From Idea to Conclusion: A Statistical Perspective

The School for Science and Math at Vanderbilt
February 5, 2025

Want to follow along?

Coming Soon to Theaters

1. **Guest Lecture**: From Idea to Conclusion: A Statistical Perspective
   School of Science and Mathematics, Vanderbilt University
   February 2025
   Slides - Example

Click on the slides!

But first, who are we?

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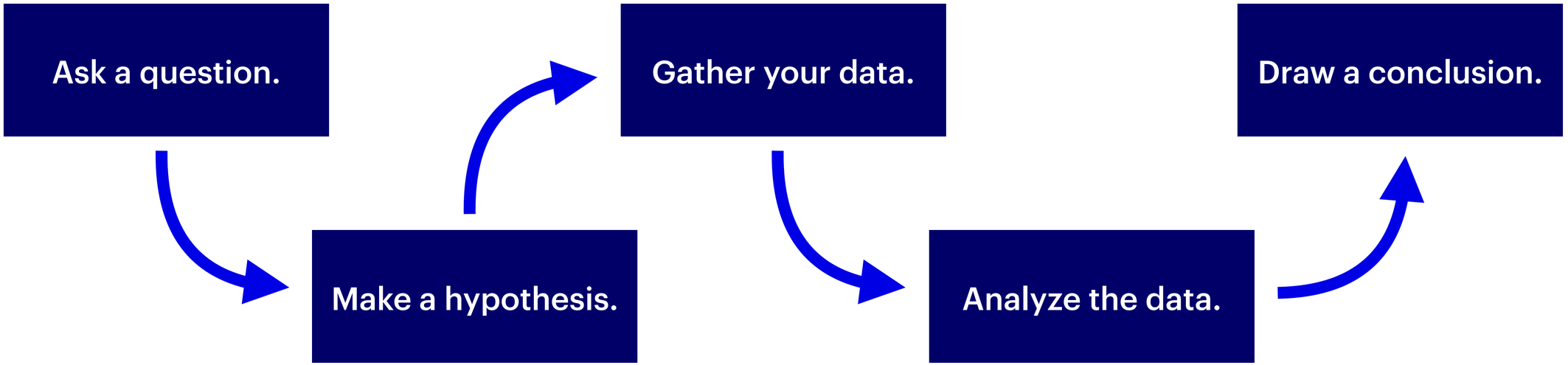
Department of Biostatistics

What's on the agenda for today?

1. Statistics & the Research Process: How do they fit together?
2. Your New Best Friend: y = mx + b
3. Interpretation: What do these numbers mean in context?
4. A Few Roadblocks & How to Get Around Them
5. Your Turn!

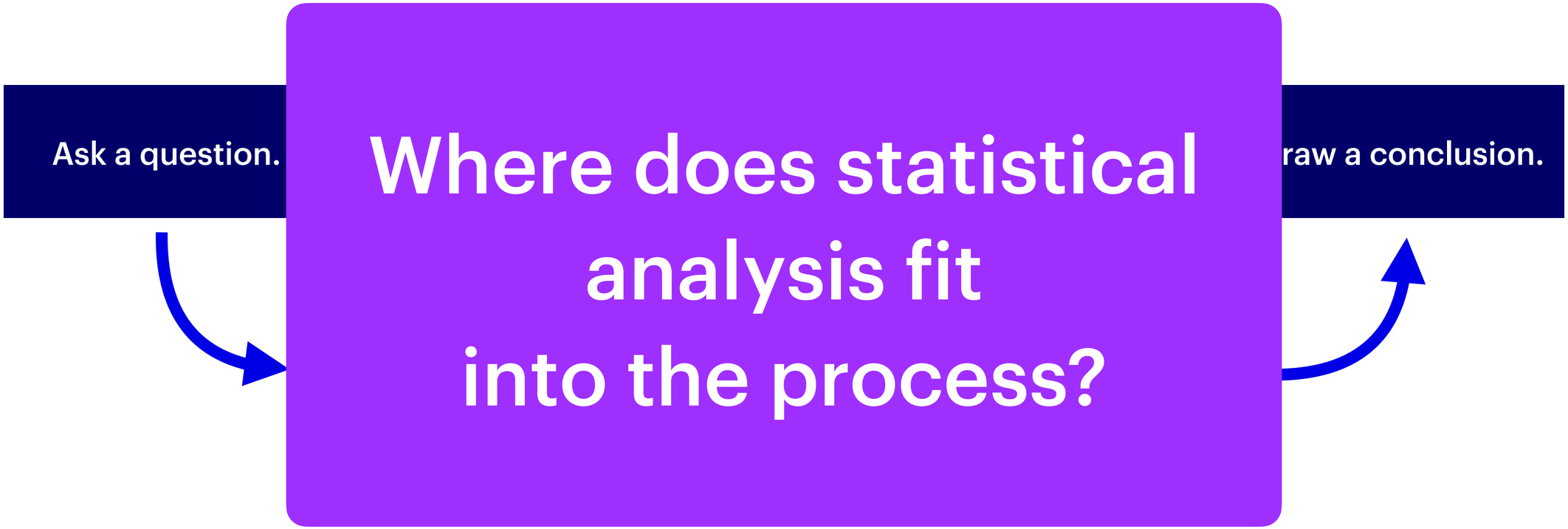
Statistics & the Research Process: How do they fit together?

Steps of the Research Process



https://www.amnh.org/explore/videos/the-scientific-process

Steps of the Research Process



https://www.amnh.org/explore/videos/the-scientific-process

Where do statistics fit into the process?

Ask a question. 20%

Make a hypothesis. 20%

Gather your data. 20%

Analyze the data. 20%

Draw a conclusion. 20%

the correct answer?

EVERYWHERE!

Step 1: Ask a question.

- Your question should be **specific** and **measurable**. Think about **who** we want to study, **what** we want to measure about them, and **how** we want to measure it.
- It’s ok if it doesn’t start out that way! We can always **refine** the question.

Does having fun make you do better in school?

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what’s wrong with this question?

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Do high school students do better in school if there are memes in their lessons?

did we fix it?

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getting better!

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Do high school students tend to have higher final grades if there are memes in their lessons?

how about now?

Step 1: Ask a question.

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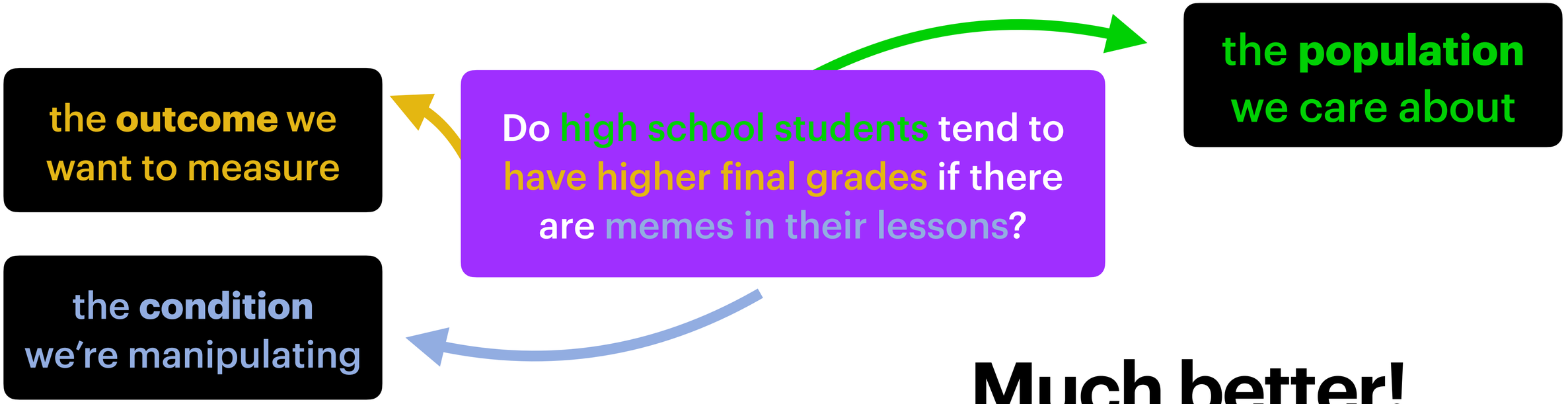
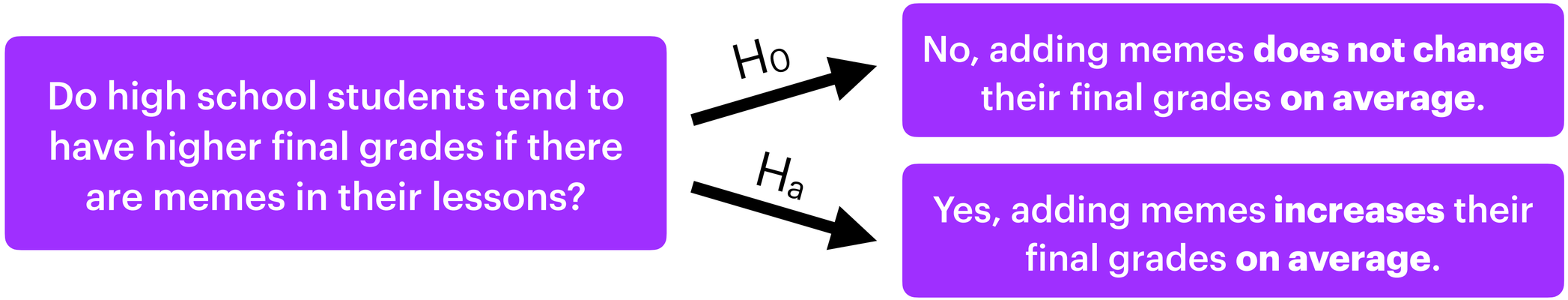


Much better!

Step 2: Make a hypothesis.

- A **hypothesis** is your best guess about what the answer to your question may be.
- We usually make two hypotheses, the **null hypothesis** and the **alternative hypothesis**.
- The **null hypothesis (H_0)** is the skeptical answer to your question.
- You hope to find evidence for the **alternative hypothesis (H_a)**.



Step 3: Gather your data.

- There are **many statistical considerations** to think about when you gather data.
- Some questions you might want to ask are:
  - **Who** am I sampling? Do I have any **criteria** for my subjects?
  - **How** am I sampling? Do I pick randomly? Am I trying to balance any factors?
  - **What measurements** am I recording for each subject? What's my **unit**?
  - **When** am I sampling? Do I have to make observations more than once per subject?
  - How do I set up my comparison? Is there a **control** group?

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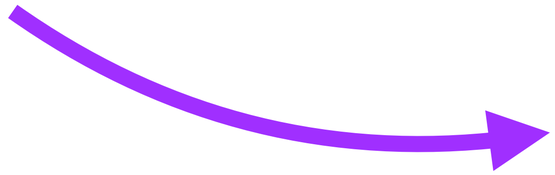
Step 4: Analyze the data.

- There are many different ways to analyze data, and your method depends on your audience!
- Sometimes, you might want to make a **graph** or a **table** summarizing your variables.
- You can run a **hypothesis test** or a **statistical model** to generate **quantitative evidence** that can help you decide which hypothesis makes more sense.
- You can make the jump from information about your **sample** to the larger **population** by using a **confidence interval**.



Don’t worry if these are new, more on these later!

Step 5: Draw a conclusion.

- Once you've made your case, go back and use the **evidence** you've gathered to answer your **original question**!
- Ask yourself if what you've measured is a **useful** comparison.
- Suppose we noticed that the average final grade in the memes class was an **A-**, but the students without memes only averaged a **B+**. Which hypothesis makes more sense?

Do high school students tend to have higher final grades if there are memes in their lessons?

H_0 → No, adding memes **does not change** their final grades **on average.**

H_a → Yes, adding memes **increases** their final grades **on average.**

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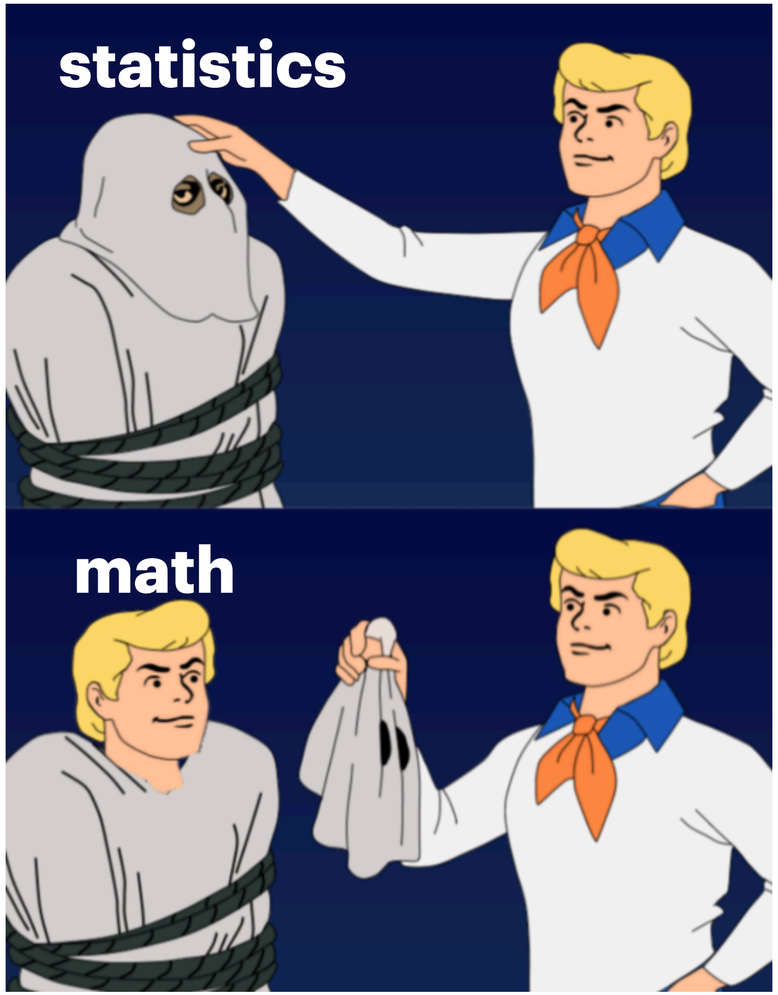
Your New Best Friend:

$$y = mx + b$$

But wait, wasn’t that the line of best fit from my math classes?



Translators to the rescue!

difference between groups (slope)

independent variable (predictor)

$$y = mx + b$$

dependent variable (outcome)

baseline outcome (intercept)

Translators to the rescue!

difference in final average grades

for memes: X = 1
no memes: X = 0

$$y = mx + b$$

average final grade

average final grade for the no meme group

What if other factors play a role?

what adding memes does to the grades

baseline grade (no memes and no iPads)

$$y = m_1x_1 + m_2x_2 + b$$

what using iPads does to the grades

What if other factors play a role?

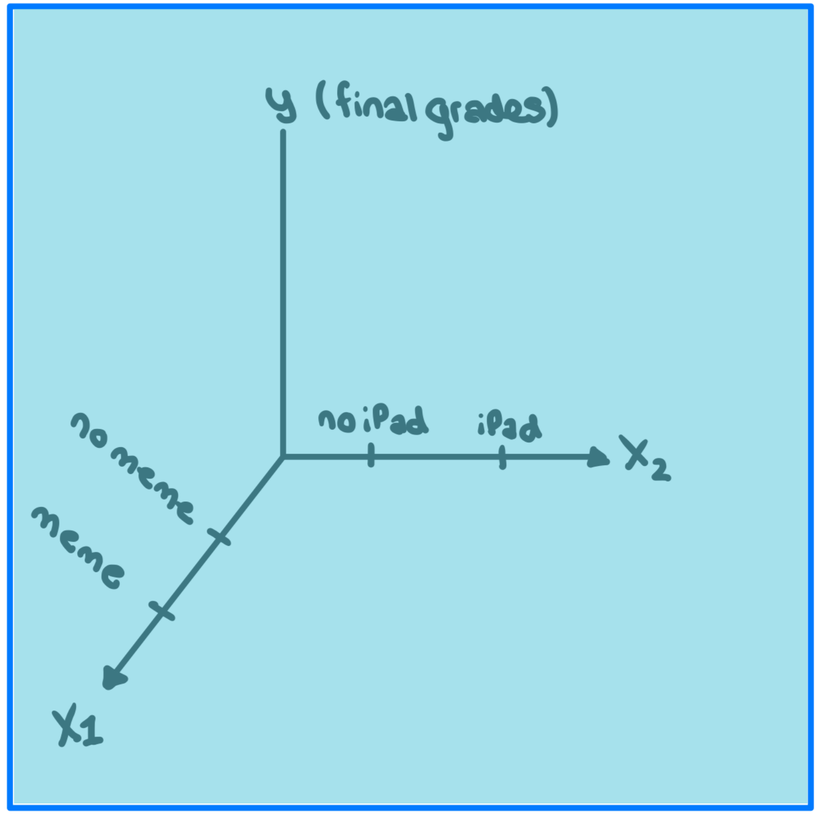
what adding

aseline grade (no

does to the g

emes and no iPads)

$$y = m_1$$

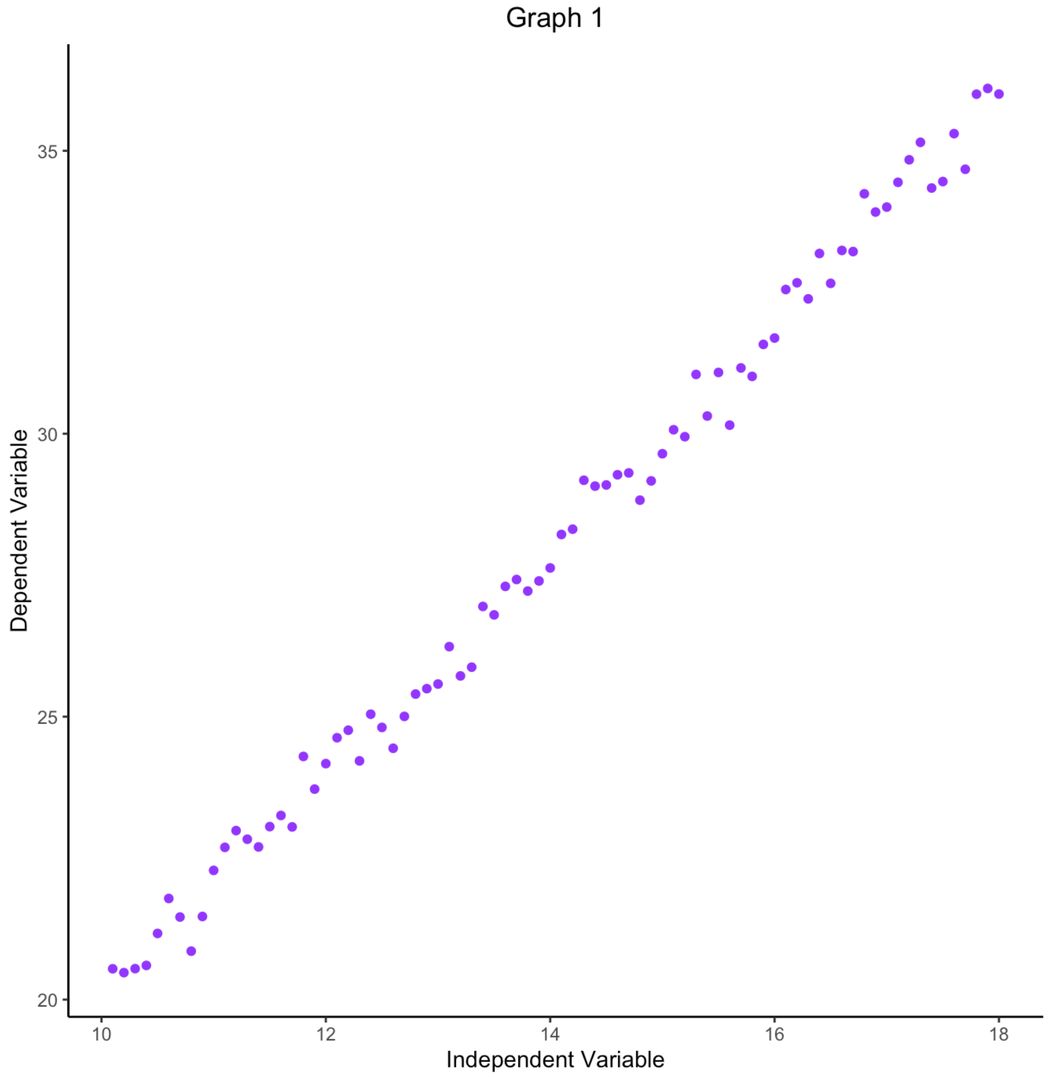


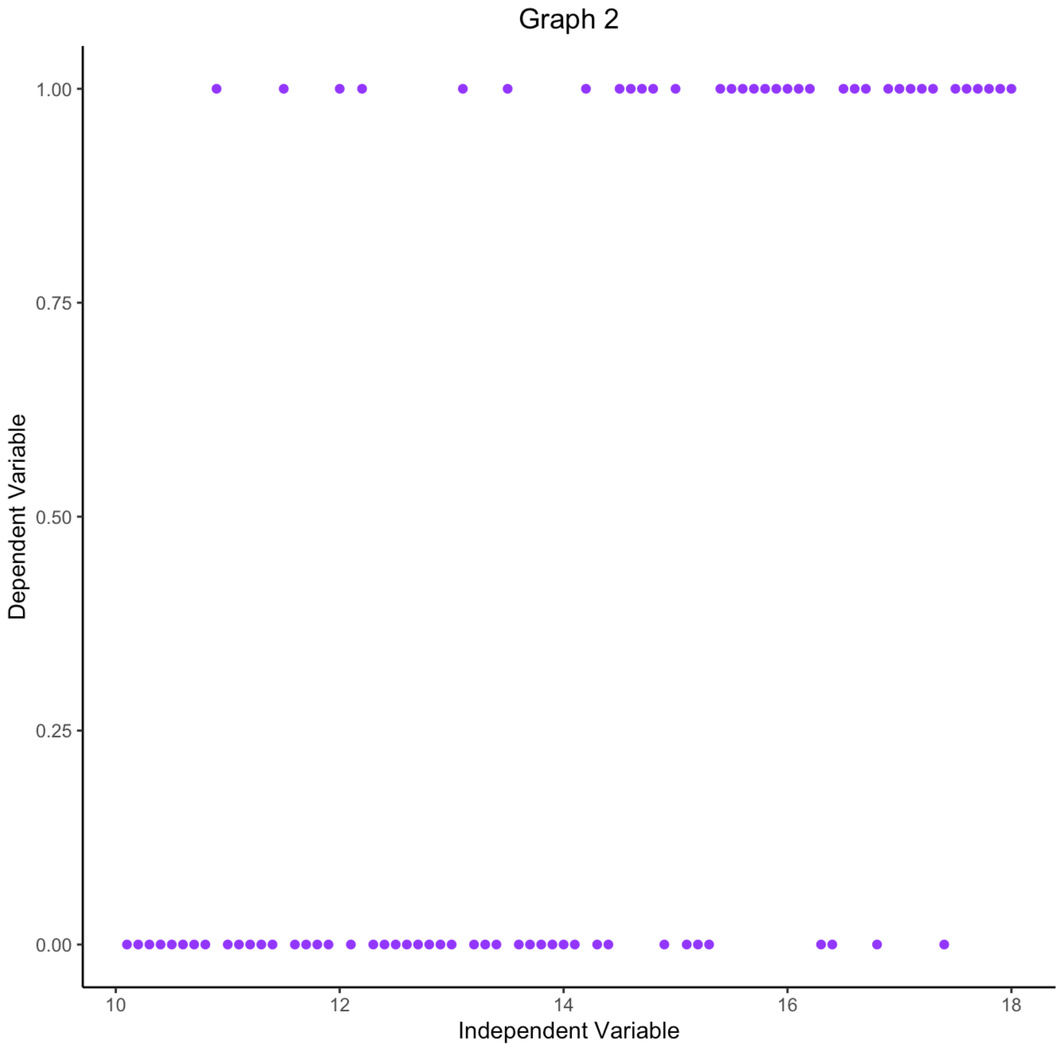
$$x_2 + b$$

s does

es

Is a line of best fit always the best idea?





🚨 New Question Alert: 🚨

Do high school students tend to pass their finals if there are memes in their lessons?

related to:

$$\frac{\text{odds of passing with memes}}{\text{odds of passing without memes}}$$

$$f(y) = mx + b$$

in this case:

$$\frac{\text{probability of passing}}{\text{probability of failing}}$$

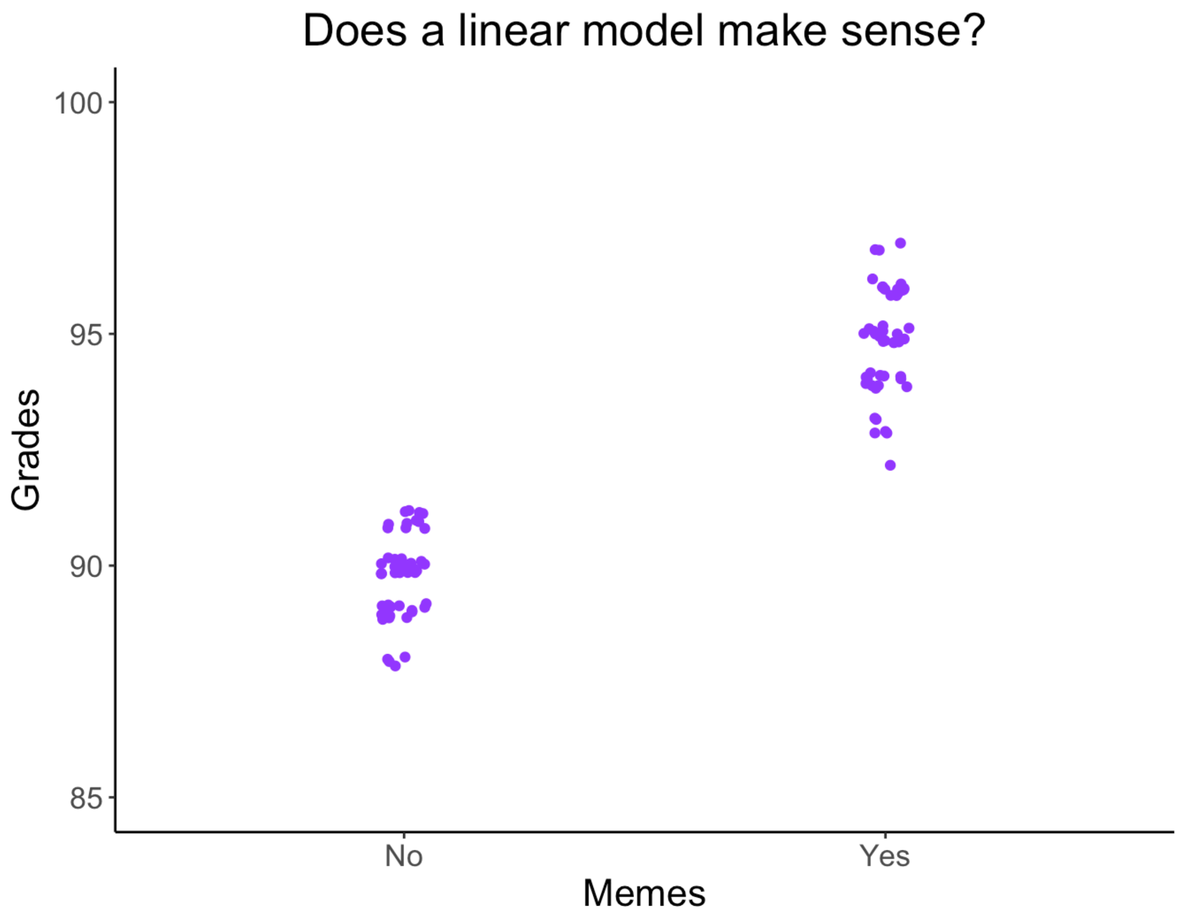
But what are odds?

$$\frac{\text{probability of outcome happening}}{\text{probability of outcome not happening}}$$

Interpretation: What do these numbers mean in context?

To Meme or Not to Meme

- We wanted to ask if high school students tend to have **higher final grades** if there are **memes** in their lessons.
- Here's some data from **100 hypothetical students** in 2 periods of the **same class**.
- The only difference between these two classes is that one period has **memes**!



Step 1: Peek* at your data.

*we kind of already did this another way too when we looked at the plot

- The **head()** command looks at the first few rows of your data.
- We tell it that the data is stored as **data_mg** and that we want to look at the first **6 rows**.
- This helps us understand how our data is **encoded**.
- How do we know that a student was in the meme class?

```
> head(data_mg, 6)
  memes grades
1     0     91
2     1     95
3     0     90
4     1     95
5     0     90
6     1     96
```

Step 2: Fit the model.

- We save the output of the **lm()** command (our model) as **linear_model**.
- We tell the lm() command which **formula** and **data** to use.
- Then, we can use **summary()** to print out some useful information about our model!
- Can you pick out what the model thinks “m” and “b” are?

```
> linear_model <- lm(formula = grades ~ memes, data = data_mg)
> summary(linear_model)

Call:
lm(formula = grades ~ memes, data = data_mg)

Residuals:
   Min     1Q Median     3Q    Max
 -2.86  -0.78   0.14   1.14   2.14

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  89.7800     0.1447  620.45   <2e-16 ***
memes         5.0800     0.2046   24.82   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.023 on 98 degrees of freedom
Multiple R-squared:  0.8628,    Adjusted R-squared:  0.8614
F-statistic: 616.2 on 1 and 98 DF,  p-value: < 2.2e-16
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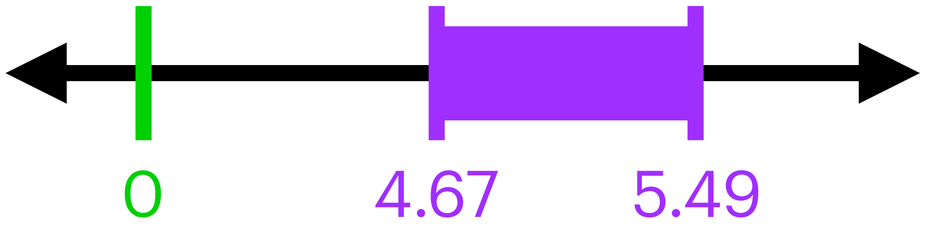
Step 3: Use the model!

- The **confint()** command takes our saved model and spits out a **confidence interval** for each estimated **parameter.**
- A **confidence interval (CI)** describes values that would **make sense** for our parameters according to our data!
- Our parameters are **m** and **b**, but what we cared about (the one in our null hypothesis) was **m**!
- If adding memes **doesn't change** the average final grades, then m should be **zero**.

pro tip: always report **both** the parameter **AND** the CI!

```
> confint(linear_model)
                2.5 %    97.5 %
(Intercept) 89.492843 90.067157
memes        4.673898  5.486102
```



Does our **95% confidence interval** catch our **null hypothesis**?

Step 4: Make a conclusion.

*The alpha level is 100% - CI%.

- If our **null hypothesis** is **outside** the confidence interval, we **reject** it (at an **alpha level*** we picked in advance).
- If our **null hypothesis** is **inside** the confidence interval, we **fail to reject** it (at that alpha level).
- Remember that “fail to reject” and “accept” do not mean the same thing!

- In our example, we estimate **m = 5.08** and **reject our null hypothesis!** We have evidence to suggest that memes in the notes increase the average final grade.

Step 5: Why does your conclusion matter?

- We hope for **significant** results, but there are two kinds of significance!
- If our results are **statistically significant**, that means we can reject our null hypothesis. Our data sample gives us evidence for the **alternative**!
- Statistics alone can’t help you determine if your results are **practically significant**. That requires **contextual knowledge!**
- In our example, we estimated that a meme group would do about **five points** better than a non meme group. This is our **effect size**.
- Pretend you’re the teacher. What’s the **minimum improvement** you’d want to see in your students’ grades before taking the time to put memes in all of your slides?

A Few Roadblocks & How to Get Around Them

Watch out, your data are rarely perfect!

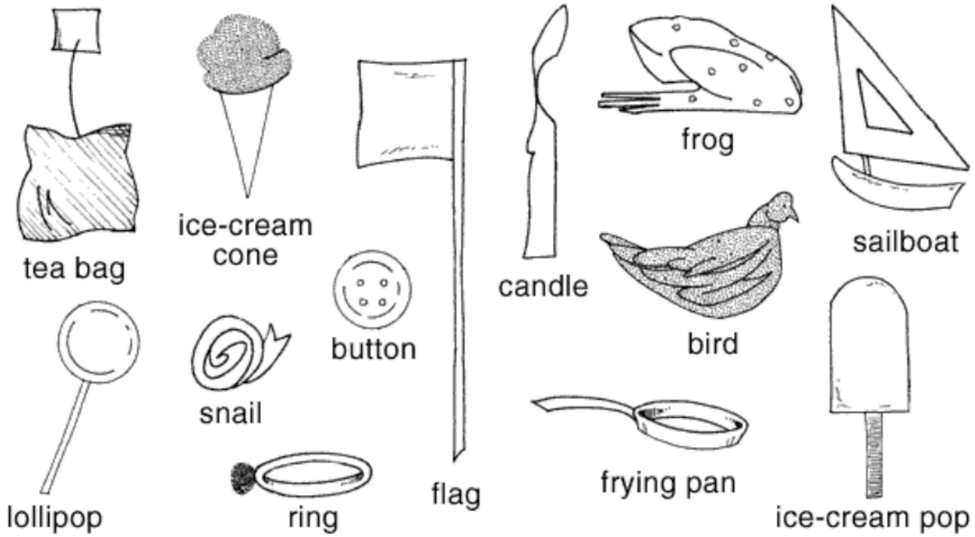
- It’s always important to **peek** at your data to see if there’s anything looking a little funny that you can easily fix.
- Look out for **missing values**! In R, something that’s missing will show up as an **NA**. Check with your research team to make sure you handle missingness **consistently**!
- Plot your data to check for **outliers**, or data points that are very different from the others. Since they behave **differently**, they might mess with your trend. Check with your team on how to handle them **consistently**!

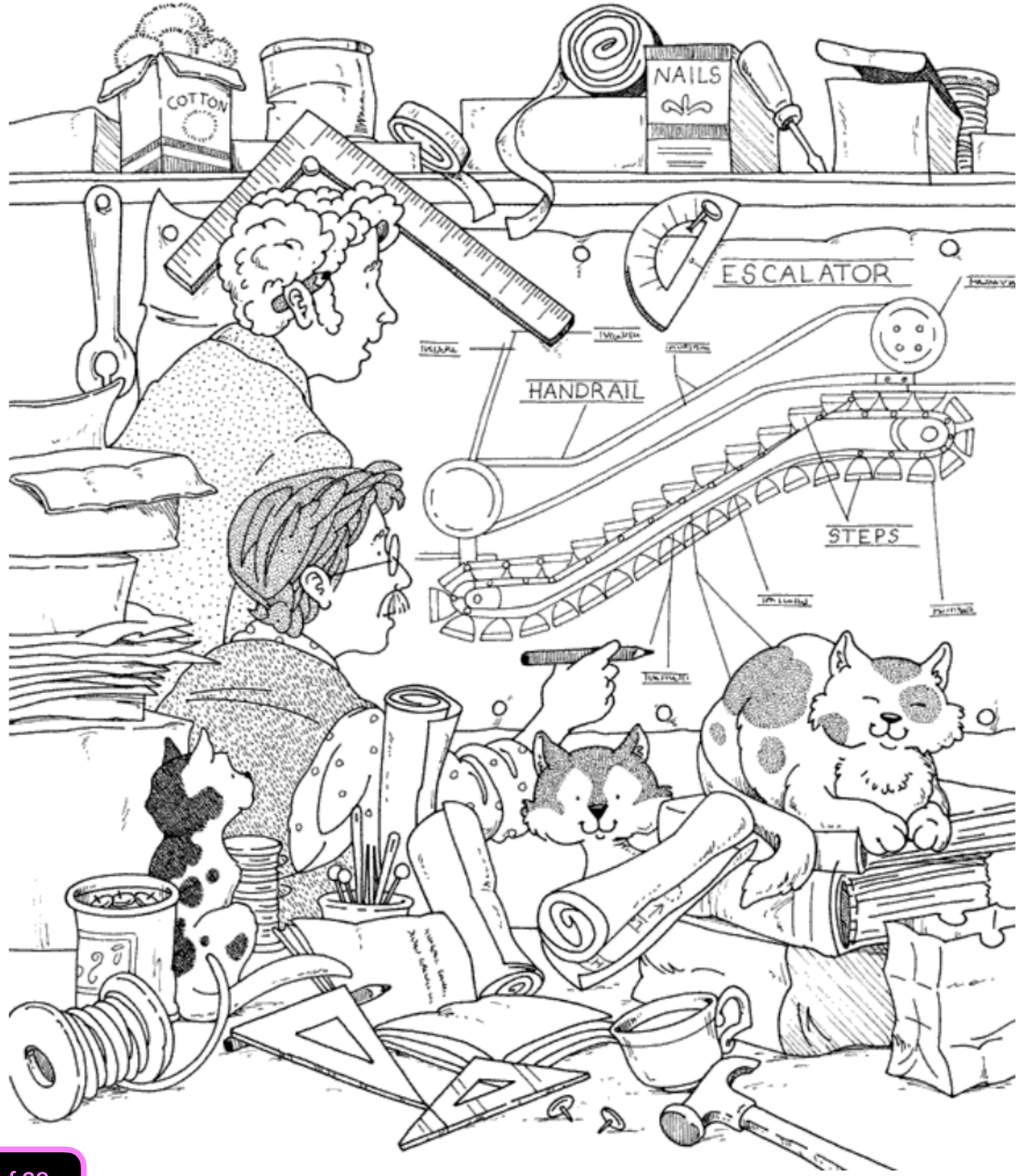
Watch out, your data are rarely perfect!

- Check and make sure your **encodings** match what you think they should be! For example, we could have encoded our glasses differently. If we had typed “Yes” instead of “1” in the spreadsheet, R might not **treat them the same way** in the model.
- Check for obvious **data errors**. For example, “yes” and “yasssss” might mean the same thing to you, but they don’t mean the same thing to a **computer**! You can always **manually fix** those before modeling.
- Always **keep a record** of any changes you make to your data!

Your Turn!

Can you find all 13?





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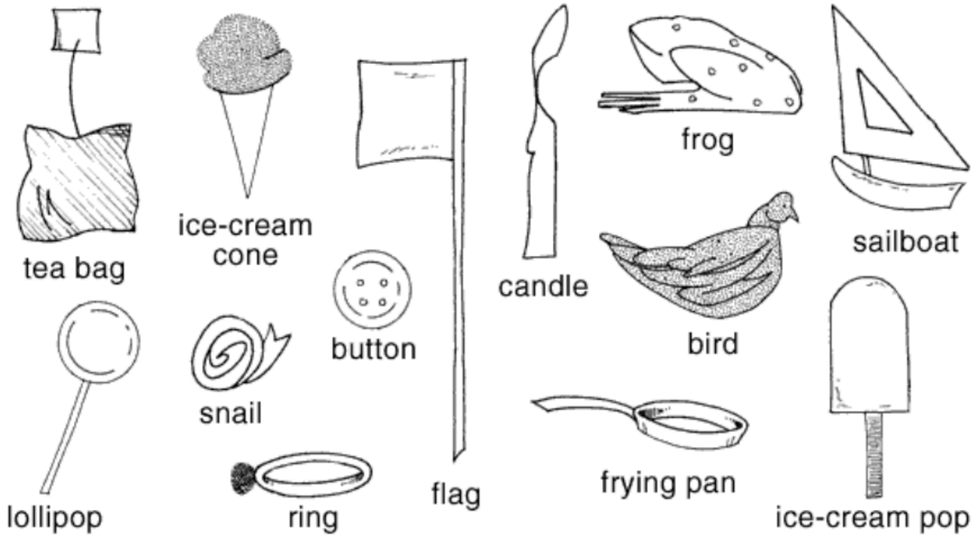

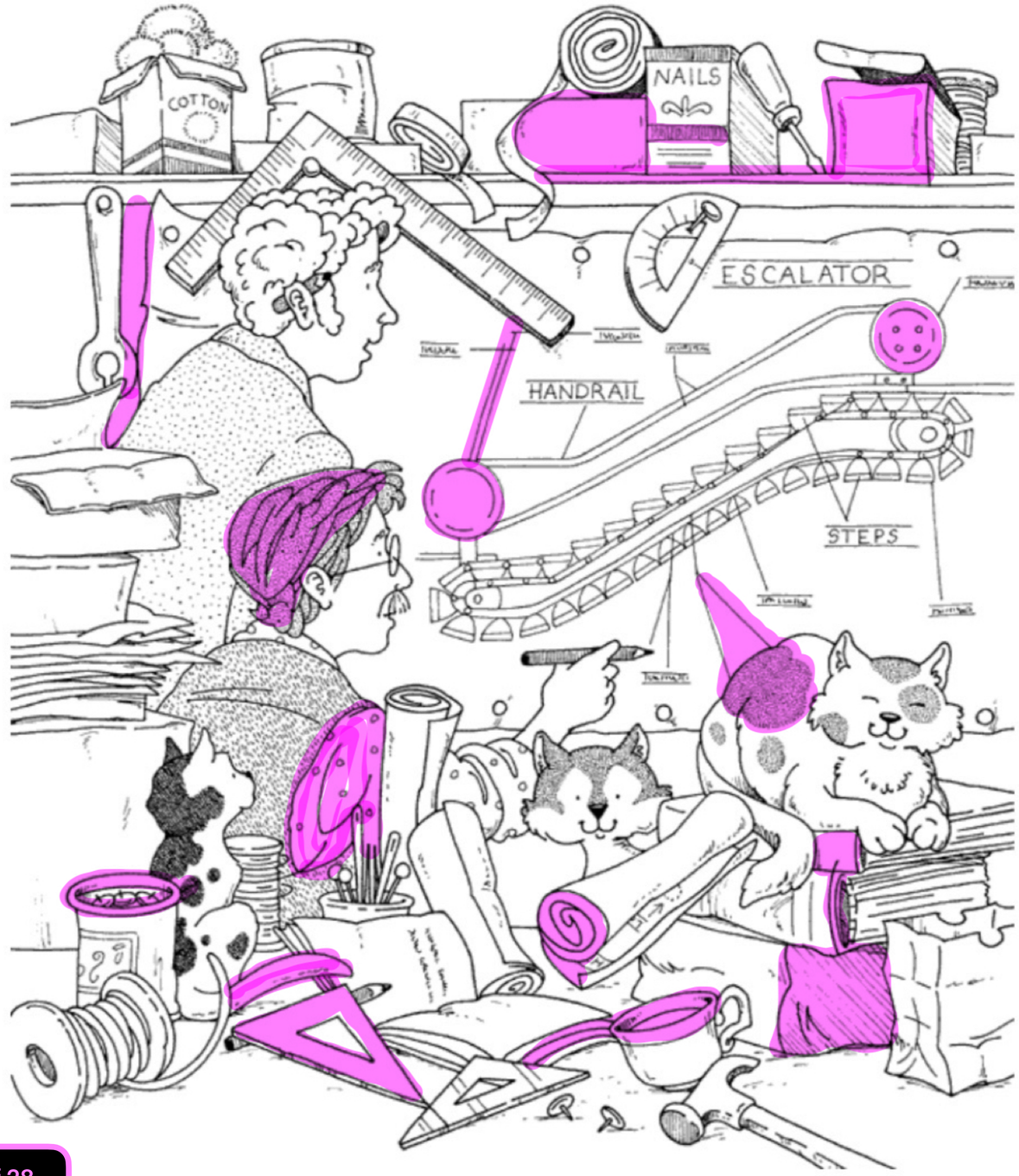

Let’s turn this into a research question about vision!

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Click “Example” and fill out a row in the spreadsheet!

We’ll code the model together.

Thanks for listening!