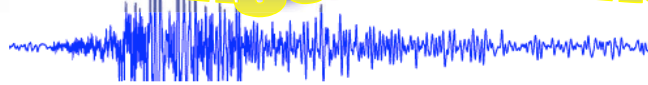**Challenge Worksheet**

Geophysics of Earthquakes

Lab 8: "Plinko" – Statistical Measurements

Can you determine the diameter of a marble without actually using a ruler?

Your Supplies:

- 1 Plinko Board – board tacked with nails
- 9 marbles
- grid marked from 0-9 on both sides
- calculator
- marker
- ruler

Background:

You are going to try and determine the size of a marble by rolling a "bombarding marble" into a grid of "target marbles." The marble diameter will be calculated from the ratio of hits to misses. The larger the marble the more hits and the smaller the marble the fewer the hits.

This is a statistical exercise and statistics rely on randomness.

Procedure:

1. The Plinko board will randomize the "bombarding marble."

2. The grid will contain 8 marbles in a random pattern.

3. How will you obtain a random pattern for the 8 marbles?? Place the marbles on the grid in a random pattern.

4. **STOP**

   (turn the page after you have set up your board.)

5. What does your grid look like?

a)

b)

c)
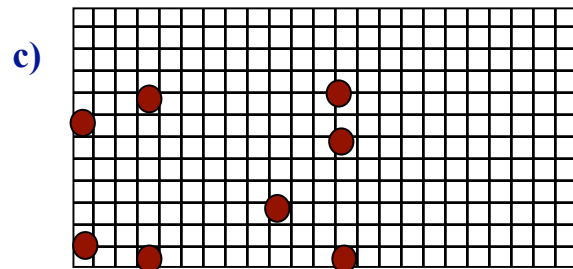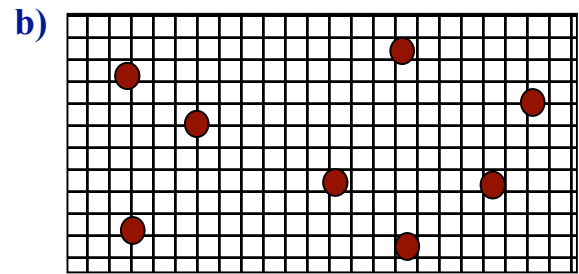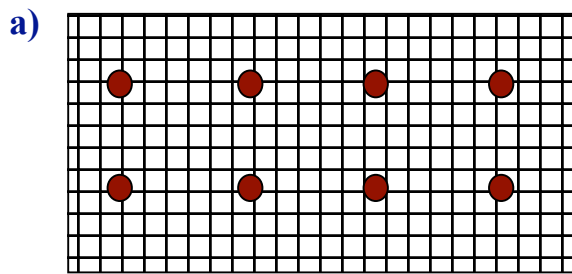
Believe it or not, your grid should look something like **c!**

With such a small sampling (a small number of marbles) a random distribution will not evenly cover the grid. By evenly covering the grid, you have imposed your own bias in the system, therefore eliminating randomness. NOT WHAT WE WANT TO DO!

6. To get a random distribution of marbles, choose **8** two-digit numbers from the table on the next page (as a group) and circle them.

7. Now place your marbles on the grid according to these numbers and the following directions: the first digit is your x-axis value and the second digit is your y-axis value.

    For example, if you choose the following numbers,   03   31   24
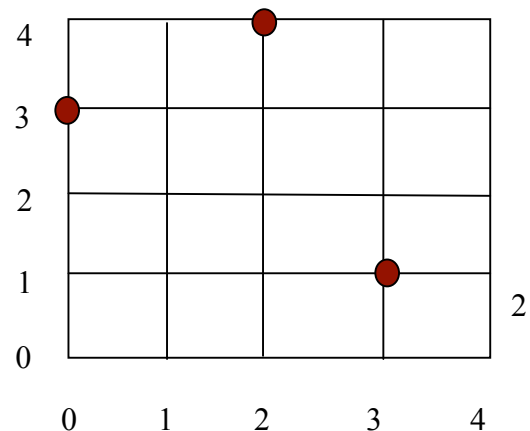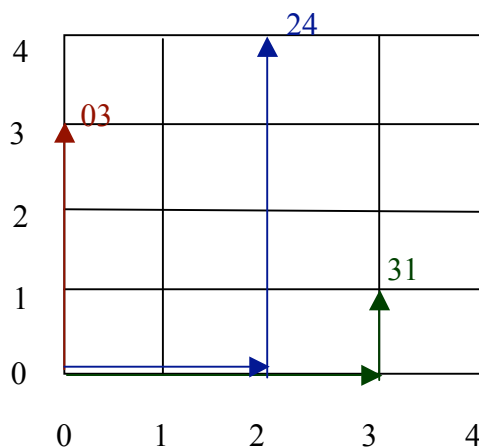
    They will plot like this….

TABLE OF 1000 RANDOM TWO-DIGIT NUMBERS
(FROM 0 to 50)

03 47	44 22	30 30	22 00	00 49	22 17	38 30	23 21	20 11	24 33
16 22	36 10	44 39	46 40	24 02	19 36	38 21	45 33	14 23	01 31
33 21	03 29	08 02	20 31	37 07	03 28	47 24	11 29	49 08	10 39
34 29	34 02	43 28	03 43	43 40	26 08	28 06	50 14	21 44	47 21
32 44	11 05	05 05	05 50	23 29	26 00	09 05	27 31	08 43	04 14
18 18	04 02	48 39	48 22	38 18	15 39	48 34	50 28	37 21	15 09
23 42	31 08	19 30	06 00	20 18	30 24	15 33	10 07	14 29	05 24
35 12	11 12	11 04	01 10	25 39	48 50	24 44	03 47	34 04	44 07
12 13	42 10	40 48	45 44	42 35	41 26	41 10	23 05	06 36	08 43
37 35	12 41	02 02	19 11	06 07	42 31	23 47	47 25	10 43	12 38
16 08	18 39	03 31	49 26	07 12	17 31	17 31	35 07	44 38	40 35
31 16	10 47	38 45	28 40	33 34	24 16	42 38	19 09	41 47	50 41
32 43	45 37	30 38	22 01	30 14	02 17	45 18	29 06	13 27	46 24
27 42	03 09	08 32	24 02	05 49	18 05	22 00	23 02	44 43	43 20
00 39	05 03	49 37	23 22	33 42	26 29	00 20	12 03	10 05	02 39
11 27	39 32	13 30	36 45	09 03	46 40	22 07	03 03	05 39	03 46
35 24	22 49	17 33	35 01	01 32	18 09	47 03	39 41	36 23	19 41
16 20	38 36	29 48	07 27	48 14	34 13	07 48	39 12	20 18	19 42
38 23	33 26	15 29	20 02	21 45	04 31	48 13	23 32	37 30	09 24
45 11	27 07	39 43	13 05	47 45	47 45	00 06	41 18	05 02	03 09
18 00	14 21	49 17	30 37	25 15	04 49	24 19	40 23	24 17	17 16
20 46	06 18	45 07	06 28	49 44	10 06	43 00	38 26	34 41	11 16
05 26	50 25	38 47	39 38	42 45	10 08	16 06	43 18	34 48	27 03
21 19	13 42	16 04	00 18	16 46	13 13	16 29	44 10	29 18	22 45
41 23	03 10	35 30	24 36	38 09	25 21	06 40	20 46	39 14	37 31
34 50	20 14	21 46	38 46	12 27	20 44	46 06	01 41	30 49	18 48
39 43	13 04	24 15	08 22	13 29	04 05	42 29	50 47	01 50	01 48
18 14	04 43	27 46	23 07	19 28	07 10	23 19	41 45	25 27	19 10
09 47	34 45	08 45	25 21	49 21	18 46	16 40	35 14	41 28	41 15
44 17	04 33	15 22	12 45	39 07	34 27	14 47	35 33	42 29	47 47
40 33	42 45	07 08	38 15	08 25	22 06	07 26	32 44	03 42	42 34
33 27	10 45	18 40	11 48	48 03	07 16	32 25	20 25	44 22	39 28
06 09	04 26	14 35	36 03	15 22	02 07	46 48	45 12	47 11	30 19
33 32	34 25	45 17	13 26	03 37	33 35	08 13	15 26	09 18	34 25
42 38	40 01	43 31	30 33	39 11	49 41	27 44	11 39	06 19	47 23
15 06	22 08	50 44	50 11	18 16	00 41	07 47	34 25	28 10	50 03
22 35	49 36	44 21	25 12	19 44	31 51	49 18	40 36	00 27	22 12
31 04	32 17	08 23	38 32	01 47	43 53	44 04	10 27	16 00	16 33
39 00	01 50	07 28	35 02	38 00	46 47	33 29	28 41	09 23	47 48
37 32	07 02	07 48	07 41	22 13	37 27	27 12	34 21	07 04	49 34
05 03	36 07	10 15	21 48	14 44	39 39	15 09	23 23	37 31	00 25
17 37	13 41	13 39	40 14	19 48	34 18	08 18	08 06	44 26	12 45
32 24	24 30	29 13	34 39	27 44	11 20	37 40	36 46	35 22	09 09
07 45	29 12	48 35	05 38	43 11	45 18	28 14	04 37	48 38	43 12
14 08	04 04	18 17	10 33	04 32	27 37	33 42	34 41	07 41	49 14
31 38	08 31	38 30	42 10	08 09	17 32	46 15	15 43	15 31	46 45
42 34	46 31	29 03	08 32	11 06	20 21	24 16	13 17	29 34	42 31
16 00	02 48	10 34	32 14	25 39	29 31	18 37	28 50	07 28	08 24
20 15	60 11	21 31	20 49	07 35	41 16	16 17	43 36	20 26	39 38
00 49	14 10	29 01	49 28	21 30	40 15	01 07	16 04	19 09	36 12

8. Now mark each of the eight points where you have placed a marble with a marker. This will make it easy to replace the marbles when they get bombarded.

9. Now you will bombard your target marbles. Take your ninth marble and drop it down the Plinko board starting on the left side and moving one nail to the right for each new run. When you reach the end begin again. You will be recording numbers of runs with hits to the number of runs with misses.

> **A Run** = Bombarding Marble falls down the board and crosses the grid in some way. If the bombarding marble does not cross the grid it is not considered a run.

A Hit =

Bombarding Marble falls down the board and hits at least one target marble. It can hit more than one, but the run is only counted as a single "hit".

OR

A Miss =

Bombarding Marble falls down the board, crosses the grid, but DOES NOT HIT a target marble. Remember, if the marble falls and does not cross the grid, it is not a run (and therefore neither a hit nor a miss), and you must redo it (move to the next nail).

10. Do 50 runs. Record the number of hits to misses in the table on the next page.

11. Measure the width of the grid **in centimeters:**

$$D = \underline{\hspace{2in}}$$

12. Take the following equation and rearrange it to solve (isolate) for the diameter of the marble:

$$R = \frac{2Nd}{D}$$

d = diameter of marble
N = number of marbles
D = width of grid
R = Ratio of hits to misses

$$\boldsymbol{d} = \underline{\hspace{2.5in}}$$

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Run	Hit	Miss	Run	Hit	Miss
1			26		
2			27		
3			28		
4			29		
5			30		
6			31		
7			32		
8			33		
9			34		
10			35		
11			36		
12			37		
13			38		
14			39		
15			40		
16			41		
17			42		
18			43		
19			44		
20			45		
21			46		
22			47		
23			48		
24			49		
25			50		
			Total		

13. What is the ratio of hits to misses for all 50 of your runs?

$$R = \frac{hits}{misses} = \underline{\hspace{4cm}}.$$

14. Now calculate R after 10 and 25 runs and fill these values in the table below. Finally, calculate d from the equation you solved for on the previous page. Enter these values as well.

Runs	R	d
10		
25		
50		

15. The actual diameter of the marble is 1.5519 cm (as measured with calibers, a tool to measure the width of a human hair). How close were you?

Now you can calculate the amount of error in your measurement. Error is defined as,

$$\frac{observed - actual}{actual} * 100\%$$

16. Calculate the error in your diameter estimates after 10, 25 and 50 runs.

Runs	Error
10	
25	
50	

If you get a negative error that just means that your estimate of the diameter was too low.

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Questions:

1. What do you notice about the error with increasing runs?

2. Would this experiment work if all the "target" marbles were different sizes?

3. What could you do to increase the accuracy of you measurement?