

```
# PHASE 1 -----
```

```
# DATA TIDYING (MISSINGNESS? FACTOR LEVELS?)
```

```
# No NAs:
```

```
summary(notes)  
is.na(notes) |> table()
```

```
# Convert to factors, and, assuming treatment coding, set reference levels.
```

```
notes <- notes |>  
  mutate(  
    medium = factor(medium, levels = c('Laptop', 'Longhand')),  
    study = factor(study, levels = c('No', 'Minimal', 'Moderate',  
    'Extensive'))  
  )
```

```
# GET SUMMARY STATS FOR RELEVANT VARIABLES
```

```
psych::describe(notes$test_score)  
table(notes$medium)  
table(notes$study)
```

```
# PLOT EACH VARIABLE INDIVIDUALLY
```

```
# Test score -- histogram:
```

```
notes |>  
  ggplot(aes(x = test_score)) +  
  geom_histogram()
```

```
# Study -- bar plot of counts
```

```
notes |>  
  ggplot(aes(x = study)) +  
  geom_bar()
```

```
# Medium -- bar plot of counts
```

```
notes |>  
  ggplot(aes(x = medium)) +  
  geom_bar()
```

```
# PLOT VARIABLES TOGETHER
```

```
# violin plot
```

```
notes |>  
  ggplot(aes(x = study, y = test_score, colour = study, fill = study)) +  
  geom_violin(alpha = 0.5) +  
  geom_jitter(alpha = 0.5) +  
  facet_wrap(~ medium) +  
  theme(legend.position = 'none')
```

```
# box plot
notes |>
  ggplot(aes(x = study, y = test_score, fill = medium)) +
  geom_boxplot()
```

SET UP CATEGORICAL PREDICTORS

```
# check contrasts
contrasts(notes$medium)
contrasts(notes$study)
```

FORMALLY STATE NULL AND ALTERNATIVE HYPOTHESES

```
# First, must write out mathematical model specification.
# Necessary so that we know which betas to hypothesise about.
# We'll shorten "medium" to "M" and "study" to "S"
```

```
$$
\text{test\_score} = \beta_0 +
(\beta_1 \cdot \text{medium}) +
(\beta_2 \cdot \text{study}_{\text{Minimal}}) +
(\beta_3 \cdot \text{study}_{\text{Moderate}}) +
(\beta_4 \cdot \text{study}_{\text{Extensive}}) + \backslash\backslash
(\beta_5 \cdot \text{medium} \cdot \text{study}_{\text{Minimal}}) +
(\beta_6 \cdot \text{medium} \cdot \text{study}_{\text{Moderate}}) +
(\beta_7 \cdot \text{medium} \cdot \text{study}_{\text{Extensive}}) +
\epsilon
$$
```

```
# RQ: Do **differences** in test scores between study conditions
# **differ** by the note-taking medium used?
```

```
# In words:
```

```
# - H0 would state that differences in test scores between study
# conditions **do not differ** by the note-taking medium used.
# - If H0 is true, all of the interaction terms are equal to zero.
# - If any of the interaction terms are significant, then we can
reject #H0.
```

```
Formally:
```

```
$$
H_{\{0\}} : \text{all } \beta_j = 0 \text{ for } j = 5, 6, 7 \backslash\backslash
H_{\{1\}} : \text{any } \beta_j \neq 0 \text{ for } j = 5, 6, 7
$$
```

THINK WHAT THE MODEL COEFS MIGHT LOOK LIKE

Model coefficients' meanings and, based on the plots, probable
values/signs (pos or neg):

- **β_0 , Intercept:**
 - **meaning:** estimated mean test score when medium = Laptop and study = No
 - **value:** probably just below 50
- **β_1 , effect of medium:**
 - **meaning:** specifically when study = No, how do test scores change between medium = Laptop and medium = Longhand?
 - **value:** probably small and positive
- **β_2 , effect of studyMinimal:**
 - **meaning:** specifically when medium = Laptop, how do test scores change between study = No and study = Minimal?
 - **value:** probably about twice the value of β_1 , positive
- **β_3 , effect of studyModerate:**
 - **meaning:** specifically when medium = Laptop, how do test scores change between study = No and study = Moderate?
 - **value:** a bit bigger than β_2 , positive
- **β_4 , effect of studyExtensive:**
 - **meaning:** specifically when medium = Laptop, how do test scores change between study = No and study = Extensive?
 - **value:** a bit bigger than β_3 , positive
- **β_5 , interaction between medium and studyMinimal:**
 - **meaning:** how does the difference between study = No and study = Minimal change, when we move from medium = Laptop to medium = Longhand?
 - **value:** probably close to zero (the difference between No and Minimal looks basically the same for both Laptop and Longhand)
- **β_6 , interaction between medium and studyModerate:**
 - **meaning:** how does the difference between study = No and study = Moderate change, when we move from medium = Laptop to medium = Longhand?
 - **value:** probably fairly large and positive (the jump from No to Moderate is bigger for Longhand than for Laptop, so we need a big positive adjustment)
- **β_7 , interaction between medium and studyExtensive:**
 - **meaning:** how does the difference between study = No and study = Extensive change, when we move from medium = Laptop to medium = Longhand?
 - **value:** probably even larger than β_6 and positive (the jump from No to Extensive is much bigger for Longhand than it is for Laptop, so we need a real big positive adjustment)

PHASE 2 -----

FIT MODEL

```
notes_md1 <- lm(test_score ~ medium * study, data = notes)
```

PHASE 3 -----

CHECK MODEL ASSUMPTIONS

normality of errors:

```
plot(notes_md1, which = 2)
```

equal variance of errors:

```
plot(notes_md1, which = 1)
```

RUN DIAGNOSTICS FOR MULTICOLLINEARITY

```
car::vif(notes_md1, type = 'predictor')
```

INTERPRET MODEL ESTIMATES

```
summary(notes_md1)
```

- **Intercept:**
 - estimated mean test score when medium = Laptop and study = No
- **mediumLonghand:**
 - specifically when study = No, test scores change by 2.9 points when we go from medium = Laptop to medium = Longhand
- **studyMinimal:**
 - specifically when medium = Laptop, test scores change by 7.5 points when we go from study = No to study = Minimal
- **studyModerate:**
 - specifically when medium = Laptop, test scores change by 11.2 points when we go from study = No to study = Moderate
- **studyExtensive:**
 - specifically when medium = Laptop, test scores change by 13.0 points when we go from study = No to study = Extensive
- **mediumLonghand:studyMinimal:**
 - when we move from medium = Laptop to medium = Longhand, the difference between study = No and study = Minimal changes by 2.4 points.
- **mediumLonghand:studyModerate:**
 - when we move from medium = Laptop to medium = Longhand, the difference between study = No and study = Moderate changes by 18.5 points.
- **mediumLonghand:studyExtensive:**
 - when we move from medium = Laptop to medium = Longhand, the difference between study = No and study = Extensive changes by 26.5 points.

GET ESTIMATED MARGINAL MEANS

```
notes_emm <- emmeans(notes_md1, ~ medium * study)
notes_emm
```

PLOT ESTIMATED MARGINAL MEANS

```
plot(notes_emm)
```

COMPUTE SIMPLE SLOPES/EFFECTS

```
pairs(
  notes_emm,
  simple = 'medium'
)
```

```
pairs(
  notes_emm,
  simple = 'study'
)
```

PLOT SIMPLE SLOPES/EFFECTS

```
cat_plot(
  notes_md1,
  pred = 'study',
  modx = 'medium',
  geom = 'line'
)
```

```
emmip(
  notes_emm,
  formula = medium ~ study,
  CIs = TRUE
)
```