Lab 1

Measurement, Precision, and Appropriate Instruments, Statistical Measures

Objectives

- Introduce students to several basic measurement instruments and when they are each most useful
- Give students practice noting and recording precision error in various instruments
- Introduce students to the process of taking several independent measurements, and recording the varied results for analysis
- Learn the standard statistical measures for data

Lab Overview

You will "visit" multiple stations, each with several different objects and measuring instruments. Your group will collect data by performing repeated measurements on the objects with the various instruments, and record your data on this worksheet, a Google sheet or a class Google sheet.

Be especially careful to …

- Ensure the apparatus is properly zeroed!
- Record your data with proper units and the proper number of significant figures!
- Identify sources of uncertainty and develop appropriate strategies to characterize and/or reduce the uncertainties!

Equipment

INSTRUMENT FOR MEASURING	OBJECTS TO BE MEASURED
• **RULER**	
• **TAPE MEASURE FROM KIT**	• **Ball, 19mm, from kit**
• **CALIPERS FROM KIT**	• **Wooden dowel from kit**
• **DIGITAL STOPWATCH, CELL PHONE APP OR WEBSITE**	• **Low ramp made with: 1) a book, ruler or any surface propped up at an angle; 2) ball from kit or your own ball**
• **ANALOG CLOCK, WITH SECOND HAND VIRTUAL OR PHYSICAL**	• **Metronome app**
• **ELECTRONIC SCALE (STUDENTS WHO ALREADY OWN ONE)**	• **IOLab from kit**
• **SPRING BALANCE FROM KIT**	

Equipment details:

Stopwatch: for half of the time measurements, a stopwatch (virtual on cell or physical stopwatch) is used. You can use a cell phone app, bookmark a stopwatch website on your computer or a physical stopwatch you already own.

Metronome: the sound in beat per minute (BPM) will be measured by the time instruments. You can download an app, bookmark a metronome website on your computer or use a physical metronome you already own.

Analog clock (virtual or physical). You need one with a second hand moving continuously. For a virtual clock, use **http://bit.ly/5BLclock**

IOLab: unbox the unit, setting aside the small components and dongle for future labs. The spring scale can attach to the top metal support wire.

What to Turn In

Each group should submit this worksheet as a pdf with measurements, calculations and question answers added to the lab manual. Each student in a group will be responsible for one station's questions and analysis, and managed by the group's Communicator. The class Google sheets for the ball diameter with the calipers and the IOLab mass do not need to be turned in.

Overview

A crucial part of any physics experiment is measuring and quantifying the uncertainties in the measurement. This lab introduces statistical methods useful in testing experimental observations against theoretical models. Throughout this class, we will follow the convention in most physics labs and use the terms "uncertainty" and "error" interchangeably.

"Random errors" are fluctuations in observations that yield different results each time the experiment is repeated so multiple measurements are necessary. The smaller the random uncertainty, the more "precise" the measurement. These types of errors are best studied by statistical techniques as the observed result distribution is randomly generated. The best estimate of the measured quantity is the "mean" of the distributed data, and the spread of data is the "standard deviation".

"Systematic errors" cause the measured quantity to be shifted either positive or negative direction from the true value. When the shift is small, measurements are considered "accurate". These types of errors typically manifest themselves as a consistent offset in all the data, can be difficult to discern, and cannot be analyzed by statistical methods. Once identified, data should be corrected to account for systematic errors before further analysis. Examples: faulty equipment calibration, parallax, zero offset.

"Precision or reading errors" occurs because we cannot read a device's scale to infinite precision. For a digital device, the uncertainty is one in the last digit whereas for an analog one it is half a division.

Other errors you could encounter in Physics 5BL labs include incorrect models, experimenter mistakes and malfunctioning equipment.

When designing and carrying out an experimental procedure, your goal is to reduce systematic errors and to minimize random errors.

Prelab

Prior to the scheduled class time, you'll need to assemble and take pictures of your measuring instruments and objects to be measured, learn to use a caliper and answer error analysis questions.

Task 1: Assemble all the kit components (tape measure, calipers, spring balance, ball, wooden dowel, wooden block) and submit a picture.

Task 2: Assemble the time measurement virtual components (stopwatch, metronome and analog clock). Note: You may use physical versions of these as well if you have access to them. Submit pictures of each screen or object.

Task 3: Assemble the time measurement physical components (low ramp and ball) and submit a picture.

Task 4: Watch a video/read an article on caliper use and submit the URL. Some suggestions: https://www.wikihow.com/Use-Calipers, or https://en.wikipedia.org/wiki/Calipers#Use

Question 5: In your own words, briefly explain the difference between parent and sample populations. Which will we be using in Physics 5BL and why?

Question 6: In your own words, briefly explain the difference between the standard deviation and standard error for the sample population.

Question 7: Do you have any questions?

Procedure and Data Collection

All three-person lab groups will be assigned to the same measurement station (length, time or mass) during the lab, starting with the length station. When all groups complete their measurements, the class will move on to the next station.

Each group should decide on the experimental procedure to generate independent trials before taking real data. Record your measurements in the lab manual tables, in a group shared document, or on a class shared document, as specified.

STATION	OBJECTS	INSTRUMENTS
#1 LENGTH	• Ball • Wooden dowel	• Ruler • Tape measure • Calipers
#2 MASS	• Ball • IOLab	• Electronic scale • Spring balance
#3 TIME	• Ramp with ball • Metronome (download an app)	• Digital stopwatch • Analog clock (virtual, with second-hand) http://bit.ly/5BLclock

- Each group will contribute their six independent diameter measurements (two per student) of the steel ball with the calipers to a class-wide Google sheet.
- Each group containing students with access to an electronic scale will contribute their six independent mass measurements of the IOLab mass to a class-wide Google sheet.

Length Station

INSTRUMENT	PRECISION ERROR (UNITS)
RULER	+- 0.05
TAPE MEASURE	+- 0.05
CALIPERS	+- 0.05

--With the other students in your group, cooperate to obtain six independent measurements of each object with the various measurement instruments. Each student should take two measurements using the group's experimental method, then pool the data to complete each table.

Make sure your experimental procedure accounts for identifying and removing any instrument zero offsets. For the ball diameter measured with the calipers, also upload all six independent measurements from your group to the class Google doc.

Measure the diameter of the ball…

…with the **ruler**

Trial #	Ball Diameter (units: cm)
1	1.78
2	1.76
3	1.80
4	1.79
5	1.82
6	1.80

…with the **tape measure**

Trial #	Ball Diameter (units: cm)
1	1.8
2	1.9
3	1.8
4	1.8
5	1.8
6	1.9

…with the **calipers**

Trial #	Ball Diameter (units: cm)
1	1.82
2	1.85
3	1.83
4	1.84
5	1.80
6	1.80

Measure the length of the dowel…

…with the **ruler**

Trial #	Dowel Length (units: cm)
1	30.50
2	30.48
3	30.47
4	30.44
5	30.48
6	30.51

…with the **tape measure**

Trial #	Dowel Length (units: cm)
1	30.60
2	30.55
3	30.60
4	30.50
5	30.45
6	30.50

Which instrument was easiest to use in measuring the ball diameter?

The calipers

Which instrument was easiest to use in measuring the dowel length?

The ruler

Which instrument(s) had a zero offset and how did the measurement technique(s) account for it?

None of the instruments had an offset. The caliper would be the one with an offset, since it has several different scales that need to be matched up before the measurement starts, but we aligned the scales before starting. Therefore, our measuring techniques didn't have to account for anything.

Were there any significant differences between the different groups' measurements of the ball diameter? Can you account for them as being systemic, random or another type of error? Give a complete explanation for the source.

Since the points where the diameter of the ball weren't specified or shown on the ball, each of us produced different measurements for the same physical object. Javier's measurements were usually more accurate, but less precise. Conversely, Allen did the direct opposite. Perhaps this was due to us approximating where the endpoints were. I would account for these differences to be slightly random, since the measurement one gives of the diameter, especially when using the ruler or tape measure, really depends on what angle you are looking at the ball from, which I consider to be a random factor.

Time Station

INSTRUMENT	PRECISION ERROR (UNITS)
ANALOG CLOCK	+- 0.5
DIGITAL STOPWATCH	+- 0.01

--With the other students in your group, cooperate to obtain six independent measurements of each object with the specified instruments and complete each table below. The group should decide on an experimental method to measure the time for a ball (from the kit or your own) to roll down a ramp. Possibilities could include each student measuring times for a ball rolling between two repeatable points in their own setup, one student rolling a ball on their ramp with the other group members watching and measuring times, or another one designed by the group. For the metronome tick measurements, each student should take two measurements, then pool the data to complete each table.

Measure the time it takes for the ball to roll from the top to the bottom of the ramp …

…with the **analog clock**.

Trial #	Rolling Time (units: **seconds**)
1	0.5
2	0.6
3	0.7
4	0.5
5	0.5
6	0.6

…with the **digital stopwatch**

Trial #	Rolling Time (units: **seconds**)
1	0.73
2	0.78
3	0.60
4	0.47
5	0.85
6	0.70

Measure the time it takes for the metronome to tick 10 times at 100 BPM…

…with the **analog clock**

Trial #	Time for 10 Ticks at 100 BPM (units: **seconds**)
1	6.0
2	6.5
3	5.5
4	5.5
5	6.5
6	6.5

…with the **digital stopwatch**

Trial #	Time for 10 Ticks at 100 BPM (units: **seconds**)
1	6.12
2	6.03
3	6.19
4	5.98
5	5.61
6	5.65

Which instrument was easiest to use in measuring the rolling time? **The stopwatch**

Which instrument was easiest to use in measuring the time for 10 ticks at 100 BPM? **The stopwatch**

Describe your group's experimental procedure for the ramp measurements, and the reasons for choosing it. What problems did you identify and solve with your procedure?

First of all, we were concerned by the fact that even though the ball was the same for all of us, the angle or length of the ramp could not be the same for all of us. Therefore, we made sure to create some standards to abide with throughout the experiment. On a flat surface, we placed the wooden block that came in the kit and then we measured a length for the ramp to be. On the ramp, we marked the point where the ramp would touch the wooden block. Now, all of us had the same setup. We were also quite worried about giving the ball some initial velocity that could alter the results. Nevertheless, we agreed to all follow the same procedure, but we still got some fairly different results, particularly when using the stopwatch. This is perhaps due to our reaction time, which is an uncontrollable external factor that we can't modify with out instruments. We then just followed the procedure that was explained to us, and got to the results displayed above.

Were there any significant differences between your group's measurements on the same metronome timing ticks? Can you account for them as being systemic, random or another type of error?

With the metronome, we all decided to use the same tool, the google metronome. As I explained before, the errors in our measurements were primarily due to discrepancies in our reaction time, both to start the stopwatch, and to stop it. We faced a similar issue with the analog clock. These disagreements led to more important disagreements in our results, which are mostly visible in our results for the metronome ticks when using a stopwatch. Allen seemed to measure short times, Javier measured long times, and I was just in the middle. This shows how relevant the time reaction errors can be. I believe this is a random error, since we don't decide our reaction time for a given event, and it is some totally or at least apparently random process.

Mass Station

INSTRUMENT	PRECISION ERROR (UNITS)
ELECTRONIC SCALE	+- 0.1 gram
SPRING BALANCE	+- 1 gram

--With the other students in your group, cooperate to obtain six independent measurements of each object with the various measurement instruments. Each student should take two measurements using the group's experimental method, then pool the data to complete each table. For the IOLab mass data, students with an electronic scale should

Each group containing students with access to an electronic scale will contribute their six independent mass measurements of the IOLab mass to a class-wide Google sheet.

Measure the mass of the ball ...

...with the **electronic scale**.

Trial #	Ball Mass (units: grams)
1	25.7
2	25.7
3	25.6
4	25.7
5	
6	

...with the **spring balance**

Trial #	Ball Mass (units: grams)
1	26
2	26
3	26
4	25
5	26
6	25

Measure the mass of the IOLab ...

...with the **electronic scale**.

Trial #	IOLab Mass (units: grams)
1	121
2	110
3	110
4	112
5	115
6	116

...with the **spring balance**

Trial #	IOLab Mass (units: _______)
1	
2	
3	
4	
5	
6	

Why would you want to zero out the spring scale between each measurement?

Between measurements, the spring might be expanded from the weight that it has been supporting. Therefore, the equilibrium length of the spring can be larger after weighting a very heavy mass than after weighting a smaller mass. Therefore, after each experiment it is convenient and ultimately necessary to adjust our scale to the spring punctual equilibrium length, ensuring that there is as little of an error as possible.

Were there any significant differences between the groups' measurements on the IOLab? Can you account for them as being systemic or random errors, or is there another reason? Discuss briefly.

We only had one group with an electronic scale, so there is no way to tell the differences between the groups' errors. Nevertheless, the errors would probably come from the fact that some IOLabs would have their batteries on and others not or similar examples.

FUN

Try making a balance from kit components and common home materials. If you need string, the kit embroidery floss may be used.

Here are some ideas for balances:

- Using office supplies
- Using the dowel or pencil as a fulcrum for ruler, with weights on top
- Using home supplies
- use coinage as weights (pennies weigh 2.50 gm, nickels 5.00 gm, dimes 2.27 gm, quarters 5.67gm)

How do the mass measurements compare to the ones made from either the spring scale or the electronic balance?

I'm not sure I followed the procedure perfectly well, but I got the grasp of it at least. I used home supplies, and the measurements were a lot more diverse. The standard deviation was greater than in the video for the electronic scale. However, it was particularly difficult to find precise decimals, since the units to measure came in 'packs' of 2.5 grams and the other weights for the coins. Therefore, I made use of the average weight of a paper clip to add paper clips instead and try to find a mass closer to the real one.

Analysis

Accounting for random error: Mean, Standard Deviation, and Standard Error[1]

Statistical Measures of Random Errors

Suppose we make N measurements $x_1, x_2, \ldots x_N$ of the same quantity x all using the same method. The fluctuations responsible for the spread in values are random, consequently they are equally likely to be positive and negative. The arithmetic mean $\bar{x}$ is therefore the best estimate of x:

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$$

The average uncertainty of the individual measurements is given by the (sample) standard deviation:

$$\sigma_{N-1} = \sqrt{\frac{1}{N-1}\sum (x_i - \overline{x})^2}$$

The uncertainty in $\bar{x}$ is the standard error, or standard deviation of the mean:

$$\alpha = \frac{\sigma_{N-1}}{\sqrt{N}}$$

A reported measurement should be presented as the best estimate $\bar{x}$ along with the uncertainty in $\bar{x}$, written as

$$\bar{x} \pm \alpha$$

with units placed at the end of the expression.

If $\alpha = 0$, the uncertainty in $\bar{x}$ is the reading (precision) error.

"Agreement Test (provisional)"

When comparing an experimentally measured value $\bar{A} \pm \alpha_{\bar{A}}$ to a known "accepted" value $\bar{B} \pm \alpha_{\bar{B}}$, they "agree" for Lab 1 ONLY if:

$$|\bar{A} - \bar{B}| < 2(\alpha_{\bar{A}} + \alpha_{\bar{B}}).$$

Note that the accepted value has an implied error of ± 1 in the quoted value's last digit if not otherwise specified.

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[1] *References: Hughes and Hase, Measurements and their Uncertainties, Ch. 1 and 2, Physics 5BL Statistics Review*

Directions

Calculate the mean, standard deviation, and standard error for each of the data sets you collected. Be careful to keep the correct number of significant figures, and report your results with units in the standard format as *Quantity = (Mean) ± (Standard Error)*, e.g., *Frog mass = 1.1 ± 0.2 kg*. Mark whether or not your result agrees with the accepted value, using the provisional Agreement Test.

> Remember: an "accepted value" without an error ALWAYS has an implied error of ± the last digit of the value provided.

Length Station Analysis

Quantity	***Measured using …***	***MEAN*** *(units: cm)*	***STANDARD DEVIATION*** *(units: cm)*	***STANDARD ERROR*** *(units: cm)*	***Result with Error*** *(# ± # with units)*
Ball diameter	**Ruler**	**1.79±0.05cm**	**0.02±0.05cm**	**0.008±0.05cm**	**1.79±0.008cm**
	Tape measure	**1.83±0.05cm**	**0.05±0.05cm**	**0.02±0.05cm**	**1.83±0.02cm**
	Calipers**	**1.82±0.05cm**	**0.02±0.05cm**	**0.008±0.05cm**	**1.82±0.008cm**
		(units: cm)	*(units: cm)*	*(units: cm)*	
Dowel length	**Ruler**	**30.48±0.05cm**	**0.02±0.05cm**	**0.01±0.05cm**	**30.48±0.01cm**
	Tape measure	**30.53±0.05cm**	**0.06±0.05cm**	**0.02±0.05cm**	**30.53±0.02cm**

** use the full-class data.

Do your results agree with the accepted values? Compare to the accepted values below and write "Yes" or "No" in the empty table.

Do your results agree with the accepted values? (Yes/No)

Quantity	Measured using …		
	Ruler	**Tape measure**	**Calipers**
Ball diameter	**No**	**No**	**No**
Dowel length	**Yes**	**Yes**	N/A

For Reference

Quantity	Accepted Value
Ball diameter	1.90 cm
Dowel length	30.5 cm

Time Station Analysis

Quantity	Measured using …	MEAN (units: s)	STANDARD DEVIATION (units: s)	STANDARD ERROR (units: s)	Result with Error
Rolling time	Analog clock	0.57+- 0.5	0.08+- 0.5	0.03+- 0.5	0.57+- 0.03
	Digital stopwatch	0.69+- 0.01	0.14+- 0.01	0.06+- 0.01	0.69+- 0.06
		(units: s)	(units: s)	(units: s)	
10 ticks at 100 BPM	Analog clock	6.08+- 0.5	0.49+- 0.5	0.2+- 0.5	6.08+- 0.2
	Digital stopwatch	5.93+- 0.01	0.24+- 0.01	0.099+- 0.01	5.93+- 0.099

Do your results agree with the accepted values? Compare to the accepted values below and write “Yes” or “No” in the empty table.

Do your results agree with the accepted values? (Yes/No)

Quantity	Measured using … Analog clock	Digital stopwatch
Rolling time	There is no accepted value in the table to the right	There is no accepted value in the table to the right
10 ticks at 100 BPM	yes	yes

For Reference

Quantity	Accepted Value
Rolling time	Not applicable
IOLab mass	6 s

In theory, it would take 6 seconds exactly to do 10 beats at 100BPM

Mass Station Analysis

Quantity	Measured using …	MEAN (units: grams)	STANDARD DEVIATION (units: grams)	STANDARD ERROR (units: grams)	Result with Error
Ball mass	Electronic scale	25.68+- 0.1	0.05 +-0.1	0.025 +-0.1	25.68+- 0.025
	Spring balance	25.67+-1	0.51+-1	0.21+-1	25.67+-0.21
		(units: grams)	(units: grams)	(units: grams)	
IOLab mass**	Electronic scale	114+-0.1	4.24+-0.1	1.73+-0.1	114+-1.73
	Spring balance	N/A	N/A	N/A	N/A

** use the full-class data

Do your results agree with the accepted values? Compare to the accepted values below and write "Yes" or "No" in the empty table.

Do your results agree with the accepted values? (Yes/No)

Quantity	Measured using …	
	Electronic scale	**Spring balance**
Ball mass	**No, but nearly**	**YES**
IOLab mass	**Yes, but without batteries**	**N/A**

For Reference

Quantity	Accepted Value
Ball mass	25.9 g
IOLab mass	203 gm

Note: the class results measure the IOLab without the batteries. I did a very inaccurate estimation at home of the weight with the batteries in the IOLab and my result was 201 grams on average