

UNCERTAINTY

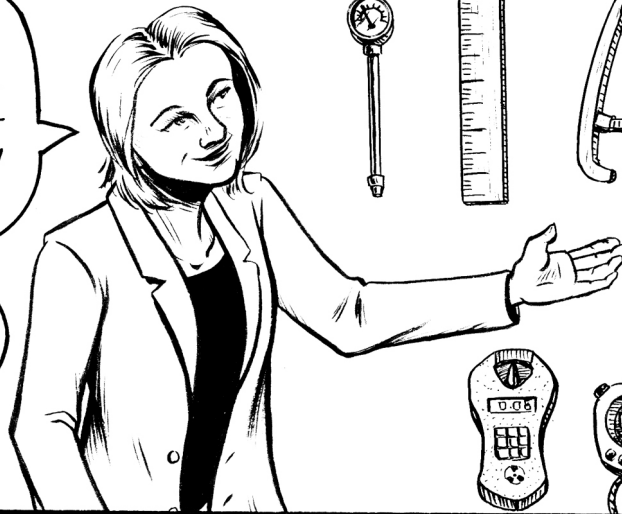
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ILLUSTRATED BY
AMANDA KAHL

CAN YOU TRUST A MEASUREMENT? IT DEPENDS!



IT'S IMPORTANT TO REMEMBER THAT THE TOOL YOU USE FOR MEASUREMENT HAS A MAJOR EFFECT ON HOW SPECIFICALLY YOU CAN QUANTIFY YOUR MEASUREMENT -

- BECAUSE IT AFFECTS THE UNITS AND SCALE THAT YOU'RE EVALUATING WITH!



FOR EXAMPLE, CONSIDER THE EXPLOSION BEHIND ME! YOU CAN DECIDE TO MEASURE IT BASED ON PERSONAL JUDGEMENT:

THAT LOOKS LIKE 1- NO, 1.4 EXPLODE-YES.



OR YOU CAN USE ACTUAL TOOLS TO CONDUCT YOUR MEASUREMENT, WITH VARIABLE DEGREES OF SPECIFICITY.

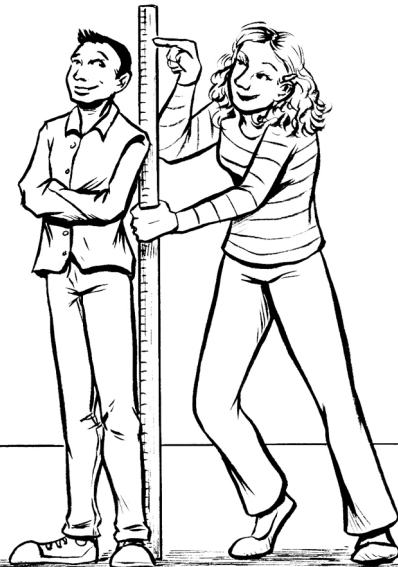
THAT'S A 5.0 ON THE RICHTER SCALE!



QUANTIFICATION MATTERS, BUT THE TOOL AT HAND IS CRITICAL. IF YOU WERE TO MEASURE SOMEONE'S HEIGHT WITH A METER STICK THAT HAD NO INCREMENTS MARKED ON IT, YOU CAN ONLY BE SO SPECIFIC.

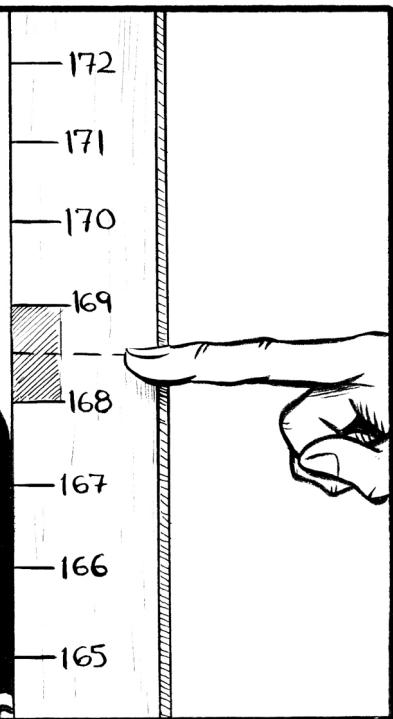


BUT THE MORE DETAILED YOUR INCREMENTS ARE, YOU CAN GET VERY SPECIFIC WITH YOUR MEASUREMENT!



AND THAT GREY AREA BETWEEN INCREMENTS - THAT IS YOUR UNCERTAINTY (OR ERROR).

YOU CAN ESTIMATE YOUR MEASUREMENT WITHIN HALF OF THE INCREMENTS YOU ARE PROVIDED, MEANING YOU CAN ONLY EVER BE SURE OF YOUR MEASUREMENT WITHIN HALF OF THE SMALLEST INCREMENT.



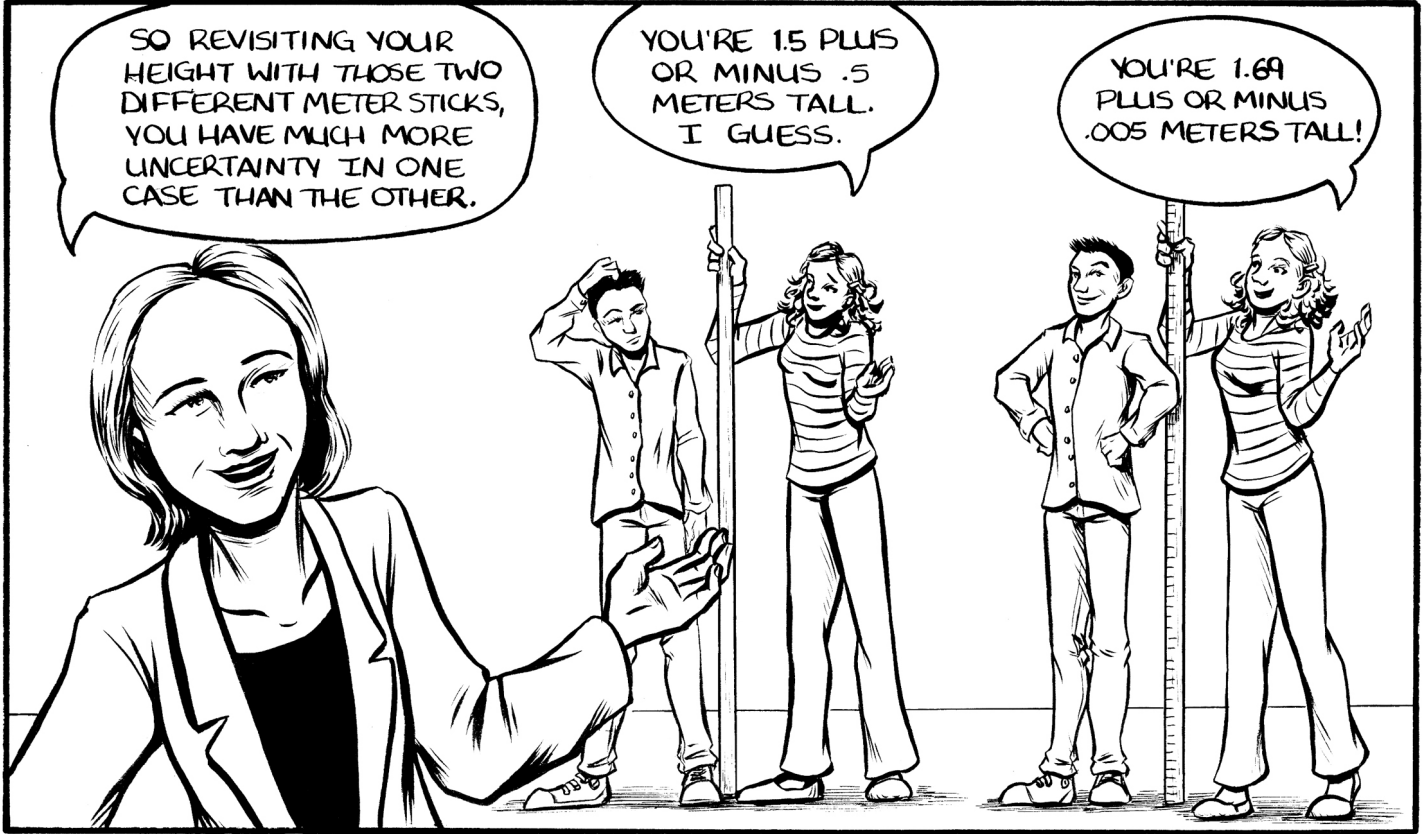
THIS EVERY DATA POINT REALLY HAS TWO PARTS:

$$x = x_{\text{best}} \pm \delta x$$

THE DATA POINT.

YOUR ESTIMATE OF THE DATA POINT'S VALUE, GIVEN YOUR MEASUREMENT.

THE UNCERTAINTY OF YOUR ESTIMATE.



SO REVISITING YOUR HEIGHT WITH THOSE TWO DIFFERENT METER STICKS, YOU HAVE MUCH MORE UNCERTAINTY IN ONE CASE THAN THE OTHER.

YOU'RE 1.5 PLUS OR MINUS .5 METERS TALL. I GUESS.

YOU'RE 1.69 PLUS OR MINUS .005 METERS TALL!



WHEN YOUR MEASUREMENT IS TOO INACCURATE, YOU MAY AS WELL BE MEASURING WITH SOME COMPLETELY USELESS TOOL, LIKE MEASURING SOMEONE'S HEIGHT IN BANANAS-

-EVEN THOUGH BANANAS AS A MEASUREMENT LENGTH IS COMPLETELY MEANINGLESS!

YOU'RE FOURTEEN BANANAS TALL, PLUS OR MINUS HALF A BANANA!

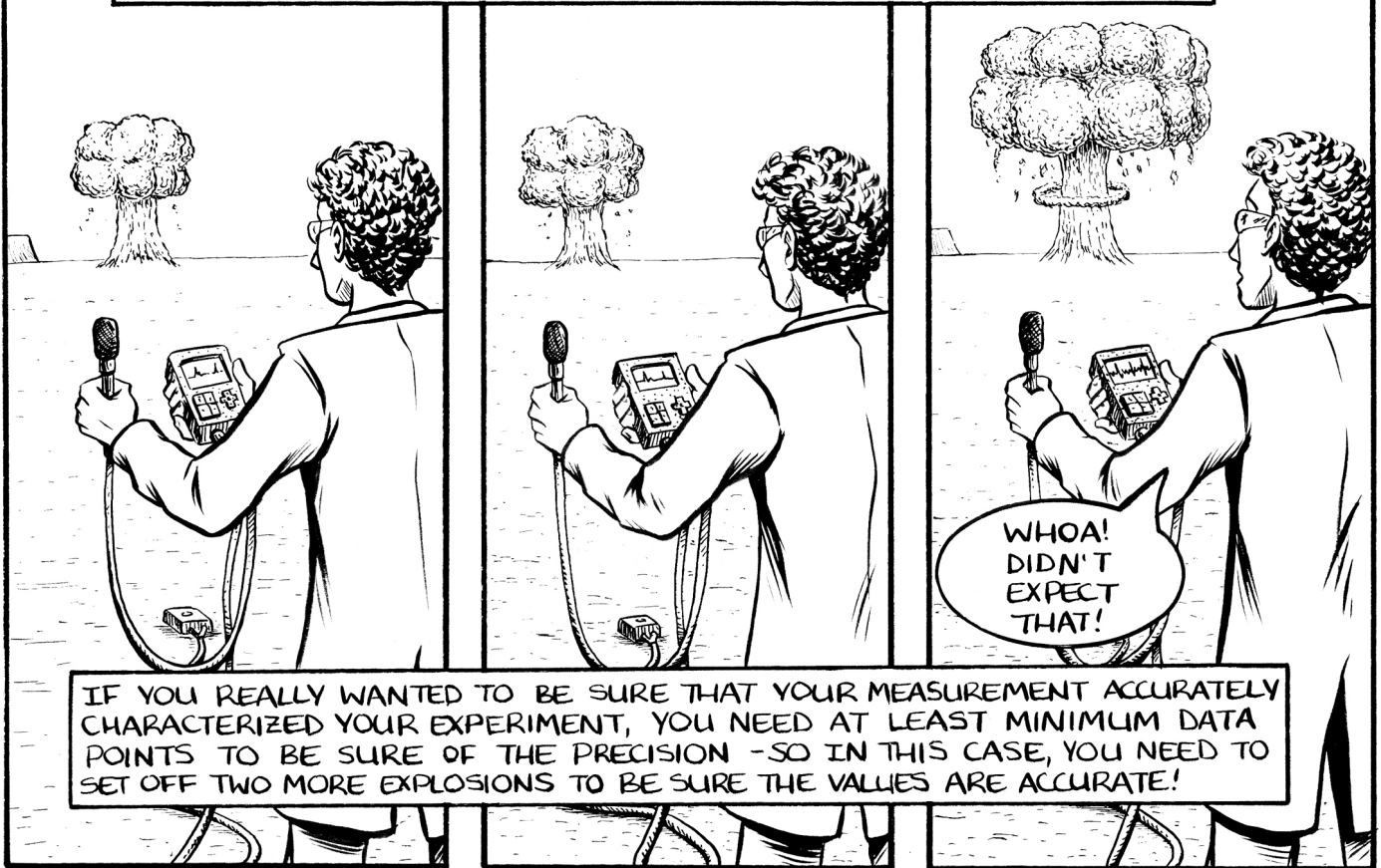
WHICH MEANS, UM, SOMETHING, I'M SURE.



SO SPECIFICITY OF MEASUREMENT MATTERS WHEN DETERMINING UNCERTAINTY!

BUT NO MEASUREMENT STANDS ALONE!

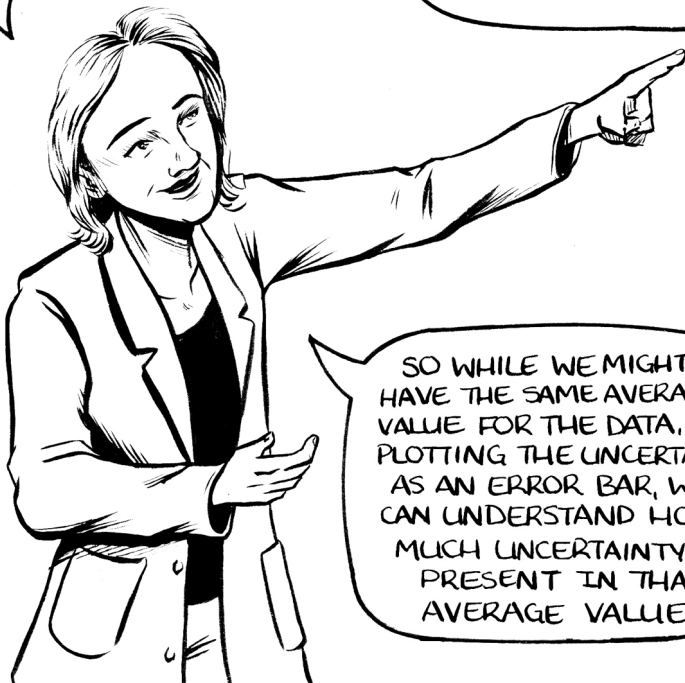
LET'S CONSIDER THAT EXPLOSION AGAIN. REALISTICALLY, YOU HAVE NO GUARANTEE THAT THE EXPLOSION WILL BE EXACTLY THAT LARGE AND DESTRUCTIVE EACH TIME. THAT ONE TIME COULD HAVE BEEN AN IMPRESSIVE FLUIKE OR EVEN A RATHER IMPRESSIVE DUD.



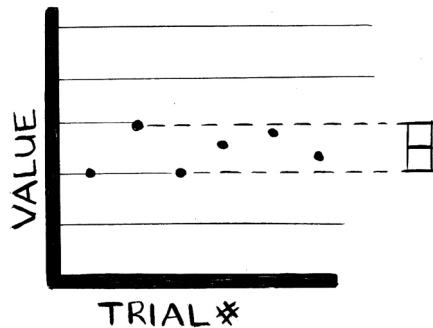
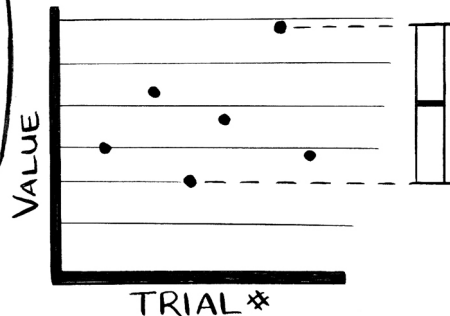
IF YOU REALLY WANTED TO BE SURE THAT YOUR MEASUREMENT ACCURATELY CHARACTERIZED YOUR EXPERIMENT, YOU NEED AT LEAST MINIMUM DATA POINTS TO BE SURE OF THE PRECISION -SO IN THIS CASE, YOU NEED TO SET OFF TWO MORE EXPLOSIONS TO BE SURE THE VALUES ARE ACCURATE!

ONCE WE HAVE AT LEAST THREE DATA POINTS, WE CAN TAKE AN AVERAGE TO DETERMINE THE MEAN VALUE- AND WE CAN CALCULATE THE STANDARD DEVIATION TO DETERMINE THE QUALITY OF OUR MEASUREMENTS.

A LARGE STANDARD DEVIATION MEANS THERE IS A LOT OF UNCERTAINTY INHERENT IN OUR VALUES- WHILE A LOW STANDARD DEVIATION MEANS OUR MEASUREMENTS WERE PRETTY PRECISE!

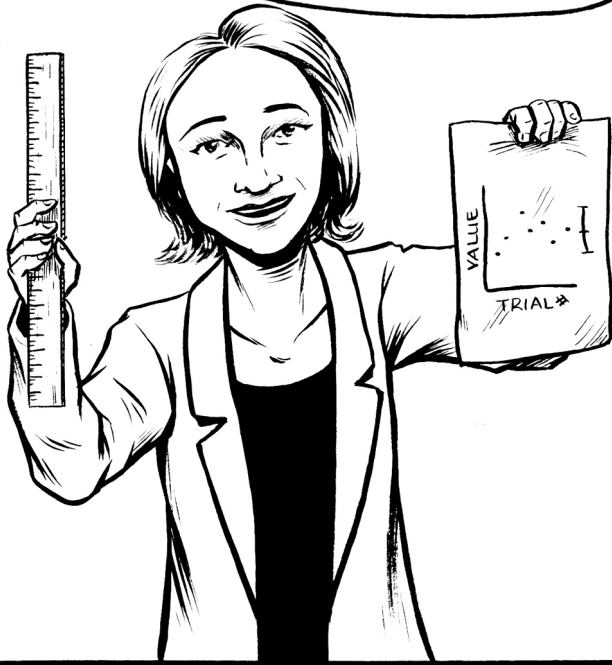


SO WHILE WE MIGHT HAVE THE SAME AVERAGE VALUE FOR THE DATA, BY PLOTTING THE UNCERTAINTY AS AN ERROR BAR, WE CAN UNDERSTAND HOW MUCH UNCERTAINTY IS PRESENT IN THAT AVERAGE VALUE.



ESSENTIALLY,
EVERY MEASUREMENT
HAS TWO
UNCERTAINTIES -

-THE MEASUREMENT
UNCERTAINTY BASED ON THE
TOOL YOU USED, AND THE
STANDARD DEVIATION BASED ON
ALL OF THE DATA YOU COLLECTED
WHICHEVER VALUE IS LARGER
IS THE VALUE YOU SHOULD
BE REPORTING-



-AND YOU **MUST**
REPORT UNCERTAINTY
WITH EACH REPORTED
DATA POINT FOR IT
TO BE ACCURATE!



UNCERTAINTY DOESN'T STOP THERE - BECAUSE ONCE YOU START ANALYZING YOUR DATA, YOU ARE LIKELY GOING TO USE RELATIONSHIPS BETWEEN DIFFERENT PROPERTIES TO CALCULATE VALUES OF NEW PROPERTIES. AND BECAUSE EACH VALUE THAT YOU ADD OR MULTIPLY TOGETHER MAY HAVE AN UNCERTAINTY ASSOCIATED WITH IT, YOU WILL NEED TO PROPAGATE THE ERROR!

CALCULATED
VALUE

$$R = X + Y - Z$$

MEASURED
VALUES

UNCER-
TAINTY
OF VALUE

$$\delta R \approx \delta X + \delta Y + \delta Z$$

UNCERTAINTIES
OF VALUES

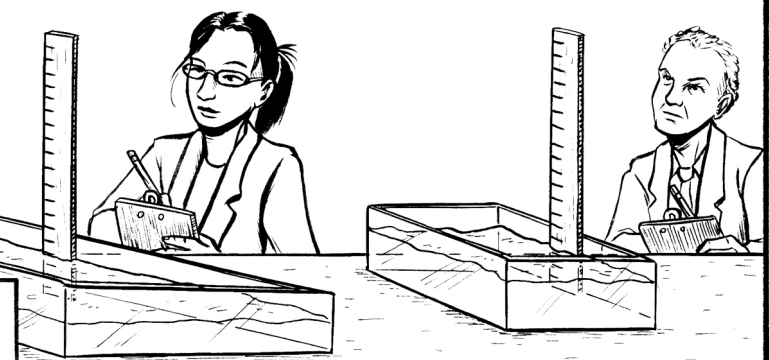
$$\delta R = \sqrt{(\delta X)^2 + (\delta Y)^2 + (\delta Z)^2}$$

$$R = \frac{X \times Y}{Z}$$

$$\frac{\delta R}{|R|} \approx \frac{\delta X}{|X|} + \frac{\delta Y}{|Y|} + \frac{\delta Z}{|Z|}$$

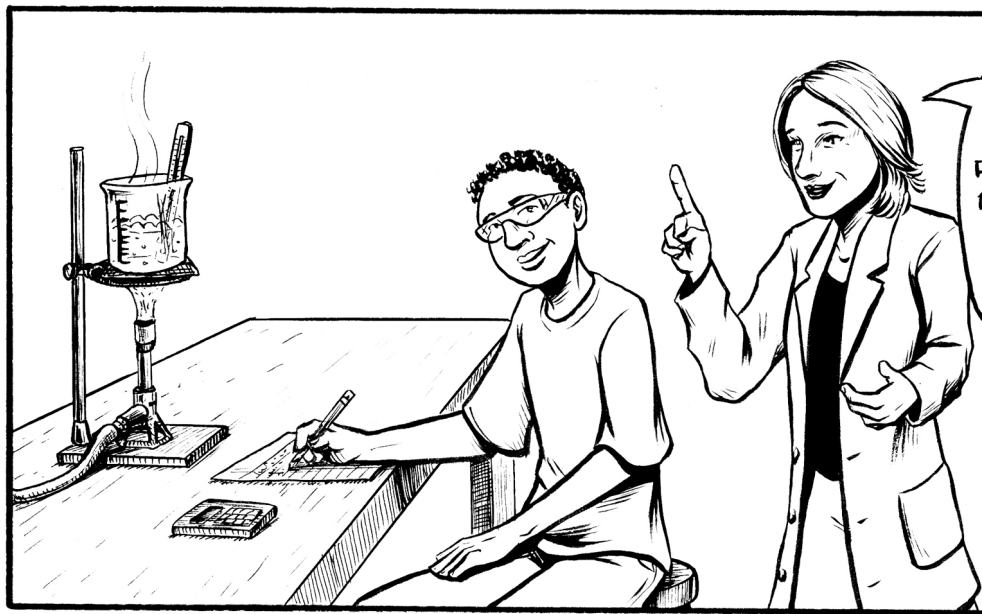
$$\delta R = |R| \times \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2}$$

PROPAGATION CAN CERTAINLY AFFECT YOUR EXPERIMENT! EVEN IF YOU ARE PRECISE WITH ONE MEASUREMENT, LARGE UNCERTAINTY WITH OTHER PARAMETERS CAN LEAD TO YOUR FINAL CALCULATED VALUE HAVING EXTREMELY HIGH UNCERTAINTY!



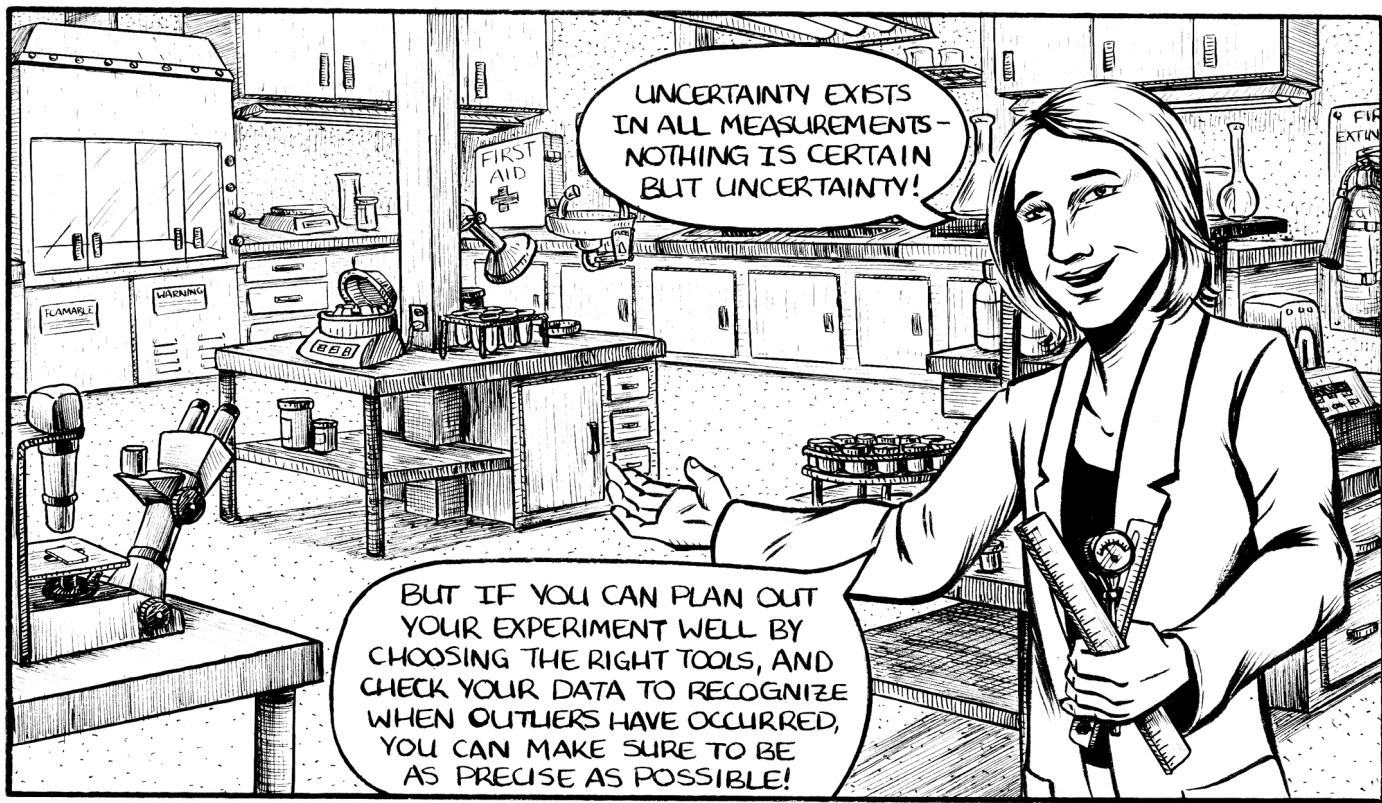
THERE ARE SIMILAR CONCERNS WITH CALIBRATION CURVES BASED ON THE PRECISION OF THE CALIBRATION DATA - BY PROPAGATING UNCERTAINTY FROM THE SLOPES OR COEFFICIENTS OF A CALIBRATION CURVE, ALL CALIBRATION CALCULATIONS WILL BE AFFECTED -

-SO BE AS PRECISE AS YOU CAN, EVEN FROM THE START OF THE EXPERIMENT!



IN GENERAL, IF YOU CAN LIMIT THE UNCERTAINTY IN YOUR FINAL VALUES TO LESS THAN 10 PERCENT OF YOUR ACTUAL VALUE, YOU'VE DONE A DECENT JOB WITH YOUR MEASUREMENTS AND EXPERIMENTS -

- AND IF YOU CAN LIMIT IT TO LESS THAN 5 PERCENT, YOU'VE DONE VERY WELL!



UNCERTAINTY EXISTS IN ALL MEASUREMENTS - NOTHING IS CERTAIN BUT UNCERTAINTY!

BUT IF YOU CAN PLAN OUT YOUR EXPERIMENT WELL BY CHOOSING THE RIGHT TOOLS, AND CHECK YOUR DATA TO RECOGNIZE WHEN OUTLIERS HAVE OCCURRED, YOU CAN MAKE SURE TO BE AS PRECISE AS POSSIBLE!