Computing in the Statistics Curriculum: Lessons Learned from the Educational Sciences

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If you have found these slides online, here are talk videos

- UCSOTS talk (5 minutes): https://youtu.be/8kqlGHcnVNY
- JSM talk (15 minutes): https://youtu.be/ZsYJ81TwGW8

Computing is fundamental to contemporary statistical practice and scientific inquiry and should be explicitly taught

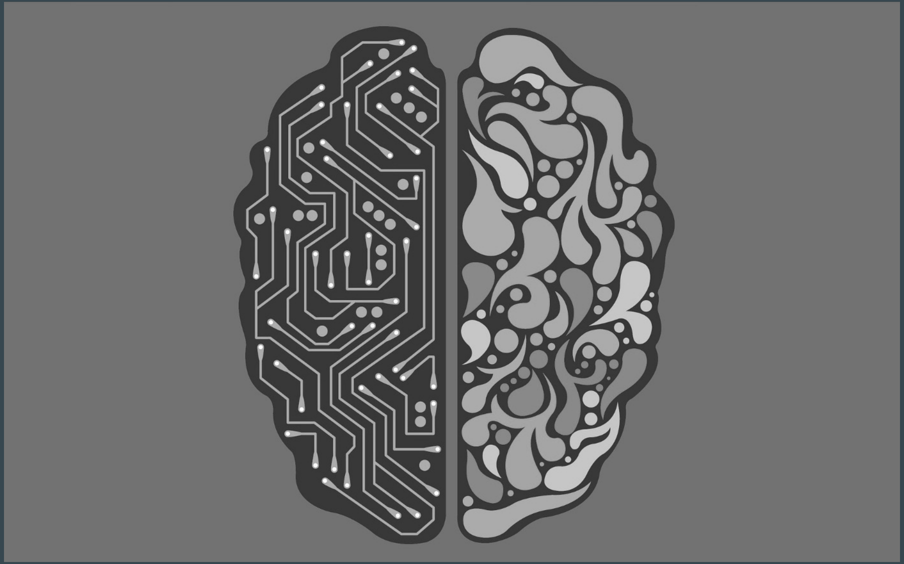
(ASA, 2017; Horton, 2015; NASEM, 2018; Nolan & Temple Lang, 2010)

Cognitive Load: Impediment to Learning

There is a finite amount of information that can be processed or stored in working memory at a time (cognitive load).

Different types of cognitive load (Hermans, 2021):

- *Intrinsic:* characteristics of the information being learned.
- *Extraneous:* the way information is presented.



Statistical Computing and Cognitive Load

- Statistical computing adds cognitive load to the learning process in statistics (e.g., Woodard & Lee, 2021)
    - Computational considerations
        - Syntax
        - Syntactical structure
        - Debugging
        - Computational thinking
    - Coding seems to be difficult for many students

- We can work to manage and lessen cognitive load by thoughtfully considering the specific coding content we teach and how we teach it.

Cognitive *Un*-loading: Make Purposeful Pedagogical Decisions

Pedagogical decisions need to be made about coding content.

- What logistical considerations do you need to account for?
- What will be taught (scope)?
- How will it be sequenced?

Example Pedagogical Decisions

- How will students compute in the course?
  - Desktop / Cloud / Both

- Where and when do students need practice with code?
  - In-class / out-of-class
  - Individual / group
  - Templates / Blank documents (RMD, R script)

- How will coding be introduced in class?
  - Live coding/ Worked examples / Group activities

- What code content do you start the course with?
  - Data structures (e.g., vectors, data frames) / “Cake” (data visualization, EDA)

Cognitive *Un*-loading: Use Consistent Syntactic Structure

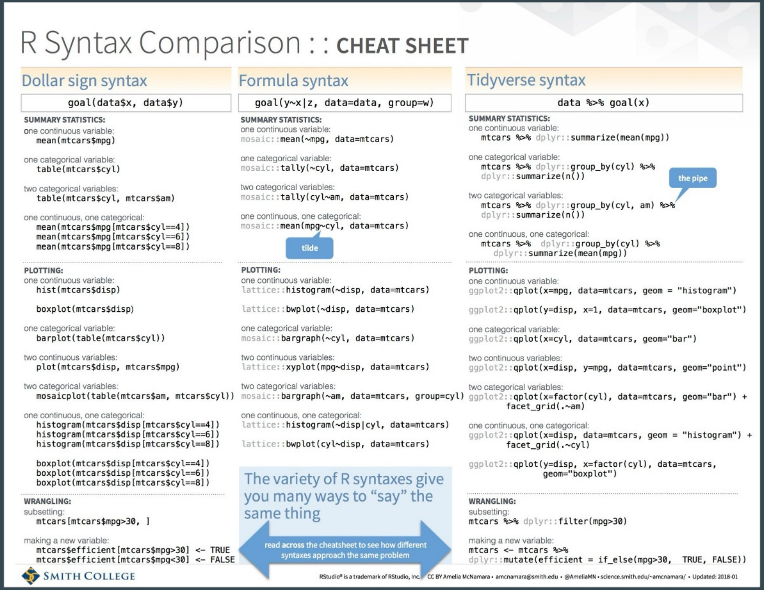
Using code with the same syntactic structure (common grammar) lessens cognitive load

- Can focus on learning new functions (verbs) and their purpose

Some syntactic structures can emphasize the relationship between syntax and concepts

- E.g., Roles of variables

Example Pedagogical Decision



R Syntax Comparison : : CHEAT SHEET

Dollar sign syntax

goal(data$x, data$y)

SUMMARY STATISTICS:

one continuous variable:
mean(mtcars$mpg)

one categorical variable:
table(mtcars$cyl)

two categorical variables:
table(mtcars$cyl, mtcars$am)

one continuous, one categorical:
mean(mtcars$mpg[mtcars$cyl==4])
mean(mtcars$mpg[mtcars$cyl==6])
mean(mtcars$mpg[mtcars$cyl==8])

PLOTTING:

one continuous variable:
hist(mtcars$disp)

boxplot(mtcars$disp)

one categorical variable:
barplot(table(mtcars$cyl))

two continuous variables:
plot(mtcars$disp, mtcars$mpg)

two categorical variables:
mosaicplot(table(mtcars$am, mtcars$cyl))

one continuous, one categorical:
histogram(mtcars$disp[mtcars$cyl==4])
histogram(mtcars$disp[mtcars$cyl==6])
histogram(mtcars$disp[mtcars$cyl==8])

boxplot(mtcars$disp[mtcars$cyl==4])
boxplot(mtcars$disp[mtcars$cyl==6])
boxplot(mtcars$disp[mtcars$cyl==8])

WRANGLING:

subsetting:
mtcars[mtcars$mpg>30,]

making a new variable:
mtcars$efficient[mtcars$mpg>30] <- TRUE
mtcars$efficient[mtcars$mpg<30] <- FALSE

Formula syntax

goal(y~x|z, data=data, group=w)

SUMMARY STATISTICS:

one continuous variable:
mosaic::mean(~mpg, data=mtcars)

one categorical variable:
mosaic::tally(~cyl, data=mtcars)

two categorical variables:
mosaic::tally(cyl~am, data=mtcars)

one continuous, one categorical:
mosaic::mean(mpg~cyl, data=mtcars)

tilde

PLOTTING:

one continuous variable:
lattice::histogram(~disp, data=mtcars)

lattice::bwplot(~disp, data=mtcars)

one categorical variable:
mosaic::bargraph(~cyl, data=mtcars)

two continuous variables:
lattice::xyplot(mpg~disp, data=mtcars)

two categorical variables:
mosaic::bargraph(~am, data=mtcars, group=cyl)

one continuous, one categorical:
lattice::histogram(~disp|cyl, data=mtcars)

lattice::bwplot(cyl~disp, data=mtcars)

The variety of R syntaxes give you many ways to "say" the same thing

read **across** the cheatsheet to see how different syntaxes approach the same problem

Tidyverse syntax

data %>% goal(x)

SUMMARY STATISTICS:

one continuous variable:
mtcars %>% dplyr::summarize(mean(mpg))

one categorical variable:
mtcars %>% dplyr::group_by(cyl) %>%
dplyr::summarize(n())

the pipe

two categorical variables:
mtcars %>% dplyr::group_by(cyl, am) %>%
dplyr::summarize(n())

one continuous, one categorical:
mtcars %>% dplyr::group_by(cyl) %>%
dplyr::summarize(mean(mpg))

PLOTTING:

one continuous variable:
ggplot2::qplot(x=mpg, data=mtcars, geom = "histogram")

ggplot2::qplot(y=disp, x=1, data=mtcars, geom="boxplot")

one categorical variable:
ggplot2::qplot(x=cyl, data=mtcars, geom="bar")

two continuous variables:
ggplot2::qplot(x=disp, y=mpg, data=mtcars, geom="point")

two categorical variables:
ggplot2::qplot(x=factor(cyl), data=mtcars, geom="bar") +
facet_grid(.~am)

one continuous, one categorical:
ggplot2::qplot(x=disp, data=mtcars, geom = "histogram") +
facet_grid(.~cyl)

ggplot2::qplot(y=disp, x=factor(cyl), data=mtcars,
geom="boxplot")

WRANGLING:

subsetting:
mtcars %>% dplyr::filter(mpg>30)

making a new variable:
mtcars <- mtcars %>%
dplyr::mutate(efficient = if_else(mpg>30, TRUE, FALSE))

SMITH COLLEGE

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- What syntax or packages will be used? In R:
  - base
  - formula (mosaic, ggformula, lattice)
  - tidyverse (ggplot2, dplyr)

Make a histogram of the bill_length_mm variable from the penguins dataset:

```
ggplot(penguins) + geom_histogram(aes(x = bill_length_mm))
histogram( ~ bill_length_mm, data = penguins)
gf_histogram( ~ bill_length_mm, data = penguins)
hist(penguins$bill_length_mm)
```

```
library(psych)

library(BHH2)

nhanes2017= read.csv("nhanes2017.csv", as.is = F)

table(nhanes2017$exerciseGT60)

par(mfrow = c(1, 2))

hist(nhanes2017$pulse[nhanes2017$exerciseGT60 == "YES"], xlim = c(min(nhanes2017$pulse), max(nhanes2017$pulse)))

hist(nhanes2017$pulse[nhanes2017$exerciseGT60 == "NO"], xlim = c(min(nhanes2017$pulse), max(nhanes2017$pulse)))

par(mfrow = c(1, 1))

tapply(nhanes2017$pulse, nhanes2017$exerciseGT60, summary)

tapply(nhanes2017$pulse, nhanes2017$exerciseGT60, describe)

t.test(pulse ~ exerciseGT60, data = nhanes2017)
```

Authentic example: Analyze the difference in pulse by exerciseGT60 from NHANES

```r
# Load libraries
library(psych)

# Import data
nhanes2017= read.csv("nhanes2017.csv")

# Get levels and sample sizes
table(nhanes2017$exerciseGT60)

# Plot histograms
par(mfrow = c(1, 2))
hist(nhanes2017$pulse[nhanes2017$exerciseGT60 == "YES"], xlim = c(min(nhanes2017$pulse), max(nhanes2017$pulse)))
hist(nhanes2017$pulse[nhanes2017$exerciseGT60 == "NO"], xlim = c(min(nhanes2017$pulse), max(nhanes2017$pulse)))
par(mfrow = c(1, 1))

# Compute summary statistics
tapply(nhanes2017$pulse, nhanes2017$exerciseGT60, FUN = describe)

# Carry out two-sample t-test
t.test(pulse ~ exerciseGT60, data = nhanes2017)
```

Use comments in your syntax

In RStudio turn on rainbow parentheses
Options > Code > Display

```r
# Load libraries
library(mosaic)

# Import data
nhanes2017 = read_csv("nhanes2017.csv")

# Get levels and sample sizes
tally(~ exerciseGT60, data = nhanes2017)

# Plot histograms
gf_histogram(~ pulse | exerciseGT60, data = nhanes2017)

# Compute summary statistics
favstats(~ pulse | exerciseGT60, data = nhanes2017)

# Carry out two-sample t-test
t_test(~ pulse | exerciseGT60, data = nhanes2017)
```

Mosaic Package
http://www.mosaic-web.org/mosaic/

The Most Important Template

The following template is important because we can do so much with it.

[ ] ([ ] ~ [ ] , data = [ ])

It is useful to name the components of the template:

goal (y ~ x , data = mydata)

We're hiding a bit of complexity in the template, and there will be times that we will want to gussy things up a bit. We'll indicate that by adding `...` to the end of the template. Just don't let `...` become a distractor early on.

goal (y ~ x , data = mydata , ...)

Cognitive *Un*-loading: An Example with Histograms in R

What you teach:

- `ggplot(penguins) + geom_histogram(aes(x = bill_length_mm))`
- `histogram( ~ bill_length_mm, data = penguins)`
- `gf_histogram( ~ bill_length_mm, data = penguins)`
- `hist(penguins$bill_length_mm)`

The order you teach it in:

- Variables -> Histograms -> R intro -> syntax
- R intro -> Variables -> Histograms -> syntax

How it's introduced:

- RMarkdown file with a worked example
- Live coding session
- Combination-- RMarkdown with some worked, some blanks

Cognitive *Un*-loading: Model Computational Thinking Norms

Modeling computational thinking and norms

- Debugging (e.g., McCauley et al., 2008)
- Normalizing emotional reactions to coding (e.g., Not panicking (e.g., DiNapoli, 2018))

Questions to help you revise how you teach coding:

- What syntactic structure makes the most sense for my students/course/goals?
- Is the code being presented to students consistent in its structure?
- How does new code connect with previous content?
- Will students see/use this code more than once?
  - **"Stitch in time saves 9"**
- How will students encounter code?
  - Live coding, scaffolded documents, cheatsheet?

Resources and Places to Start

- Introductory statistics labs in R, Amelia McNamara (formula or tidyverse)
- Speaking R, Amelia McNamara (guidance for live coding and reading code)
- Statistical Modeling and Computation for Educational Scientists, Andrew Zieffler (tidyverse)
- Simulation Based Inference, Randy Pruim (formula)
- Data Science in a Box, Mine Çetinkaya-Rundel (tidyverse)

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