even at absolute zero. Rather, at absolute zero the molecules and atoms are all in the ground state (that is, the lowest possible energy state) and the system has the least possible amount of kinetic energy allowed by the laws of physics. On the Kelvin scale, absolute zero is the temperature 0°K .

The work of the French physicist Jacques Charles (1746–1823) was used to determine absolute zero. Charles discovered that the volume of a gas under constant pressure increases linearly with temperature.

Assume that one mole of hydrogen is held at a constant pressure of one atmosphere. The table below contains the data from an experiment where volume, V , is measured in liters at various temperatures, T , measured in degrees Celsius.

T ($^\circ\text{C}$)	V (l)
-50	18.3
-30	20.0
-10	21.6
0	22.4
10	23.3
30	24.9
50	26.5
70	28.2

- (a) Do the data support the contention that V is a linear function of T ? Explain.
- (b) Clearly, there is a physical lower limit to the volume: It can be no smaller than 0 liters. Use the relation found above with $V = 0$ to find the corresponding temperature of absolute zero (on the Celsius scale). (The actual value is approximately -273.15°C . How does your answer compare?)
12. Consider a survey of anemia in women taken in a rural area of Appalachia. A random sample of 20 women had a blood sample taken and their hemoglobin level (g/dl) and packed cell volume (%) measured. They were also asked to report their age in years.

Subject	Hb	PCV	Age
1	11.1	35	20
2	10.7	45	22
3	12.4	47	25
4	14.0	50	28
5	13.1	31	28
6	10.5	30	31
7	9.6	25	32
8	12.5	33	35
9	13.5	35	38
10	13.9	40	40
11	15.1	45	45
12	13.9	47	49
13	16.2	49	54
14	16.3	42	55
15	16.8	40	57
16	17.1	50	60
17	16.6	46	62
18	16.9	55	63
19	15.7	42	65
20	16.5	46	67

- (a) Are the two measures of anemia correlated?
- (b) Is there a significant linear relationship between hemoglobin level and age?
13. Cricket metabolism and chirping speed vary with ambient temperature, and the speed also varies by species. In 1897, Amos Dolbear published an article “The Cricket as a Thermometer” (*American Naturalist*, **31**: 970–971) that noted a correlation between the ambient temperature and the rate at which snowy tree crickets, *Oecanthus fultoni*, chirp. A formula that appeared in the article,

$$T = 50 + \frac{N - 40}{4}$$

expressed temperature, T , in degrees Fahrenheit as a function of the number of chirps per minute, N , and later became known as Dolbear’s law.

Interestingly Dolbear, who was a physicist invented a so-called “talking telegraph” and also the first telephone receiver with a permanent magnet in 1865, 11 years before Alexander Graham Bell patented his model. Dolbear lost his patent claim in a case before the U.S. Supreme Court.

- (a) In his paper, Dolbear did not provide any data for his formula. A subsequent article (Edes, R. 1899. Relation of the chirping of the tree cricket (*Oecanthus niveus*) to temperature. *American Naturalist*, **33**: 935–938) provided the following data for temperature (T) and number (N) of chirps recorded per minute for the snowy tree cricket. Determine the regression equation for these data. Remember temperature is the independent variable. Use two decimal places for the slope.

T	56	56	58	60	61	62	63	63	64	64	64	65	66	66	67	72	73	74	75	78
N	65	72	76	82	85	95	96	94	95	95	97	99	102	103	106	134	136	140	144	160

- (b) Your equation in (a) should be an expression of the form $\hat{N} = \bar{N} + b(T - \bar{T})$. The reason that Dolbear’s law is written with T as a function of N is that it allows one to use the number of chirps to estimate the temperature. Additionally, it is written using $\frac{N-40}{4}$ so that one only has to count the number of chirps in 15 seconds (this is $\frac{N}{4}$) and add 40 (that is, $50 - \frac{40}{4}$) to obtain the estimated temperature. For example, if you counted 25 chirps in 15 seconds (equivalent to 100 chirps/min), the temperature estimate would be $25 + 40 = 65^\circ$. Using your equation from (a), estimate $\mu_{N|65^\circ}$, the mean number of chirps at 65° . Is it exactly $N = 100$?
- (c) Find a 95% confidence interval for $\mu_{N|65^\circ}$. Does the interval contain $N = 100$? Try the same questions for a 99% confidence interval.
- (d) Use your equation in (a) to solve for N . How similar is it to Dolbear’s law? Hint: Simplify Dolbear’s law before comparing.
14. The following data were recorded as part of a study on sustainable farming techniques that took place in Boone County, IA. (Davis, Adam S. et al. Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health. *PLOS ONE*. October 10, 2012. DOI:10.1371/journal.pone.0047149) Means are for the April–November growing seasons.

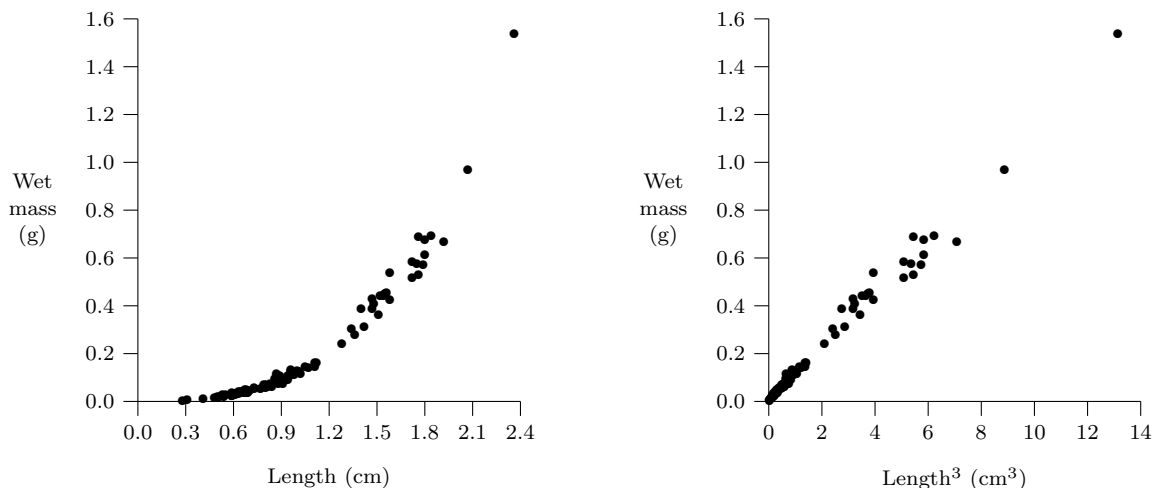
Year	Mean air temperature ($^\circ\text{C}$)	Total precipitation (mm)
2003	14.9	790
2004	15.0	697
2005	15.9	748
2006	15.6	777
2007	16.4	839
2008	15.2	1145
2009	14.8	755
2010	16.5	1165
2011	15.2	701
50-yr mean	15.5	725

- (a) Create five number summaries for both data sets.
- (b) Create box plots for both data sets.
- (c) Did either temperature or precipitation differ significantly from their 50-yr means?
- (d) Create a scatterplot of temperature versus precipitation.
- (e) Were temperature and precipitation correlated during this time period?
15. The zebra mussel, *Dreissena polymorpha*, originated in the Balkans, Poland, and the former Soviet Union. They get their common name from the striped pattern of their shells. Zebra mussels were first discovered in North America in 1988. By 1990, zebra mussels had been found in all the Great Lakes. The following year, zebra mussels escaped the Great Lakes basin and found their way into the Illinois and Hudson rivers. It is highly likely that the presence of zebra mussels in the Great Lakes was a result of a ballast water introduction. Zebra mussels are notorious for their biofouling capabilities by colonizing water supply pipes of hydroelectric and nuclear power plants, public water supply plants, and industrial facilities.



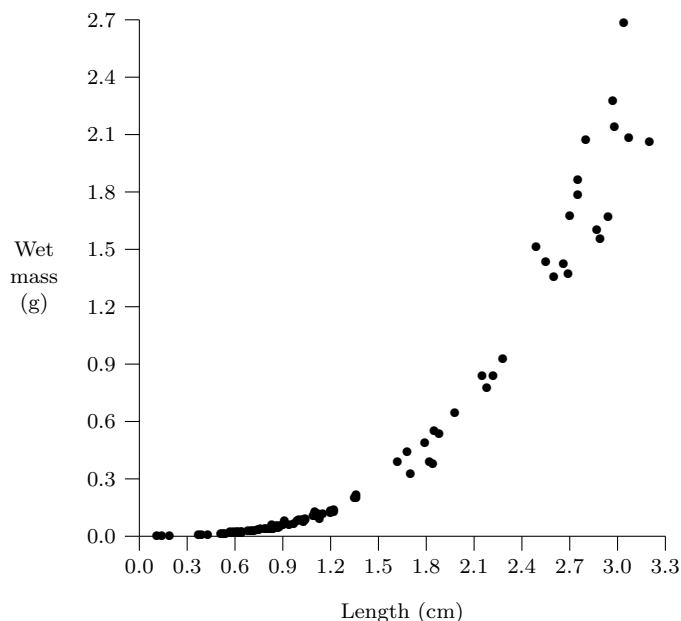
As part of a study of the impact of zebra mussels on Seneca Lake, one of the Finger Lakes in New York, two students collected length (cm) and wet mass (g) data on 98 individuals. One of the goals of the study was to relate these two measures. It was hoped that a regression equation could be developed so that in future studies only length would have to be measured and that wet mass could be estimated using the regression equation.

A preliminary plot (graph on the left below) showed that the data were not linear. This makes sense; mass ought to be a product of three dimensions, length, width, and height, $m \propto lwh$. However, it is also reasonable to assume that width and height are linearly related to length. With this in mind, using length as a substitute for height and width, the mass was plotted as a function of the cube of the length (l^3) in a second plot (graph on the right below). (Dave Costello and Jess Werder, Hobart and William Smith Colleges Department of Biology. 2002. Personal communication.)



Length ³ (cm ³)	Mass (g)	Length ³ (cm ³)	Mass (g)	Length ³ (cm ³)	Mass (g)	Length ³ (cm ³)	Mass (g)
1.030301	0.1242	1.157625	0.1419	0.068921	0.0077	0.205379	0.0214
6.229504	0.6923	0.884736	0.1290	0.493039	0.0671	0.389017	0.0523
0.226981	0.0264	0.753571	0.0925	0.300763	0.0406	13.144256	1.5365
5.832000	0.6743	0.314432	0.0453	8.869743	0.9680	2.744000	0.3861
3.241792	0.4053	0.531441	0.0605	5.088448	0.5166	0.226981	0.0298
0.857375	0.1056	0.250047	0.0381	0.389017	0.0574	5.832000	0.6100
2.863288	0.3120	0.804357	0.0950	5.451776	0.6853	0.941192	0.1100
1.404928	0.1605	0.205379	0.0223	0.636056	0.0916	3.442951	0.3628
0.531441	0.0612	2.515456	0.2772	0.021952	0.0025	3.944312	0.4247
0.658503	0.1129	0.830584	0.1074	0.110592	0.0150	0.132651	0.0197
1.030301	0.1208	0.681472	0.0717	0.125000	0.0166	5.451776	0.5300
0.250047	0.0325	0.166375	0.0247	5.359375	0.5751	1.000000	0.1284
0.551368	0.0630	7.077888	0.6677	1.367631	0.1583	0.328509	0.0348
0.456533	0.0499	3.944312	0.5354	1.221612	0.1386	0.226981	0.0286
0.029791	0.0044	0.125000	0.0152	0.328509	0.0418	0.592704	0.0695
3.176523	0.4263	0.512000	0.0537	0.512000	0.0688	0.274625	0.0368
0.205379	0.0322	1.367631	0.1453	0.148877	0.0245	0.262144	0.0399
0.274625	0.0388	0.704969	0.0863	3.511808	0.4400	2.097152	0.2379
3.176523	0.3861	5.088448	0.5823	0.287496	0.0360	0.753571	0.0906
0.205379	0.0264	2.406104	0.3008	0.884736	0.1233	0.157464	0.0197
0.314432	0.0360	0.343000	0.0442	0.205379	0.0327	3.652264	0.4383
1.061208	0.1138	0.884736	0.1098	3.723875	0.4467	0.704969	0.1040
0.571787	0.0726	0.830584	0.0906	0.300763	0.0457	5.735339	0.5700
0.592704	0.0585	0.753571	0.0739	0.857375	0.1064		
3.796416	0.4515	0.216000	0.0303	0.314432	0.0402		

- (a) Find the equation of the regression line for mass and and the cube of the length using these data.
- (b) Test whether the slope is significantly different from 0.
- (c) If a zebra mussel's length was 1.1 cm, what would its predicted wet mass be?
- (d) The quagga mussel, *D. bugensis*, is a related species to the zebra mussel which is also invading the lakes and rivers of North America. Carry out a similar analysis on the length (cm) and mass (g) measurements of 100 individuals taken from Seneca Lake in the study mentioned above. Note: These are the raw data which have not been transformed in any way.



Length (cm)	Mass (g)	Length (cm)	Mass (g)	Length (cm)	Mass (g)	Length (cm)	Mass (g)
2.94	1.6695	0.74	0.0298	0.97	0.0629	0.88	0.0503
0.39	0.0054	0.64	0.0203	0.68	0.0266	1.10	0.1251
2.55	1.4354	0.71	0.0244	1.10	0.1062	2.22	0.8390
1.03	0.0757	0.51	0.0107	0.64	0.0178	0.99	0.0803
2.87	1.6005	0.61	0.0217	1.98	0.6415	1.22	0.1377
0.70	0.0255	0.37	0.0049	1.00	0.0830	2.70	1.6751
1.20	0.1317	0.79	0.0358	2.75	1.8601	0.87	0.0442
0.64	0.0215	0.62	0.0177	1.10	0.1154	1.04	0.0835
2.69	1.3717	0.59	0.0191	0.81	0.0375	1.09	0.1062
0.43	0.0061	2.98	2.1393	2.97	2.2730	1.79	0.4876
3.04	2.6827	2.80	2.0701	0.52	0.0103	0.54	0.0087
1.02	0.0802	0.53	0.0129	0.14	0.0004	1.22	0.1267
0.59	0.0189	1.88	0.5345	0.90	0.0580	0.87	0.0518
0.57	0.0195	1.04	0.0893	0.91	0.0773	2.89	1.5542
1.13	0.0912	0.62	0.0218	0.94	0.0586	1.02	0.0862
0.85	0.0441	2.18	0.7745	0.84	0.0395	0.58	0.0173
0.90	0.0556	3.07	2.0822	2.49	1.5137	0.79	0.0364
3.20	2.0601	1.35	0.1992	0.83	0.0386	1.85	0.5507
0.76	0.0396	1.62	0.3875	1.68	0.4385	1.36	0.1975
2.66	1.4222	2.15	0.8371	1.20	0.1199	1.84	0.3769
0.86	0.0532	2.75	1.7839	0.58	0.0178	0.75	0.0296
1.36	0.2132	0.72	0.0247	1.15	0.1139	2.28	0.9276
0.83	0.0601	0.11	0.0003	1.12	0.1173	0.85	0.0503
0.19	0.0008	0.82	0.0379	0.83	0.0496	0.61	0.0175
1.82	0.3897	2.60	1.3553	1.11	0.1124	1.70	0.3265

- (e) Just by looking at the two regression equations, which species would you expect to be longer and thinner in shape?

Additional Problems for Chapter 11

- Snakes are often preyed upon by other species of snakes. Consequently, the ability of prey snakes to detect chemical cues of predator snakes in order to avoid them and, thereby, minimize encounters with such predators should confer a selective advantage. A series of trials were carried out to examine the ability of pine snake hatchlings, *Pituophis melanoleucus*, to discriminate among the odors of: (1) other pine snakes, (2) corn snakes, *Elaphe guttata*, which cohibernate with and sometimes lay their eggs in the nests of pine snakes, and (3) predators including king snakes, *Lampropeltis getulus*. A Y-shaped maze with clean wood shavings in the base section was used for each trial. In the trials one arm of the maze was designated as the control arm and contained wood shavings from a cage with no snake in it (clean shavings). The other arm of the maze contained shavings from the cage of one of the following: an adult pine snake, an adult king snake, or an adult corn snake. Pine snake hatchlings were placed at the base of the Y-shaped maze and the number of snakes selecting each arm of the maze was then recorded. (Based on data in: Burger, J. Response of hatchling pine snakes (*Pituophis melanoleucus*) to chemical cues of sympatric snakes. *Copeia*, 1990(4), 1160–1165.)

Experiment	Control	Pine	Corn	King
Control and pine	2	24		
Control and corn	14		12	
Control and king	26			0

If pine snakes are unable to detect any chemical odors of other snakes, then there should be a 50% chance that the pine snake hatchlings would select the control arm. Use a binomial test with $p = 0.5$ for each of the three experiments to test whether there is any difference in the number of times pine snake hatchlings select the control arm of the maze versus the experimental arm. How would you summarize the results?

- A number of articles in both the scientific and popular press have been written about the income and social advantages enjoyed by those who are taller. According to Wikipedia, for the 46 U.S. presidential elections in which the heights of both candidates are known, the taller candidate won 27 times, the shorter candidate won 17 times, and the candidates were the same height 2 times. (See http://en.wikipedia.org/wiki/List_of_heights_of_United_States_presidential_candidates.)
 - Is there evidence that the taller candidate has a statistically greater probability than chance of defeating the shorter candidate?
 - But wait, there's more! In three of the cases in which the shorter candidate won, the taller candidate actually received more popular votes but lost in the Electoral College. This happened in 1824, 1888, and 2000 (the other time that the electoral vote winner was not the popular vote winner was in 1876, for which we do not know the height of the loser). So, of the 46 cases for which we have data, the taller candidate has won the popular vote 30 times, and the shorter candidate 14 times, and the candidates were the same height 2 times. Is there evidence that the taller candidate has a statistically greater probability than chance of defeating the shorter candidate in the popular vote?

3. As noted in Example 10.5, DeMeis and Stearns studied age effect on academic and social performance. As part of the preliminary analysis, they needed to determine whether month of birth was uniformly distributed for the population they studied. Their sample of 2802 students is given below:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Births	258	195	216	251	242	267	234	225	215	257	228	214

- (a) Suppose that you reasoned as follows: “There are 12 months in the year and 2802 students in the population sample. Therefore, one would expect $\frac{2802}{12} = 233.5$ births per month.” Carry out a chi-square test of hypotheses where H_0 : The numbers of births per month follow a uniform distribution versus H_a : The numbers of births per month do not follow a uniform distribution. What do you conclude?
- (b) Critique the reasoning in the previous part and then suggest and carry out an alternative and more accurate chi-square test. What do you conclude this time?
4. In the 47-year period from 1949 to 1995, there were 26 cyclones within 250 nautical miles of Honolulu. Does the number of cyclones/year (see the table below) follow a Poisson distribution? (Based on data reported in: Chu, P-S. and J. Wang. 1998. Modeling return periods of tropical cyclone intensities in the vicinity of Hawaii. *Journal of Applied Meteorology*, **37**: 951–960.)

Cyclones/year	x_i	0	1	2	3
Frequency	f_i	28	14	3	2

5. In a study of sand dune communities at 18-Mile Swamp on North Stradbroke Island, two 50-m transects were laid out parallel to the foredune at distances of 10 m and 20 m from the foredune. At 100 points along each transect, the item directly under the tape was recorded as sand, living organic matter, or leaf litter. Determine whether the type of cover is independent of the distance from the foredune. Clearly state the null and alternative hypotheses.

Distance (m)	Sand	Organic	Litter
10	54	30	16
20	37	34	29

6. Some studies indicate that there is an association between mitral valve prolapse (MVP) and sickle cell anemia. Using the following data, test this hypothesis. [Based on data reported in: Husain, A. et al. 1995. Prevalence of mitral valve prolapse in Saudi sickle cell disease patients in Dammam—A prospective-controlled echocardiographic study. *Annals of Saudi Medicine*, **15**(3): 244–248.]

	Sickle cell status			Total
	Normal	Disease	Trait	
MVP	23	16	6	45
No MVP	109	104	22	235
Total	132	120	28	280

7. In mice, coat color is essentially controlled by two autosomal genes (A, a and B, b). Individuals with the A_B_ genotype are agouti (mousy brown); those with A_bb are black and those with aa__ are albino. The blanks indicate either allele of the specific gene may be present. The following cross was made:

$$AaBb \times aabb$$

which resulted in the following phenotypes for the offspring.

115 agouti
100 black
185 albino

Analyze the data to determine if the A and B loci are independently assorting.

8. L. S. Penrose investigated the *atd* angles in the parents and siblings of trisomy 21 individuals. (See Problem 19 in Chapter 6 for background). Part of Penrose's data set is presented below. (Based on data reported in: Penrose, L. S. 1954. The distal triradius *t* on the hands of parents and sibs of mongol imbeciles. *Annals of Human Genetics*, **19**: 10–38.)

Subjects	$\leq 56^\circ$	$\geq 57^\circ$	Total
Control	3745	347	4092
Parents and sibs	1213	183	1396
Total	4958	530	5488

Is the proportion of large *atd* angles (at least 57°) in the control group the same as in a group of relatives of individuals with Down syndrome?

9. Analyze Problem 26 in Chapter 2 as a chi-square test for $r \times k$ contingency tables.
10. In a study to test the effectiveness of acupuncture as an alternative to surgery for impingement of the shoulder, 200 middle-aged women with unilateral shoulder impingement were randomly assigned one of the two treatments. The patients were evaluated one year after surgery or the completion of an acupuncture series. Each patient self-identified as completely recovered or still having shoulder problems. The data are presented below.

	Recovered	Not recovered
Surgery	70	50
Acupuncture	53	27

Analyze the data appropriately. Is acupuncture an effective treatment alternative to surgery for shoulder impingement?

11. The following data are lengths (in cm) for 12 jellyfish from Salamander Bay in New South Wales, Australia. Do they appear to be normally distributed? (*HSDS*, #335)

14.0 16.5 17.0 18.0 19.0 19.0 19.0 20.0 20.0 20.0 21.0 22.0

12. In a study of the brush box tree, *Lophostemon confertus*, the size of the leaves in relationship to the size of the tree was investigated. As part of this study, one group of students measured the widths (mm) of 20 leaves from a 2.5 m sapling at Simpson's Falls, Brisbane Forest Park. Determine whether the sample supports the contention that the widths of the leaves are normally distributed.

95 85 75 75 85 65 69 55 69 55
69 55 85 70 50 72 55 65 60 55

13. The new one euro coins are the same weight and diameter throughout Europe, but each country has its own symbol on one side. To check the Belgian one euro coin for fairness students in a statistics class spun the coin on a table 250 times and got 140 heads. Do these results indicate a bias in the Belgian €1 coin?

Analyze the results using both the binomial test and the chi-square goodness of fit test. Do both tests support the same conclusion?

14. Consider once again the height data (in cm) for 10 male science faculty at Hobart and William Smith. Is it plausible that they are drawn from a normal distribution?

171 175 177 178 180 182 190 192 195 202

15. For research on sensitive topics such as alcohol or illicit drug use, the traditional methods of data collection have been person-to-person interviews or phone surveys. With the rise of the internet, web-based surveys have been used as an alternative means of collecting such data. Given the anonymity of the web and its pervasive use by young people, researchers believe that response rates to web surveys may be higher than to traditional methods.

In a study comparing completion rates of surveys, data collected from a web-based survey were compared to data collected from a telephone survey on alcohol use by women in their first year at a particular college. The class was divided into two halves. The results were the 48% of 250 women completed the phone survey while 55% of 280 women completed the web survey. (The group sizes were not equal because not all students in the survey could be contacted.) Was the web completion rate significantly greater than the completion rates for the phone interview?

16. The cranial capacity of humans and whether it is related to intelligence and other social characteristics has been a subject of much speculation and debate. One large study of a population in India found the mean cranial capacity for adult males to be $\mu = 1252 \text{ cm}^3$ with $\sigma = 113 \text{ cm}^3$. The data (cm^3) below are from a smaller, more recent study of 11 male cadavers. May the researchers assume that the sample comes from the same normally distributed population?

1029 1110 1158 1170 1188 1214 1226 1255 1298 1349 1425

17. The following data are the number of days that snow was on the ground in Rochester, NY for the 12 years from 1990 to 2001. Do these data come from a population that is normally distributed? (Based on data at: New England Integrated Sciences and Assessments project. <http://neisa.unh.edu/Climate/index.html>)

57 70 101 97 58 73 53 58 56 64 102 38

18. Reconsider the data below from Problem 5 in Chapter 1 concerning water pennies. Test whether their lengths (in mm) are normally distributed.

8.1	7.0	7.0	5.5	5.9
7.9	7.3	7.5	7.3	8.0
8.3	8.5	7.3	7.7	8.2
7.2	6.8	8.4	6.8	8.6
6.8	6.3	6.9	6.8	7.4

19. Reconsider the data below from Example 6.13. In the US, adult male heights are known to be normally distributed with a mean of 178 cm and standard deviation of 7 cm. May we assume that the sample of 10 male faculty heights in the science division at Hobart and William Smith Colleges come from this this same population?

171 175 177 178 180 182 190 192 195 202

20. Reconsider the data in Example 1.10. Test whether the weights of the lake trout caught in the derby follow a normal distribution.
21. A recent article (García-Berthou E. and C. Alcaraz. 2004. Incongruence between test statistics and P values in medical papers. *BMC Medical Research Methodology*, 4: 13) sampled articles in the journal *Nature* in volumes 409–412 and recorded the last digit of 610 test statistics that appeared there. Their data are presented below. (Source: Jeng, M. 2006. Error in statistical tests of error in statistical tests. *BMC Medical Research Methodology*, 6: 45.)

Terminal digit	Frequency
0	67
1	67
2	65
3	71
4	51
5	58
6	53
7	61
8	62
9	55

The question of interest to the authors of the original article was whether these digits came from a uniform distribution. Carry out a test to determine this, as suggested below.

- (a) To determine which test is appropriate, first determine whether the distribution of final digits is a discrete or a continuous distribution. (Think about whether there is a finite or infinite number of possible values.)
- (b) Having determined the type of distribution that was sampled, now determine whether any parameters need to be estimated from the data to determine the distribution precisely.
- (c) Select and carry out the correct test to determine whether the data come from a uniform distribution. where any number between 10 and 60 could appear.)
22. In a recent book entitled *Blink*, Malcolm Gladwell writes: “I polled about half of the companies on the Fortune 500 list—the largest corporations in the United States—asking each company questions about its CEO. The heads of big companies are, as I’m sure comes as no surprise to anyone, overwhelmingly white men, which undoubtedly reflects some kind of implicit bias. But they are also virtually all tall: In my sample, I found that on average CEOs were just a shade under six feet. Given that the average American male is 5’9” that means that CEOs, as a group, have about three inches on the rest of their sex. But this statistic actually understates matters. In the U.S. population, about 14.5 percent of all men are six feet or over. Among CEOs of Fortune 500 companies, that number is 58 percent. Even more strikingly, in the general American population, 3.9 percent of adult men are 6’2” or taller. Among my CEO sample, 30 percent were 6’2” or taller.” (Source: Gladwell, M. 2005. *Blink*. New York, NY. Little, Brown, and Co. 86–87.)
- (a) Assume that Gladwell obtained information from 250 companies that had male CEOs. Determine the probability that 58% would be 6’0” or taller, given that only 14.5% of U.S. men are 6’0” or taller.
- (b) Determine the probability that 30% would be 6’2” or taller, given that only 3.9% of U.S. men are 6’0” or taller.
- (c) If adult male heights are normally distributed with a mean of 5’9” and 14.5% are 6’0” or taller, what is the standard deviation for the population?
- (d) Using your value of σ from the previous part, what proportion of adult males should be 6’2” or taller? Does this agree with Gladwell’s assertion?
- (e) If the male CEOs represent a different population in which heights are distributed normally, determine point estimates for the mean and standard deviation of this population.

23. (a) It has been suggested that because of the war in Iraq, the U.S. military had more difficulty obtaining recruits for its all-volunteer army. As support for this, some pointed to the increase in the number of so-called “moral waivers” to recruits with criminal pasts that ordinarily would not have been eligible for military service. In 2003 the U.S. Army recruited 69,571 men and women and granted 4,918 moral waivers. In 2006 there were 69,395 total recruits with 8,129 moral waivers. Was there a significant increase in the proportion of recruits granted moral waivers from 2003 to 2006? (Source: Alvarez, L. 2007. Army giving more waivers in recruiting. www.nytimes.com/2007/02/14/us/14military.html)
- (b) While the majority of such moral waivers were for misdemeanors, most often committed by juveniles, some of waivers were for felonies. (A felony is defined as a crime that carries a sentence of a year or more in prison.) In 2003, 411 of the moral waivers were for felonies, while in 2006, 901 were for felonies. Of those recruits receiving moral waivers, did the proportion of moral waivers given to felons increase significantly from 2003 to 2006? (Source: Military granting more criminal waivers. www.cbsnews.com/stories/2007/02/14/national/main2474041.shtml)
24. In 2007, Warren Jeffs was in jail in Washington County, UT, charged with two counts of rape as an accomplice for his role in the 2001 spiritual marriage of a 14-year-old girl to her 19-year-old cousin. His attorneys want the criminal trial moved to Salt Lake County, saying months of publicity in Washington County have soured the public on Jeffs, leader of the Fundamentalist Church of Jesus Christ of Latter Day Saints.
- A poll conducted for the defense found 51.9% of 210 Washington County residents believe Jeffs is “definitely guilty,” according to documents filed in 5th District Court. Another 23.3% said Jeffs was “probably guilty.” Some 270 miles north in Salt Lake County, 38.8% of 206 respondents said they believe Jeffs is “definitely guilty” and 38.8% said he was “probably guilty.”
- “The 13 percent difference of respondents who believe the defendant is definitely guilty in Washington County versus Salt Lake County is statistically significant,” pollster Dan Jones said in an affidavit. (See: Dobner, J. www.signonsandiego.com/news/nation/20070326-1620-wst-polygamistleader.html, *San Diego Union-Tribune*, March 26, 2007.)
- (a) Do you agree with Mr. Jones? Explain.
- (b) Is there any difference between the two counties significant if those who believe Mr. Jeffs is probably guilty are included?
25. As part of the Copenhagen heart study, the medical histories of 20,000 men and women have been followed for 20 years. Participants were originally examined in the mid-1970s and extensive histories taken. Among the aging conditions tracked was arcus senilis (Latin: senile bow), a cloudy opaque arc or circle around the edge of the cornea, often seen in the eyes of the elderly. The prevalence of arcus increases with age at a somewhat faster rate for men. Approximately 25% of men and 15% of women 50 years of age have some form of the condition.
- (a) At the start of the study there were 487 women in the 50–59 age group that had arcus and 16 years later 127 of them had died. There were 2286 women in the same age group that did not have the condition and 16 years later 434 were dead. Is arcus senilis associated with an increased mortality rate for women in this age group? (Adapted from: Schnohr, P. et al. 1998. Longevity and gray hair, baldness, facial wrinkles, and arcus senilis in 13,000 men and women: The Copenhagen City Heart Study. *The Journals of Gerontology: Series A*, **53A**(5): M347–350)
- (b) At the start of the study there were 193 women in the 70–79 age group that had arcus and 16 years later 139 of them had died. There were 177 women in the same age group that did not have the condition and 16 years later 115 had died. Is arcus senilis associated with an increased mortality rate for women in this age group?
- (c) Comment on the size of the difference in mortality between those with arcus senilis and those without it in each age group. How does this compare with the significance of the hypothesis testing in each case? What explains this result?

26. In recent years, increased attention has been given to the ecology of small mammals considered from a landscape perspective. Investigations which have examined the effects of forest fragmentation and mammal dispersion in the clear-cut areas surrounding these fragments have demonstrated that landscape structure affects the dispersion and distribution of mammals in the area. In most cases, mammals are more abundant on the edge (that is, the ecotonal area between the remaining forest and the clear-cut areas) than in any other type of landscape feature investigated. Possible reasons for this are the greater complexity of vegetation and the availability of two or more habitat types. Species inhabiting the edge are provided with a greater amount of food and cover than they would obtain from any single type of habitat. In one such study conducted in 1995 and repeated in 1998, three parallel transects of Sherman live traps were placed approximately 10 m apart in each of three study areas: a hardwood forest fragment, its edge, and a surrounding clear-cut area. (See F. D. Martin, et al, "Role of edge effect on small mammal populations in a forest fragment," www.srs.gov/general/sci-tech/fulltext/tr2000103/tr2000103.html.)

- (a) In 1995 the sampling effort was nearly double that of 1998 (almost twice as many traps used). Determine whether the distribution of mammals captured was independent of the year of capture.

Location	Year		Total
	1995	1998	
Interior	26	12	38
Edge	46	25	71
Clear-cut	10	6	16

- (b) For the 1998 study, the traps were ranked by numbers mammals captured over an 18-day period. Test whether there was a difference by site in small mammal captures (that is, distribution) using the data reported below. If there was, determine which sites were different.

Location	Interior	Edge	Clear-cut
n_i	10	10	10
Rank sum R_i	132	218	115

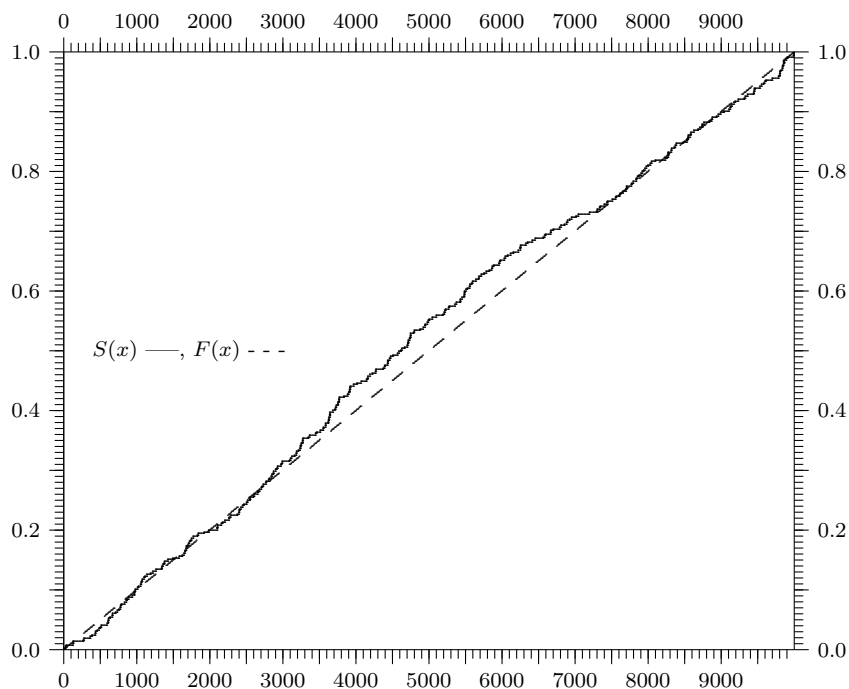
27. In an elementary genetics experiment two fruit flies thought to be heterozygous for a recessive gene causing reduced wings (apterous) were mated together with the expectation that if they were, indeed, heterozygous they would produce progeny in a 3 wild type to 1 apterous ratio. Their progeny consisted of 17 wild type and 2 apterous flies. Use the binomial test to see if these results warrant rejection of the original assumption.
28. Many states now have state lotteries. Typical of these games is the New Jersey Pick-4 lottery. Participants may choose any of the ten-thousand four-digit numbers from 0000 to 9999. Winning numbers are chosen twice a day, at midday and in the evening. Assuming that the lottery is fair, each number has an equal probability $p = 0.0001$ of being selected. This means that the cumulative distribution of winning numbers should be approximately the continuous uniform distribution

$$F(x) = \frac{x+1}{10000}.$$

Thus, the graph of $F(x)$ is a straight line connecting the points $(0, 0.0001)$ and $(9999, 1)$. The figure below illustrates the empirical distribution of 365 winning numbers for 2004 (from midday on January 1 to midday on July 1).

- (a) Explain why the cumulative distribution function $F(x)$ is not equal to $\frac{x}{10000}$. Why did we say "the cumulative distribution of winning numbers should be approximately the continuous uniform distribution $F(x) = \frac{x+1}{10000}$?"

- (b) Carefully state the null and alternative hypotheses for a Kolmogorov-Smirnov test to determine whether the lottery is fair.
- (c) Determine the critical value for the test statistic K .
- (d) Carefully draw the c.v.-corridor on the plot above. Hint: Use the critical value to determine the endpoints of the boundary lines for the c.v.-corridor.
- (e) What is the outcome of the test?



365 winning NJ Pick Four Lottery Numbers Midday 1 January to midday 1 July 2004

29. Patients afflicted with Parkinson's disease suffer from increasingly severe tremors and periodically rigid limbs as their brains stop producing dopamine, a chemical that is needed for movement. The standard treatments for the disease include drugs that stimulate the production of dopamine. A new treatment, deep brain stimulation in which electrodes are surgically implanted in the brain, was approved by the Food and Drug Administration in 2002. The devices send tiny electrical impulses to the brain that disable overactive nerve cells.

In a study, 255 people with advanced Parkinson's were randomly assigned to one of two treatments: surgery plus the standard medications or medications only. After six months neurologists examined the patients and observed the following results: In the experimental surgery group, 86 out of 121 had meaningful improvement in movement; in the medication only group, 43 out of 134 patients had improvement.

The new treatment is not without risk. For example, some patients got infections or other complications after surgery. Others feel so much better that they 'forget' they have Parkinson's and engage in activities that make falling more likely. Overall in the surgery group 49 experienced some adverse effect; in the medication only group 15 experienced such difficulties. (Based on Weaver, F. M., et. al. Deep brain stimulation vs best medical therapy for patients with advanced Parkinson disease: A randomized controlled trial. *JAMA*. **301**(1): 63–73.)

- (a) It should be relatively clear from the data that there was a significant increase in the proportion of patients showing improvement with deep brain stimulation compared to medication only treatment. Find a 95% confidence interval for the difference in the proportion of patients experiencing improvement and interpret the result.
- (b) Find a 95% confidence interval for the difference in the proportion of patients experiencing adverse effects with deep brain stimulation compared to the medication only treatment. Interpret the result.

- 30.** Ibuprofen and acetaminophen with codeine are commonly prescribed to children with fractures. A randomized trial was carried out to determine the efficacy of these medications for the outpatient treatment in the first 72 hours after emergency department discharge for children with simple arm fractures. A total of 244 children completed the study: 116 had been prescribed acetaminophen with codeine and 128 had been prescribed ibuprofen.

Parents were instructed to use the study medications every 4 to 6 hours as needed for pain, with a maximum of 4 allowed doses in a 24-hour period. If necessary, parents were to use the ‘rescue medication’ (which was the alternative medication in the study) if the pain relief was insufficient 1 hour after using the study medication. The outcome measured was the failure of the prescribed study medication to adequately reduce pain, leading to the use of the rescue medication. Thirty-six of the children taking acetaminophen with codeine found it necessary to use the rescue medication at some point in the 72-hour period, while 26 of those taking ibuprofen used the rescue medication. (Source: Drendel, A. et al. A randomized clinical trial of ibuprofen versus acetaminophen with codeine for acute pediatric arm fracture pain. *Annals of Emergency Medicine*. 2009.)

Find a 95% confidence interval for the difference in the proportion of children requiring the rescue medication and interpret the result. Suppose children taking acetaminophen with codeine have significantly more adverse side-effects, such as nausea and vomiting, than those taking ibuprofen. Which medication would you recommend and why?

- 31.** Prostate cancer patients now have two choices for surgical removal of the prostate gland: the newer minimally invasive laparoscopic surgery (sometimes with the aid of robotic tools) and the more traditional the more extensive open surgery which requires an incision several inches in length. Studies have shown that those selecting minimally invasive surgery are less likely to experience immediate complications such as pneumonia. Other studies have shown both types of surgery lead to similar outcomes in the control of the cancer. Recent studies have focused on long-term surgical complications such as impotence and incontinence.

One retrospective study assessed the outcomes of 1,938 men who had minimally invasive prostate surgery from 2003 to 2007 and 6,899 men who had open surgery. They found that 308 men who had minimally invasive surgery became incontinent compared to 842 who had open surgery. Determine whether there is a significant difference in the proportion of patients becoming incontinent with the two types of surgery. (Based on Hu, J. C., et. al. 2009. Comparative effectiveness of minimally invasive vs open radical prostatectomy. *JAMA*. **302**, 1557–1564.)

- 32.** The roles of smoking and alcohol on the development of Alzheimer’s disease remain unclear. Researchers in Spain performed a case-control study on the effects of both exposures before the age of onset of the disease in the cases (and same reference age for their age-matched controls) on disease risk. Interviews were conducted with population controls and relatives of those with Alzheimer’s disease identified through local Alzheimer’s disease associations (Based on García, Ana M., et. al. 2010. Isolated and joint effects of tobacco and alcohol consumption on risk of Alzheimer’s Disease *Journal of Alzheimer’s Disease* **20**: 577–586.)

(a) In the first part of the study, the control group consisted of $n_1 = 246$ people of which 52 were smokers while $n_2 = 176$ people with Alzheimer’s were identified of which 42 were smokers before the onset of the disease. Is the proportion of those who smoke and do not develop Alzheimer’s different from the proportion of those who smoke and develop Alzheimer’s disease?

(b) In the second part of the study, the control group consisted of $n_1 = 245$ people of which 152 consumed alcohol moderately while $n_2 = 175$ people with Alzheimer’s were identified of which 80 had consumed alcohol moderately before the onset of the disease. Is the proportion of those who consume alcohol and do not develop Alzheimer’s different from the proportion of those who consume alcohol and develop Alzheimer’s disease?

- 33.** From the *New York Times*: Over the past 30 years, in vitro fertilization has been reassuringly safe. Millions of healthy children have been born and developed normally. However, some studies indicate that there may be some abnormal patterns of gene expression associated with IVF and a possible increase in rare but devastating genetic disorders that appear to be directly linked to those unusual gene expression

patterns. There also appears to be an increased risk of premature birth and of babies with low birth weight for their gestational age.

In November 2008, the Centers for Disease Control and Prevention published a paper reporting that babies conceived with IVF, or with a technique in which sperm are injected directly into eggs, have a slightly increased risk of several birth defects, including a hole between the two chambers of the heart, a cleft lip or palate, an improperly developed esophagus and a malformed rectum. The study involved 9,584 babies with birth defects and 4,792 babies without. Among the mothers of babies without birth defects, 1.11 percent (53) had used IVF or related methods, compared with 2.40 percent of mothers of babies (230) with birth defects. Would you say there is a significant increase in the number of birth defects. (See www.nytimes.com/2009/02/17/health/17ivf.html)

34. The *Journal of the American Medical Association* recently published a study showing that people in their thirties and forties who get less than optimal sleep are more likely to develop plaque in the arteries of their hearts early in life. A group of 495 people aged 35 to 47 were followed for five years. At the beginning of the study all participants were given CT scans which indicated all were free of artery disease. The data below are the final results of CT scans for the two groups of participants: those with more than 7 hours of sleep per night and those with less than 7 hours of sleep per night. Calcifications of arteries are a sign of early heart disease.

	< 7 hours sleep	> 7 hours sleep	Total
Calcification present	15	27	42
Calcification absent	230	223	453
Total	245	250	495

35. Recently a number of studies have looked at the relationships between height and health. Genes such as the IGF-2 gene stimulate cell growth and, therefore, could be implicated in both extraordinary height and the stimulation of certain cancers. Below are data collected on 10,000 American men.

	Height below 72 in	Height above 72 in	Total
Cancer free	7800	2065	9865
Bladder/prostate cancer	80	55	135
Total	7880	2120	10,000

Are the bladder/prostate cancer rates significantly higher in tall men?

36. Gene interactions can lead to a myriad of distortions in classical mendelian ratios. Consider two independently assorting gene loci controlling fruit shape in the summer squash *Cucurbita pepo*. A recessive genotype (aabb) at both loci leads to a long shape. A dominant allele at one of the loci (A_bb or aaB_) leads to a sphere shape. Dominant alleles at both loci (A_B_) generates a disc shape. Two plants with the AaBb genotypes were crossed and generated the following progeny:

Shape	Number
Disc	162
Sphere	135
Long	23
Total	320

From the above results would you say the data support the hypothesis of 2 gene loci assorting independently with the gene interactions described? **Note:** This is essentially problem 6 in Chapter 11.

37. Just before Wimbledon in 2009, Alan Schwarz wrote an article for the *New York Times* entitled “That Shot Was Out? A Clue On When to Challenge a Call.” (See www.nytimes.com/2009/06/24/sports/tennis/24tennis.html)

When a line judge at Wimbledon rules on a hair-splittingly close call and says the ball is out, the inevitably disgruntled player should not only consider challenging the call for review by digital replay system. He should consult a recent issue of *Current Biology*.

A vast majority of near-the-line shots called incorrectly by Wimbledon line judges have come on balls ruled out that were actually in, according to a study published in October by researchers at the University of California-Davis. To the vision scientist, the finding added to the growing knowledge of how the human eye and brain misperceive high-speed objects. To the tennis player, it strongly suggests which calls are worth challenging and which are best left alone.

The researchers identified 83 missed calls during the 2007 Wimbledon tournament. (Some were challenged by players and overruled, and others were later identified as unquestionably wrong through frame-by-frame video.) Seventy of those 83 calls, or 84 percent, were on balls ruled out—essentially, shots that line judges believed had traveled farther than they actually did.

Called perceptual mislocalization by vision scientists, this subconscious bias is known less formally to Wimbledon fans as “You cannot be serious!”—John McEnroe’s famous dissent when, yes, a 1981 shot was ruled out. Now that players can resort to a more evolved appeal procedure, the researchers’ discovery suggests that players should generally use their limited number of challenges on questionable out calls rather [than] those that are called in, because such out calls have a far better chance of being discovered as mistaken on review, then overturned.

“What we’re really interested in is how visual information is processed, and how it can be used to a player’s advantage,” said David Whitney, an associate professor at U.C.-Davis’s Center for Mind and Brain, who is the paper’s lead author. “There is a delay of roughly 80 to 150 milliseconds from the first moment of perception to our processing it, and that’s a long time.” . . .

Theoretically, line judges should be equally likely to call an out ball in as they are an “in” ball out. But when objects travel faster than humans’ eyes and brains can precisely track them—for example, Andy Roddick’s 150-mile-per-hour serves—they are left having to fill in the gaps in their perception. In doing so, they tend to overshoot the object’s actual location and think it traveled slightly farther than it truly did.

- (a) Under the assumption that linesman are equally likely to call an out ball in as they are an in ball out, is the observation that 70 of 83 erroneous calls would be balls ruled out that were actually in statistically significant?
- (b) The authors of the original paper used a χ^2 test and reported a test statistic of 39.1. How did they do the calculation? Is that the value that you get? (See: Whitney, D., *et. al.* Perceptual mislocalization of bouncing balls by professional tennis referees. *Current Biology*, **18**(20): R947–R949.)
38. As a hermit crab grows or as the shell it occupies becomes damaged, it will exchange the shell for a larger and/or better quality empty shell. Where shell resources are limited, there is often competition among crabs for such shells. Hermit crabs occupying damaged shells are at additional risk for predation and consequently it is thought that this increases the likelihood of such crabs exchanging shells.
- In a study of the behavior of *Coenobita clypeatus*, a terrestrial hermit crab, researchers attempted to determine whether hermit crabs in damaged shells outcompete size-matched crowded hermit crabs when they both were given the opportunity to move to a new, high-quality shell. In the experiment, $n = 13$ size-matched pairs crabs consisting of one uncrowded crab occupying a highly damaged shell and one crowded crab occupying an intact shell were marked and tested. Once the pairs were established, a single high-quality shell of appropriate size for the pair was introduced to their environment. After 24 hours, the researchers recorded which crab had acquired the new shell and found that in 10 of the 13 trials the crab with the damaged shell now occupied the new shell. Do these data support the claim that hermit crabs occupying damaged shells exchange outcompete crabs occupying shells that are crowded?

(Source: Lewis, S. and Randi Rotjan. 2009. Vacancy chains provide aggregate benefits to *Coenobita clypeatus* hermit crab. *Ethology*, **115**: 356–365.)

39. Crocodile species show substantial variation in their jaw proportions, dental form, and body size. A team of researchers were interested in how these factors relate to biomechanical performance during feeding and their relevance to crocodilian evolutionary success. As part of their study, they measured adult bite forces and body mass in all 23 extant crocodilian species. Their data are presented below. (Source: Gregory M. Erickson, *et al.* 2012. *Insights into the Ecology and Evolutionary Success of Crocodilians Revealed through Bite-Force and Tooth-Pressure Experimentation*, Vol 7, No. 3 www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0031781)

Taxon	Mean Body Mass (kg)	Bite Force (Newtons)
<i>Crocodylus actus</i>	132	3999
<i>Crocodylus intermedius</i>	182	6276
<i>Crocodylus johnsoni</i>	20	1292
<i>Crocodylus mindorensis</i>	69	2736
<i>Crocodylus moreletti</i>	110	4399
<i>Crocodylus niloticus</i>	86	3043
<i>Crocodylus novaeguinae</i>	154	5360
<i>Crocodylus palustris</i>	207	7295
<i>Crocodylus porosus</i>	272	8983
<i>Crocodylus rhombifer</i>	52	2107
<i>Crocodylus siamensis</i>	69	3415
<i>Mecistops cataphractus</i>	67	2082
<i>Ostreolaemus tetraspis</i>	17	1787
<i>Gavialis gangeticus</i>	112	1895
<i>Tomistoma schiegetii</i>	142	3397
<i>Alligator mississippiensis</i>	142	5117
<i>Alligator sinensis</i>	14	1084
<i>Caiman crocodilius</i>	20	1215
<i>Caiman latirostris</i>	30	1467
<i>Caiman yacare</i>	18	971
<i>Melanosuchus niger</i>	59	2696
<i>Paleosuchus palpebrosus</i>	13	900
<i>Paleosuchus trigonatus</i>	22	1082

- (a) Are crocodilian body mass and bite force correlated?
 (b) Is there a significant linear relationship between crocodilian body mass and bite force?
40. White-throated sparrows, *Zonotrichia albicollis*, occur in two distinct color morphs referred to as brown and white. It was suspected that females select males of the opposite morph (that is, white females select brown males and vice versa). This phenomenon is known as negative assortative mating. In 50 mated pairs, the color combinations were as follows:

		Males		Total
		White	Brown	
Females	White	7	23	30
	Brown	14	6	20
Total		21	29	50

Do these data support the assumption that negative assortative mating occurs in this species?

41. In her article (Way to a man’s heart? Her natural scent. *USA Weekend*. February 26, 2010.) Sharon Jayson wrote:

Wearing fancy perfumes may not be an effective way to attract a man, according to new research that suggests a potential mate may prefer a woman’s natural scent.

In two studies in the journal *Psychological Science*, researchers at Florida State University asked women to wear T-shirts for three nights during different phases of their menstrual cycles. Then, men smelled the shirts. Some men smelled shirts that hadn’t been worn by anyone, others smelled those worn by women.

Based on saliva samples, men were found to have higher levels of testosterone if they had smelled the shirts worn by ovulating women. Men also rated those worn shirts as more pleasant-smelling.

The authors say their research is the first direct evidence ‘that olfactory cues to female ovulation influence biological responses in men.’

They conclude that this biological response may promote men’s natural mating-related behavior.

- (a) Suppose 20 men were asked to evaluate T-shirts for pleasantness. The shirts were worn to bed for three nights by women who were in the ovulatory phase (+) of their menstrual cycle or in the luteal phase (–) of the menstrual cycle. Each test subject was required to choose one or the other of the two shirts as more pleasant. This is called a “forced choice” test. Were the T-shirts worn by ovulating women significantly more pleasant smelling to men?

Ovulating	Not ovulating
13	7

- (b) Now suppose 200 men were surveyed and 130 found the T-shirts of ovulating women more pleasant. Would that result indicate a significant preference for the smell of ovulating women?

Review Problems and Answers

1. Clearly indicate true (T) or false (F) for each:

- (a) The normal distribution is really an infinite family of curves utilizing different values of μ and σ .
- (b) Of the ANOVA techniques presented in Chapters 8 and 9 only the factorial design ANOVA tests for interaction among treatments.
- (c) All Analysis of Variance F tests are right-tailed regardless of the alternative hypotheses.
- (d) If any two events are independent, they are also mutually exclusive.
- (e) Regression analysis differs from correlation analysis because we assume in regression that independent variable, x , is under our control and measured without error.
- (f) Conditional probabilities are useful only when the two events in question are independent.
- (g) In a test of hypothesis it is generally easier to know the probability of a Type I error than the probability of a Type II error.
- (h) Comparing the P value to the alpha level is equivalent to comparing the test statistic to a critical value with the same alpha level.
- (i) The Bonferroni-Holm t tests and Tukey tests are mean separation techniques that should be used only if the global F test of a model I ANOVA is significant.
- (j) According to the Central Limit Theorem, the distribution of sample means is approximately normally shaped for large samples regardless of the shape of the distribution of the X_i 's.
- (k) To completely describe a binomial distribution one must know n and p , but to completely describe a Poisson distribution one only needs to know μ .
- (l) If the probability of a Type I error is denoted by α , the probability of a Type II error can be denoted as $1 - \alpha$.

Practice Problems

The remaining problems in this section were designed to review fundamental concepts. They are not placed in any descriptive context, but are meant to check whether students are able to carry out basic calculations. Each question is immediately followed by its answer. The problems are listed in the same order as the corresponding material in the text. Several problems include multiple samples. We often assign different samples to different groups in class and have them compare answers.

2. Assume an entire population is surveyed and the following data reported. Find the population mean, the uncorrected sum of squares, the correction term, the corrected sum of squares, the population variance, and the population standard deviation.

82	38	78	31	38
23	55	78	65	66
80	48	67	53	83

3. From a population with mean $\mu = 50.0$ and standard deviation $\sigma = 12.0$ eight random samples of 10 individuals are drawn. For each, find the sample mean, the uncorrected sum of squares, the correction term, the corrected sum of squares, the sample variance, and the standard error.

Sample									
1	2	3	4	5	6	7	8		
52	59	50	39	44	50	67	55		
43	59	41	42	47	45	78	58		
55	43	46	60	60	42	43	50		
44	52	35	54	41	52	38	61		
45	56	40	41	49	52	73	41		
59	58	36	53	38	58	45	50		
38	50	48	46	58	62	54	25		
48	36	57	44	68	47	41	41		
41	49	58	43	51	30	51	59		
61	50	48	63	51	47	57	55		

4. A population has a normal distribution with mean $\mu = 50$ and standard deviation $\sigma = 12$.
- Calculate the probability that X is greater than 62.
 - Calculate the probability that X is less than 25.
 - Calculate the probability that X is greater than 50 but less than 79.
 - Calculate the probability that X is less than 50 but greater than 43.
 - Calculate the probability that X is less than 70.
 - Calculate the probability that X is greater than 27.
 - Calculate the probability that X is not between 23 and 77.
 - Calculate the probability that X is between 23 and 77.
 - Calculate the probability that X is between 34 and 57.
 - Calculate the probability that X is not between 35 and 60.
5. From a population with mean $\mu = 50.0$ and standard deviation $\sigma = 12.0$ eight random samples of 10 individuals are drawn. For each, find the sum, the uncorrected sum of squares, the sample mean, the sample variance, and the standard error. Then find 90%, 95%, 98%, and 99% confidence intervals for the population mean.

Sample							
1	2	3	4	5	6	7	8
42	61	45	28	50	51	46	54
52	55	60	51	58	55	35	52
38	44	62	36	50	54	62	78
46	50	28	20	41	27	70	46
47	47	45	62	53	51	45	53
58	51	38	40	52	57	56	76
25	70	67	55	61	24	44	38
48	48	53	68	22	51	48	43
68	45	42	56	50	68	50	36
70	60	48	62	44	51	39	47

6. Eight random samples of 10 individuals are drawn from a population. For each, find the sum, the uncorrected sum of squares, the sample mean, the sample variance, and the standard error. Then find 90%, 95%, 98%, and 99% confidence intervals for the population variance.

Sample							
1	2	3	4	5	6	7	8
48	42	53	52	33	44	45	65
58	44	41	68	61	44	49	47
47	61	42	56	59	63	58	70
35	47	57	54	48	44	55	25
67	42	32	51	50	45	59	27
62	58	61	49	35	67	45	48
53	75	47	53	43	42	49	55
48	60	57	35	48	57	57	62
50	20	35	48	51	41	50	41
70	49	51	53	42	44	60	38

7. Eight random samples of 10 individuals are drawn from a population. For each, find the sum, the uncorrected sum of squares, the sample mean, the sample variance, and the standard error. For each sample test (i) $H_0 : \mu \leq 50$ versus $H_a : \mu \geq 50$ (ii) $H_0 : \mu \geq 50$ versus $H_a : \mu \leq 50$ (iii) $H_0 : \mu = 50$ versus $H_a : \mu \neq 50$ all at the $\alpha = 0.05$ level.

Sample							
1	2	3	4	5	6	7	8
66	37	44	47	45	47	63	51
53	45	75	55	34	18	41	33
37	52	55	47	51	20	34	56
31	40	52	52	23	61	43	31
75	21	44	60	33	68	57	47
54	40	72	14	45	30	13	37
37	82	50	72	57	29	49	47
75	43	61	54	72	55	49	44
48	72	46	66	29	51	40	68
49	30	24	54	53	62	47	57

8. Population 1 has a mean of 50.0 and a standard deviation of 12.0. Population 2 has a mean of 50.0 and a standard deviation of 6.0. Each population is sampled four times. For each of the eight samples, find the sum, the uncorrected sum of squares, and the sample variance. Then for each pair of samples (one from each population), test at the $\alpha = 0.05$ level whether they have significantly different variances.

Example 1		Example 2		Example 3		Example 4	
Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
42.0	50.0	42.0	49.0	51.0	53.5	56.0	54.5
56.0	53.5	40.0	51.0	52.0	50.5	52.0	52.5
40.0	45.0	42.0	61.0	44.0	51.0	42.0	48.5
72.0	50.5	57.0	43.5	46.0	50.0	37.0	52.0
51.0	48.5	48.0	47.5	53.0	39.0	33.0	37.0
53.0	56.5	44.0	48.5	65.0	39.0	38.0	52.5
70.0	51.5	22.0	50.5	35.0	45.5	44.0	45.5
61.0	50.0	47.0	52.5	50.0	47.0	47.0	60.0
54.0	56.0	64.0	54.0	42.0	42.5	39.0	50.5
40.0	53.0	58.0	55.0	35.0	46.0	28.0	48.0

9. In each of the four examples below, (unpaired) samples were drawn from two populations. Use an appropriate t test to test the hypotheses: $H_0 : \mu_1 = \mu_2$ versus $H_a : \mu_1 \neq \mu_2$ at the $\alpha = 0.05$ level.

Example 1		Example 2		Example 3		Example 4	
Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
44.0	47.0	48.0	51.0	63.0	37.0	59.0	48.0
52.0	54.0	58.0	47.0	53.0	52.5	43.0	48.0
55.0	38.5	55.0	49.5	56.0	44.0	50.0	44.5
54.0	46.5	55.0	49.0	39.0	55.0	53.0	49.5
49.0	51.0	39.0	47.5	47.0	36.0	39.0	46.5
52.0	56.0	57.0	49.0	54.0	62.5	41.0	63.0
43.0	37.5	56.0	42.5	47.0	47.5	49.0	48.5
54.0	48.0	62.0	51.5	42.0	55.0	45.0	45.0
46.0	48.0	54.0	53.0	28.0	44.5	43.0	57.5
48.0	42.5	53.0	50.0	52.0	50.0	58.0	54.5

10. In each of the four examples below, paired samples were drawn from two populations. Use an appropriate t test to test the hypotheses: $H_0 : \mu_1 = \mu_2$ versus $H_a : \mu_1 \neq \mu_2$ at the $\alpha = 0.05$ level.

Pair	Example 1		Example 2		Example 3		Example 4	
Sample	1	2	1	2	1	2	1	2
1	44	57	45	75	42	37	44	73
2	57	57	42	50	48	49	22	44
3	22	52	78	54	57	44	60	53
4	48	57	55	73	46	68	52	43
5	53	37	60	44	22	50	32	33
6	33	59	40	49	43	65	50	50
7	48	54	50	58	56	24	30	42
8	47	55	49	47	57	56	42	48
9	53	45	56	51	40	58	42	32
10	53	59	52	55	61	46	47	51

11. Carry out a one-way analysis of variance at the $\alpha = 0.05$ level using the following data.

Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5
45	63	38	83	52
49	65	36	98	41
40	61	56	58	62
48		39	64	57
				75
				38
				59
				42

12. Carry out a randomized complete block design ANOVA using the data below to test the

Block (<i>j</i> th)	Treatment (<i>i</i> th)			
	1	2	3	4
1	52	54	67	41
2	55	51	48	36
3	63	53	56	54
4	52	56	31	40
5	21	30	60	33

13. Carry out a regression analysis for each of these four sets of paired data.

Observation	Example 1		Example 2		Example 3		Example 4	
	X	Y	X	Y	X	Y	X	Y
1	19	26	17	30	14	28	21	36
2	16	23	18	33	20	35	24	35
3	22	31	22	28	17	22	16	24
4	14	30	20	31	19	28	21	31
5	16	27	25	33	21	33	13	27
6	22	30	17	29	21	26	15	29
7	21	37	18	24	17	28	20	27
8	17	31	23	34	18	32	21	37
9	20	31	19	30	17	33	17	28
10	19	25	30	34	19	27	17	29

14. Carry out a Pearson correlation analysis for each of these four sets of paired data testing $H_0 : \rho = 0$ versus $H_a : \rho \neq 0$.

Observation	Example 1		Example 2		Example 3		Example 4	
	X	Y	X	Y	X	Y	X	Y
1	26	30	15	26	17	33	17	30
2	18	33	17	31	20	34	17	33
3	24	38	12	24	15	22	21	26
4	25	28	19	33	15	23	16	29
5	17	34	20	30	21	31	17	24
6	20	31	16	26	26	35	16	33
7	20	32	25	32	23	32	22	29
8	25	30	25	34	25	30	25	34
9	19	25	21	32	20	29	27	39
10	19	26	22	29	21	29	18	35

15. For the data in the table below, test the null hypothesis H_0 : The ratio of Class 1 to Class 2 to Class 3 is 2 to 1 to 1, respectively.

Class	Observed
1	49
2	30
3	21
Total	100

16. Test the null hypothesis H_0 : There is no association between X and Y classifications (they are independent) for the data in the following 2×2 contingency table.

	X_1	X_2	Total
Y_1	14	13	27
Y_2	12	19	31
Total	26	32	58

17. Test the null hypothesis H_0 : There is no association between X and Y classifications (they are independent) for the data in the following 4×3 contingency table.

	X_1	X_2	X_3	Total
Y_1	15	23	25	63
Y_2	17	15	21	53
Y_3	27	29	13	69
Y_4	22	28	10	60
Total	81	95	69	245

G U I D E

The following flow charts can be used as quick reference guides to help find the appropriate statistical tests for hypotheses of any of the various experimental designs presented in this text.

