

Engaging with MIDFIELD Data

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Chapter 1

Introduction

1.1 Objectives

MIDFIELD contains individual Student Unit Record (SUR) data for 1.7M students at 33 US institutions (as of June 2021). MIDFIELD is large enough to permit grouping and summarizing by multiple characteristics, enabling researchers to examine student characteristics (race/ethnicity, sex, prior achievement) and curricular pathways (including coursework and major) by institution and over time.

The goal of this workshop is to engage ASEE members with MIDFIELD data, in part using two R packages: **midfieldr** to provide tools for working with SURs and **midfelddata** to provide practice data.

By the end of the workshop, participants should be able to:

- Describe key variables in MIDFIELD data tables
- Explore and tell a story from MIDFIELD data
- Begin using R, **midfieldr**, and **midfelddata**
- Explain key features of effective data displays

1.2 Description

The robustness of the MIDFIELD data allows us to emphasize an intersectional approach to the study of student records, permitting multiple categories of inequity such as race/ethnicity and sex to be considered simultaneously.

To introduce beginners to R, participants work through a self-paced tutorial covering basic elements of the R computing language and environment. To introduce **midfieldr** and using it to work with student record data, participants

work through software tutorials that explore the SUR data and develop a persistence metric case study.

For more experienced R users or anyone working at a faster pace, we offer a series of self-paced tutorials that introduce key features of `midfieldr` and how they are applied to compute persistence metrics and graph results.

We also discuss the merits of the multiway graph design that is recommended for displaying results of this type. The agenda includes an interactive session to demonstrate contemporary principles of effective data display.

1.3 Pre-workshop homework

To get the most out of the workshop, you should have the essential software installed and running several days before the workshop to give you time to contact us with questions if anything goes amiss.

Install everything describes the homework.

1.4 Agenda

Our three hours are organized approximately as shown.

Min	Topic
15	Introduction
35	Exploring the data structure
35	Working with R
15	Break
20	Designing effective displays
50	Working with R (continued)
10	Next steps & assessing the workshop

1.5 Facilitators

Susan Lord Director of the MIDFIELD Institute and Professor and Chair of Integrated Engineering at the University of San Diego. She is a Fellow of the IEEE and the ASEE. Dr. Lord has considerable experience facilitating workshops including the National Effective Teaching Institute (NETI) and special sessions at FIE. (slord@san-diego.edu)

Matthew Ohland MIDFIELD Director and Principal Investigator. He is Professor and Associate Head of Engineering Education at Purdue University and a Fellow of IEEE, ASEE, and AAAS. Dr. Ohland has considerable experience facilitating workshops including the NETI and CATME training. (ohland@purdue.edu)

Marisa Orr MIDFIELD Associate Director and Associate Professor in Engineering and Science Education with a joint appointment in Mechanical Engineering at Clemson University. She received the 2009 Helen Plants Award for the best nontraditional session at FIE, “Enhancing Student Learning Using SCALE-UP Format.” (marisak@clemson.edu)

Richard Layton MIDFIELD Data Visualization Specialist and Professor Emeritus of Mechanical Engineering at Rose-Hulman Institute of Technology. He is the lead developer of the R packages used in this workshop. Dr. Layton has considerable experience facilitating workshops, including FIE workshops on data visualization (2014) and midfieldr (2018). (graphdoctor@gmail.com)

Russell Long MIDFIELD Managing Director and Data Steward. He developed the stratified data sample for the R packages used in this workshop. Mr. Long is a SAS expert with over twenty years of experience in institutional research and assessment. (ralong@purdue.edu)

1.6 Licenses

The following licenses apply to the text, data, and code in these workshops. Our goal is to minimize legal encumbrances to the dissemination, sharing, use, and re-use of this work. However, the existing rights of authors whose work is cited (text, code, or data) are reserved to those authors.

- CC-BY 4.0 for all text
- GPL-3 for all code
- CC0 for all data

1.7 Acknowledgement

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Chapter 2

Install everything

If you are trying R for the first time, it is vital that you attempt to set up your computer with the necessary software in advance or it will be difficult to keep up.

This chapter describes all of the pre-workshop homework:

- Already installed?
- Install R and RStudio
- Create a project

- Add some folders
- Install CRAN packages
- Install MIDFIELD packages

2.1 Already installed?

If you do not have R and RStudio installed, please skip this section and start with the next section. If you are already an R and RStudio user, this is a great time to check for updates.

Updating RStudio

- RStudio menu *Help > Check for Updates* will tell you if you are current or not.
- To update, close RStudio on your machine, download the new version from the RStudio website, and run the `RStudio-some-version-number.exe`. (Windows users *might* have to run the executable as an administrator.)

Update your packages

How to upgrade all out-of-date packages in *What They Forgot to Teach You About R* by Jennifer Bryan and Jim Hester.

Updating R

The easiest way to update R is to simply download the newest version. RStudio will automatically use the latest you've installed.

Alternatively, Windows users can use the `installr` package:

- Install the `installr` package
- If open, close R and RStudio
- Navigate to your most recent `Rgui.exe` file located in your Programs directory, e.g., `C:\Program Files\R\R-4.0.0\bin\x64\Rgui.exe`
- Right-click on `Rgui.exe` and run as administrator
- In the R GUI window that appears, run the commands

```
# Windows users only
library("installr")
updateR()
```

Updating your R library

How to transfer your library when updating R also by Bryan and Hester. Requires the `fs` package.

Once your updates are complete

Skip the next section and continue the homework with

- Create a project
- Add some folders
- Install CRAN packages
- Install MIDFIELD packages

2.2 Install R and RStudio

The first steps are to install R and RStudio. Windows users may have to login as an Administrator before installing the software.

- Install R for your operating system
- Install RStudio, a user interface for R

Once the installation is complete, you can take a 2-minute tour of the RStudio interface.

- Let's start (00:57–02:32) by R Ladies Sydney [Richmond, 2018]

The same video includes a longer (7 minute) tour of the four quadrants (panes) in RStudio if you are interested.

- The RStudio quadrants (07:21–14:40) by R Ladies Sydney [Richmond, 2018]

2.3 Create a project

To begin any project, we create an RStudio *Project* file and directory. You can recognize an R project file by its *.Rproj* suffix.

If you prefer your instructions with commentary,

- Start with a Project (02:34–04:50) by R Ladies Sydney [Richmond, 2018]

If you prefer basic written instructions,

- RStudio, *File > New Project... > New Directory > New Project*
- Or, click the *New Project* button in the Console ribbon,

In the dialog box that appears,

- Type the workshop name as the directory name, for example, **workshop**, or if you like more detail, **midfield-workshop-asee-2021**
- Use the browse button to select a location on your computer to create the project folder
- Click the *Create Project* button

Whenever you work with the workshop materials, launch the **workshop.Rproj** file (using the name you actually used) to start the session.

2.4 Add some folders

While file organization is a matter of personal preference, we ask that you use the directory structure shown here for your work in the workshop. Assuming we called our project **workshop**, the minimal directory structure has three folders in it plus the **.Rproj** file at the top level.

```
\workshop
  \data
  \results
  \scripts
  workshop.Rproj
```

We use the folders as follows:

- **data** data files
- **results** finished graphs and tabulated data formatted for display
- **scripts** R scripts that operate on data to produce results

To create folders:

- use your usual method of creating new folders on your machine
- or you can use the *New Folder* button in the Files pane

For a video guide,

- Make some folders (04:50–06:08) by R Ladies Sydney [Richmond, 2018]

2.5 Install CRAN packages

The fundamental unit of shareable code in R is the *package*. For the R novice, an R package is like an “app” for R—a collection of functions, data, and documentation for doing work in R that is easily shared with others [Wickham, 2014].

Most packages are obtained from the CRAN website [cra, 2018-04-22]. To install a CRAN package using RStudio:

- Launch RStudio

The RStudio interface has several panes. We want the *Files/Plots/Packages* pane.

- Select the *Packages* tab

Next,

- Click *Install* on the ribbon
- In the dialog box, type the name of the package. For our first package, type `data.table` to install the `data.table` package [Dowle and Srinivasan, 2021]
- Check the *Install dependencies* box
- Click the *Install* button

During the installation, Windows users might get a warning message about Rtools, something like:

```
WARNING: Rtools is required to build R packages but is
not currently installed. Please download and install the
appropriate version....
```

Rtools is needed for packages with C/C++/FORTRAN code from source—which does not apply to us. You may ignore the warning and carry on.

In the RStudio Console, you should see a message like this one,

```
package 'data.table' successfully unpacked and MD5 sums checked
```

If successful, the package will appear in the Packages pane, e.g.,

Repeat the process for the following packages

Once the Console prompt “>” reappears, you can confirm a successful installation by viewing the package help page. In the Console, run:

```
# type in the RStudio Console
library("midfielddata")
help("midfielddata-package")
```

If the installation is successful, the code chunk above should produce a view of the help page as shown here.

2.7 Exiting R and RStudio

When you exit R/RStudio, you probably get a prompt about saving your workspace image.

The answer is No.

You can turn this prompt off by using the pulldown menu,

- *Tools > Global Options...*
- In the dialog box, *Save workspace to .RData on exit*: Select “Never”

You finished your homework!

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Chapter 3

Working with R

R is an open source language and environment for statistical computing and graphics [R Core Team, 2021], ranked by IEEE in 2020 as the 6th most popular programming language (Python, Java, and C are the top three) [Cass, 2020]. If you are new to R, some of its best features, paraphrasing Wickham [2014], are:

- R is free, open source, and available on every major platform.
- R packages provide effective tools for data analysis and visualization.
- More than 17,750 open-source R packages are available (Jul 2021). Many are cutting-edge tools.

RStudio, an integrated development environment (IDE) for R, includes a console, editor, and tools for plotting, history, debugging, and workspace management as well as access to GitHub for collaboration and version control [RStudio Team, 2016].

3.1 Prerequisites

Before proceeding, you should have completed

- Install everything
- Launched your workshop project—`workshop.Rproj` or other name that you selected—to start the R session

With these prerequisites accomplished, and working in your RStudio `workshop.Rproj` project, you can create a save a script by:

- Use the pulldown menu, *File > New File > R Script*
- File menu > Save As...
- In the dialog box, navigate to your `scripts` directory, type a file name, for example, `01-R-basics.R` (file names in R can start with numerals),

and *Save*.

We suggest you start a new R script for each tutorial and save it to the **scripts** directory. For example, at the end of the workshop, your scripts directory might contain the following files:

```
\scripts
  \01-R-basics.R
  \02-getting-started.R
  \03-case-study-programs.R
  \04-case-study-students.R
  etc.
```

3.2 New to R?

Prerequisites should be completed before proceeding. By the end of the workshop, our R beginners will have made progress on two or possibly three tutorials:

- R basics An introduction to R.
- Getting started: Examine the MIDFIELD practice data
- Case study programs Gather CIP codes and program names

If there is still time remaining, continue to any tutorial listed in the After the workshop section.

3.3 Familiar with R?

Prerequisites should be completed before proceeding. By the end of the workshop, our more experienced R users will have made substantive progress on two or possibly three tutorials:

- Getting started: Examine the MIDFIELD practice data
- Case study programs Gather CIP codes and program names
- Case study students Gather students who pass the data sufficiency criterion.

If there is still time remaining, continue to any tutorial listed in the After the workshop section.

3.4 After the workshop

At this point, the learning is self-directed. Choose the skills you want to continue working on. We have a set of tutorials for

- Developing R skills

- Continuing the case study
- Exploring midfieldr functions

3.4.1 Developing R skills

The basic skills tutorials take about 50 minutes each.

- R basics
- Graph basics
- Data basics

3.4.2 Continuing the case study

The case study is a quick tour of a typical workflow using student unit record data. This is a “big picture” development—functions are used without detailed explanations or development so that we can focus on the logic of the analysis. For exploring midfieldr functions and methods in greater detail, see the vignettes listed in the next section.

- Case study programs
- Case study students
- Case study stickiness
- Case study graduation rate

3.4.3 Exploring midfieldr functions

Deep dive into the midfieldr functionality. The work flow follows the same general pattern as the quicker case study, but pauses to explore each function in more detail, exploring the arguments and strategies for use. In general, each tutorial is self-contained so you may enter at almost any point.

- Program codes and names Practice strategies of searching `cip` for programs we want to study.
- Subsetting MIDFIELD data Use programs codes to subset the MIDFIELD data tables.
- Data sufficiency What it is and how it is applied to student unit-record (SUR) data.
- Timely completion What it is and how it is applied to SUR data.
- FYE programs What they are and how they are accommodated with SUR data.
- Multiway graphs How to graph and interpret a common data structure encountered when working with SUR data.
- Tabulating data How to tabulate multiway data for publication.

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Chapter 4

R basics

This tutorial is an introduction to R adapted from [Healy, 2019b] with extra material from [Matloff, 2019]. If you already have R experience, you might still want to browse this section in case you find something new.

Prerequisites should be completed before proceeding. After that, the tutorial should take no longer than 50 minutes.

4.1 Style guide

A style guide is about making your script readable. We ask you to observe a small set of guidelines that will help us help you when you have questions about your script.

Comments in R are denoted by a hash tag #.

- Everything to the right of the hash tag is ignored by R.
- Comments that describe “why” are generally more useful than comments that explain “how.”

Spaces around operators. Use whitespace to enhance readability. Place spaces around operators (=, +, -, <-, etc.). Always put a space after a comma, but never before (just like in regular English).

```
# poor
height<-feet*12+inches
mean(x,na.rm=10)

# better
height <- (feet * 12) + inches
mean(x, na.rm = 10)
```

Use vertical white space. Lack of vertical white space makes your script harder to read (like a story with no paragraphs).

```
# Poor, no paragraph breaks
library("data.table"); library("GDAdata")
speed_ski <- copy(SpeedSki)
setDT(speed_ski)
speed_ski <- speed_ski[, .(Event, Sex, Speed)]
setnames(speed_ski, old = c("Event", "Sex", "Speed"), new = c("event", "sex", "speed"))
```

Instead, group chunks of code into paragraphs separated by blank lines to reveal the structure of the program. Comments at the start of a code chunk can explain your intent (like a topic sentence). Here we illustrate commenting on “why” rather than “how”.

```
# Better example with code in paragraphs

library("data.table")
library("GDAdata")

# Leave the original data unaltered before data.table conversion
speed_ski <- copy(SpeedSki)
setDT(speed_ski)

# Only three variables are required
speed_ski <- speed_ski[, .(Event, Sex, Speed)]

# Lowercase column names are our preferred style
setnames(speed_ski,
         old = c("Event", "Sex", "Speed"),
         new = c("event", "sex", "speed"))

# RDS format preserves factors
saveRDS(speed_ski, "data/speed_ski.rds")
```

For more information of R scripting style generally see McConnell [2004] and Wickham [2019].

4.2 Open an R script

Use *File > New File > R Script* to create a new R script

- Name the script 01-R-basics.R. By using a number at the start of the file name, the files stay in order in your directory.
- Save it in the `scripts` directory.
- Code chunks like the one below can be copied and pasted to your R script.

Add a minimal header at the top of the script. Use `library()` to load the packages we will be using.

```
# R basics
# name
# date

# packages
library("midfieldr")
library("data.table")
```

After adding a code chunk to your script, run the script. Options for running a script:

- To run an entire script, select all lines with `ctrl A` then run the lines using `ctrl Enter` (for the Mac OS: `cmd A` and `cmd Return`).
- To run select lines, use the cursor to select the lines you want to run, then `ctrl Enter` (for the Mac OS: `cmd Return`).
- To run from the beginning to a line, place your cursor at the line, then `ctrl alt B` (`cmd option B` Mac OS)

If you get an error similar to:

```
Error in library("data.table") : there is no package called 'data.table'
```

then the package needs to be installed. If you need a refresher on installing packages, see [Install CRAN packages](#). Once the missing package is installed, you can rerun the script.

The following code chunk is optional for controlling the number of rows of a data frame that are printed to the Console screen.

```
# Optional code to control data.table printing
options(
  datatable.print.nrows = 10,
  datatable.print.topn = 5,
  datatable.print.class = TRUE
)
```

Guidelines

- As you work through the tutorial, type a line or chunk of code then *File > Save* and run the script.
- Confirm that your result matches the tutorial result.
- **Your turn** exercises give you chance to devise your own examples and check them out. You learn by doing (but you knew that already)!

4.3 Everything in R has a name

In R, every object has a name.

- named entities, like `x` or `y`
- data you have loaded, like `my_data`
- functions you use, like `sin()`

Some names are forbidden

- reserved words, like `TRUE` or `FALSE`
- programming words, like `Inf`, `for`, `else`, and `function`
- special entities, like `NA` and `NaN`

Some names should not be used because they name commonly used functions

- `q()` quit
- `c()` combine or concatenate
- `mean()`
- `range()`
- `var()` variance

Names in R are case-sensitive

- `my_data` and `My_Data` are different objects
- We use the style of naming things in lower case with words separated by underscores (no spaces), e.g., `speed_ski`. The camel-case is also popular, e.g., `SpeedSki` or `speedSki`. The choice is yours.

If you want to know if a name has already been used in a package you have loaded, go to the RStudio console, type a question mark followed by the name, e.g.,

```
# Type in the Console
`? c()`
`? mean()`
```

If the name is in use, a help page appears in the RStudio Help pane.

4.4 Everything in R is an object

Origins of R objects

- Some objects are built in to R
- Some objects are loaded with packages
- Some objects are created by you

Type this line of code in your script, *Save*. `c()` is the function to combine or concatenate its elements to create a vector.

```
# Type in the R script
c(1, 2, 3, 1, 3, 25)
```

Run the script and your Console should show `[1] 1 2 3 1 3 25`.

In these notes, when we show results printed in your Console, we preface the printout with `#>` (which does not appear on your screen) to distinguish the results from the script. For example, we show the line from above and its output like this:

```
c(1, 2, 3, 1, 3, 25)      # <- typed in the script
#> [1] 1 2 3 1 3 25      # <- appears in the Console
```

The `[1]` that leads the output line is a label identifying the index of the element that starts that line. More on that in a little while.

You create objects by assigning them names.

- `<-` is the assignment operator, keyboard shortcut: `alt-` (Mac OS option-)

```
# Practice assigning an object to a name
x <- c(1, 2, 3, 1, 3, 25)
y <- c(5, 31, 71, 1, 3, 21, 6)
```

To see the result in the Console, type the object name in the script, *Save*, and run. (Remember, type the line of code but not the line prefaced by `#>`—that’s the output line so you can check your results.)

```
# Type in the R script or in the Console
x
#> [1] 1 2 3 1 3 25

y
#> [1] 5 31 71 1 3 21 6
```

Objects exist in your R project workspace, listed in the RStudio Environment pane

Data are also named objects. For example, `midfieldr` has several toy data sets included for use in illustrative examples like this one. Type its name in the script,

```
# Examine a data frame included with midfieldr
toy_student
#>           mcid      institution      transfer hours_transfer
#>           <char>           <char>           <char>           <num>
#> 1: MID25783939 Institution M First-Time in College           NA
```

```
#> 2: MID25784402 Institution M First-Time in College NA
#> 3: MID25805538 Institution M First-Time in College NA
#> 4: MID25808099 Institution M First-Time in College NA
#> 5: MID25816437 Institution M First-Time in College NA
#> ---
#> 96: MID26656134 Institution L First-Time in College NA
#> 97: MID26656367 Institution L First-Time in College NA
#> 98: MID26663803 Institution L First-Time in College NA
#> 99: MID26678321 Institution L First-Time in College NA
#> 100: MID26692008 Institution L First-Time in College NA
#>      race      sex
#>      <char> <char>
#> 1:      White Female
#> 2:      White  Male
#> 3:      White Female
#> 4:      White Female
#> 5:      White  Male
#> ---
#> 96: Native American  Male
#> 97: Hispanic/Latinx  Male
#> 98:  International  Male
#> 99:      White Female
#> 100:      White  Male
```

To view the help page for the data, type in the Console

```
# type in the Console
? toy_student
```

If we wanted the first five rows of the toy data, we use the `[]` operator.

```
# Practice using the '[' operator
toy_student[1:5]
#>      mcid      institution      transfer hours_transfer      race      sex
#>      <char>      <char>      <char>      <num> <char> <char>
#> 1: MID25783939 Institution M First-Time in College      NA White Female
#> 2: MID25784402 Institution M First-Time in College      NA White  Male
#> 3: MID25805538 Institution M First-Time in College      NA White Female
#> 4: MID25808099 Institution M First-Time in College      NA White Female
#> 5: MID25816437 Institution M First-Time in College      NA White  Male
```

To view the help page for the `[]` operator, surround the symbol with “back-ticks” (on your keyboard with the tilde `~` symbol). For example,

```
# view the help page on the R extract operator
? `[`
```

To extract a single column, e.g. the ID column, but preserve the data frame

structure,

```
# Subset a column as a data table
toy_student[, .(mcid)]
#>           mcid
#>      <char>
#>  1: MID25783939
#>  2: MID25784402
#>  3: MID25805538
#>  4: MID25808099
#>  5: MID25816437
#> ---
#> 96: MID26656134
#> 97: MID26656367
#> 98: MID26663803
#> 99: MID26678321
#> 100: MID26692008
```

We can also extract the column as a vector using slightly different syntax,

```
# Subset a column as a vector
toy_student[, mcid]
#>  [1] "MID25783939" "MID25784402" "MID25805538" "MID25808099" "MID25816437"
#>  [6] "MID25826223" "MID25828870" "MID25831839" "MID25839453" "MID25840802"
#> [11] "MID25841465" "MID25845841" "MID25846316" "MID25847220" "MID25848589"
#> [16] "MID25852023" "MID25853332" "MID25853799" "MID25877946" "MID25880643"
#> [21] "MID25887008" "MID25899243" "MID25911361" "MID25913454" "MID25931457"
#> [26] "MID25947836" "MID25982250" "MID25995980" "MID25997636" "MID26000057"
#> [31] "MID26004638" "MID26013461" "MID26020535" "MID26046521" "MID26048632"
#> [36] "MID26060301" "MID26062203" "MID26062778" "MID26086310" "MID26088450"
#> [41] "MID26102824" "MID26136319" "MID26138017" "MID26152744" "MID26161677"
#> [46] "MID26170598" "MID26173721" "MID26181209" "MID26187436" "MID26204281"
#> [51] "MID26211998" "MID26235812" "MID26244053" "MID26247839" "MID26305709"
#> [56] "MID26305863" "MID26309255" "MID26319252" "MID26332563" "MID26356320"
#> [61] "MID26358462" "MID26370377" "MID26383411" "MID26384771" "MID26391215"
#> [66] "MID26400804" "MID26413466" "MID26417039" "MID26418247" "MID26421588"
#> [71] "MID26421846" "MID26422829" "MID26429192" "MID26433811" "MID26435945"
#> [76] "MID26439623" "MID26441609" "MID26453554" "MID26461158" "MID26481120"
#> [81] "MID26526195" "MID26528318" "MID26546600" "MID26560837" "MID26561940"
#> [86] "MID26575282" "MID26577489" "MID26578111" "MID26588553" "MID26592425"
#> [91] "MID26592668" "MID26596818" "MID26605008" "MID26607528" "MID26655230"
#> [96] "MID26656134" "MID26656367" "MID26663803" "MID26678321" "MID26692008"
```

Here you can see how the row labels in the printed output work. There are 5 IDs per row, so the second row starts with the 6th ID, indicated by [6]. The last row starts with the 96th value [96] and ends with the 100th value.

The “toy” data sets in `midfieldr` (`toy_student`, `toy_course`, `toy_term`, and

`toy_degree`) include student unit records for only 100 students—not a statistically representative sample—used for package examples like those above.

4.5 R functions do things

Functions do something useful

- Functions are objects that perform actions for you
- Functions produce output based on the input it receives
- Functions are recognized by the parentheses at the end of their names

The parentheses are where we include the inputs (arguments) to the function

- `c()` concatenates the comma-separated numbers in the parentheses to create a vector
- `mean()` computes the mean of a vector of numbers
- `sd()` computes the standard deviation of a vector of numbers
- `summary()` returns a summary of the object

If we try `mean()` with no inputs, we get an error statement

```
mean()
#> Error in mean.default() : argument "x" is missing, with no default
```

Let's determine some summary statistics on our student transfer hours. Add these lines to your script, *Save*, and run.

```
# Extract a column as a vector
transfer_hours <- toy_student[, hours_transfer]

# Examine the vector
transfer_hours
#> [1] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA 30 55 NA 24 NA NA NA
#> [26] NA NA NA NA 4 NA 2 NA NA NA 1 7 1 3 1 5 NA NA NA NA NA NA NA NA NA NA
#> [51] NA NA NA NA NA NA NA NA NA NA NA 80 NA NA NA NA NA NA NA NA NA NA NA NA NA
#> [76] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA

# Operate on the vector
mean(transfer_hours)
#> [1] NA
```

We have to set the optional argument `na.rm` (“remove NA”) to take a mean

```
# Operate and ignore NA values
mean(transfer_hours, na.rm = TRUE)
#> [1] 17.75

# Another operation
sd(transfer_hours, na.rm = TRUE)
```

```
#> [1] 25.63068

# The summary also shows the count of NAs
summary(transfer_hours)
#>      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.     NA's
#>      1.00   1.75   4.50   17.75   25.50   80.00     88
```

Functions to examine a data frame.

- `names()` Data frame column names
- `head()` and `tail()` First few and last few rows of a data frame

```
# Practice finding column names
names(toy_student)
#> [1] "mcid"          "institution"    "transfer"       "hours_transfer"
#> [5] "race"          "sex"

# Practice examining the first few rows of a data frame
head(toy_student)
#>      mcid  institution      transfer hours_transfer  race  sex
#>      <char>      <char>      <char>      <num> <char> <char>
#> 1: MID25783939 Institution M First-Time in College      NA White Female
#> 2: MID25784402 Institution M First-Time in College      NA White  Male
#> 3: MID25805538 Institution M First-Time in College      NA White Female
#> 4: MID25808099 Institution M First-Time in College      NA White Female
#> 5: MID25816437 Institution M First-Time in College      NA White  Male
#> 6: MID25826223 Institution M First-Time Transfer      NA White Female

# Practice examining the last few rows of a data frame
tail(toy_student)
#>      mcid  institution      transfer hours_transfer
#>      <char>      <char>      <char>      <num>
#> 1: MID26655230 Institution L First-Time in College      NA
#> 2: MID26656134 Institution L First-Time in College      NA
#> 3: MID26656367 Institution L First-Time in College      NA
#> 4: MID26663803 Institution L First-Time in College      NA
#> 5: MID26678321 Institution L First-Time in College      NA
#> 6: MID26692008 Institution L First-Time in College      NA
#>      race  sex
#>      <char> <char>
#> 1:      White Female
#> 2: Native American  Male
#> 3: Hispanic/Latinx  Male
#> 4: International  Male
#> 5:      White Female
#> 6:      White  Male
```

Functions to examine columns (variables) in a data frame.

- `sort()` and `unique()` often used together
- `is.na()` to return TRUE for every NA element in an object, otherwise TRUE
- `sum()` applied to `is.na()` converts logical TRUE to 1 and FALSE to 0 and adds the elements. The resulting integer is the number of NA values in the vector.

```
# Determine the unique values in a column
sort(unique(toy_student[, sex]))
#> [1] "Female" "Male"

# Find the rows with NA values.
is.na(toy_student[, sex])
#> [1] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [13] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [25] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [37] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [49] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [61] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [73] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [85] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
#> [97] FALSE FALSE FALSE FALSE

# How many values are NA?
sum(is.na(toy_student[, sex]))
#> [1] 0
```

Repeat for other columns.

```
# Practice examining another column
sort(unique(toy_student[, institution]))
#> [1] "Institution A" "Institution B" "Institution C" "Institution D"
#> [5] "Institution E" "Institution F" "Institution G" "Institution H"
#> [9] "Institution J" "Institution K" "Institution L" "Institution M"
sum(is.na(toy_student[, institution]))
#> [1] 0

# Practice examining another column
sort(unique(toy_student[, race]))
#> [1] "Asian" "Black" "Hispanic/Latinx" "International"
#> [5] "Native American" "Other/Unknown" "White"
sum(is.na(toy_student[, race]))
#> [1] 0

# Practice examining another column
```

```
sort(unique(toy_student[, hours_transfer]))
#> [1] 1 2 3 4 5 7 24 30 55 80
sum(is.na(toy_student[, hours_transfer]))
#> [1] 88
```

The help pages for functions are accessed via the Console. By viewing the help page you can find descriptions of arguments and their default settings if any. Try a few:

- ? mean()
- ? sd()
- ? summary()
- ? names()
- ? head()
- ? sort()
- ? unique()
- ? is.na()
- ? sum()

4.6 R functions come in packages

Functions are bundled in packages

- Families of useful functions are bundled into packages that you can install, load, and use
- Packages allow you to build on the work of others
- You can write your own functions and packages too
- A lot of the work in data science consists of choosing the right functions and giving them the right arguments to get our data into the form we need for analysis or visualization

For example, to see the list of functions in the `midfieldr` package,

```
# Showing all functions in the midfieldr package
sort(getNamespaceExports("midfieldr"))
#> [1] "add_completion_timely" "add_data_sufficiency" "add_institution"
#> [4] "add_race_sex"          "add_timely_term"      "condition_fye"
#> [7] "condition_multiway"    "filter_match"         "filter_search"
```

To view a help page, type, e.g.,

```
# Type in the Console to view a help page
? add_race_sex()
```

In contrast, do the same for the `data.table` package,

```
# A package with many functions.
sort(getNamespaceExports("data.table"))
```

```
#> [1] "%between%"      "%chin%"          "%flike%"
#> [4] "%ilike%"         "%inrange%"       "%like%"
#> [7] ".__C__data.table" ".__C__IDate"     ".__C__ITime"
#> [10] ".__T__$:base"    ".__T__$<:-:base" ".__T__$[:base"
#> [13] ".__T__$[<:-:base" ".__T__$[<:-:base" ".BY"
#> [16] ".EACHI"         ".GRP"            ".I"
#> [19] ".Last.updated"  ".N"              ".NGRP"
#> [22] ".rbind.data.table" ".SD"             "!="
#> [25] "address"        "alloc.col"       "as.data.table"
#> [28] "as.IDate"       "as.ITime"        "as.xts.data.table"
#> [31] "between"       "chgroup"         "chmatch"
#> [34] "chorder"       "CJ"              "copy"
#> [37] "cube"          "data.table"      "dcast"
#> [40] "dcast.data.table" "fcase"           "fcoalesce"
#> [43] "fifelse"       "fintersect"      "first"
#> ... etc. truncated
```

Don't panic! We will use only a small number of these functions from `data.table`. For example, the `%ilike%` function, view its help page by running

```
# Type in the Console to view the help page
? `%ilike%`
```

4.7 R objects have class

Everything is an object and every object has a class.

```
class(x)
#> [1] "numeric"

class(summary)
#> [1] "function"
```

Certain actions will change the class of an object. Suppose we try create a vector from the `x` object and a text string,

```
new_vector <- c(x, "Apple")

new_vector
#> [1] "1"      "2"      "3"      "1"      "3"      "25"     "Apple"

class(new_vector)
#> [1] "character"
```

By adding the word “Apple” to the vector, R changed the class from “numeric” to “character”. All the numbers are enclosed in quotes: they are now character strings and cannot be used in calculations.

The most common class of data object we will use is the data frame. The data in `midfieldr` are stored as data frames, e.g.,

```
# examine another midfieldr data set
study_stickiness
#>      program      race  sex  ever  grad stick
#>      <char>    <char> <char> <int> <int> <num>
#> 1:    Civil    Asian Female   17   12  70.6
#> 2:    Civil    Black Female   54   28  51.9
#> 3:    Civil    White Female  329  232  70.5
#> 4:    Civil    Asian   Male   37   24  64.9
#> 5:    Civil    Black   Male   98   43  43.9
#> ---
#> 34: Mechanical Hispanic/Latinx Male   76   47  61.8
#> 35: Mechanical International Male   37   19  51.4
#> 36: Mechanical Native American Male   14    8  57.1
#> 37: Mechanical Other/Unknown Male   48   28  58.3
#> 38: Mechanical White Male  1940  1265  65.2

class(study_stickiness)
#> [1] "data.table" "data.frame"
```

- Six columns: `program`, `race`, `sex`, `ever`, `grad`, `stick`.
- Three columns are labeled `<char>` for character, categorical variables
- Two columns are labeled `<int>` for integer
- One column is labeled `<num>` for double precision

The additional class shown `data.table` is an augmented version of the base R `data.frame` class. When working with these objects you can use base R `data.frame` syntax or `data.table` syntax.

If you have a `data.frame` object that is not a `data.table`, e.g. the `airquality` data frame that comes with R

```
class(airquality)
#> [1] "data.frame"

head(airquality)
#>   Ozone Solar.R Wind Temp Month Day
#> 1   41     190  7.4   67     5   1
#> 2   36     118  8.0   72     5   2
#> 3   12     149 12.6   74     5   3
#> 4   18     313 11.5   62     5   4
#> 5   NA      NA 14.3   56     5   5
#> 6   28      NA 14.9   66     5   6
```

You can convert it to `data.table` object with `as.data.table()` and assign it to

a `_slightly`) different name.

```
air_quality <- as.data.table(airquality)

class(air_quality)
#> [1] "data.table" "data.frame"

air_quality
#>      Ozone Solar.R Wind Temp Month Day
#>      <int>  <int> <num> <int> <int> <int>
#>  1:    41    190   7.4   67    5    1
#>  2:    36    118   8.0   72    5    2
#>  3:    12    149  12.6   74    5    3
#>  4:    18    313  11.5   62    5    4
#>  5:    NA     NA  14.3   56    5    5
#> ---
#> 149:    30    193   6.9   70    9   26
#> 150:    NA    145  13.2   77    9   27
#> 151:    14    191  14.3   75    9   28
#> 152:    18    131   8.0   76    9   29
#> 153:    20    223  11.5   68    9   30
```

The data frame as a whole has a class; so do the individual columns.

```
class(air_quality[, Ozone])
#> [1] "integer"

class(air_quality)
#> [1] "data.table" "data.frame"
```

4.8 R objects have structure

To see inside an object ask for its structure using the `str()` function.

```
str(x)
#> num [1:6] 1 2 3 1 3 25

str(toy_term)
#> Classes 'data.table' and 'data.frame': 169 obs. of 6 variables:
#> $ mcid      : chr "MID25899243" "MID26319252" "MID25841465" "MID26560837" ...
#> $ institution: chr "Institution B" "Institution E" "Institution M" "Institution J" ...
#> $ term       : chr "19943" "20021" "20023" "19981" ...
#> $ cip6       : chr "240102" "140801" "260101" "999999" ...
#> $ level      : chr "03 Junior" "04 Senior" "02 Sophomore" "02 Sophomore" ...
#> $ hours_term : num 5 5 16 12 15 21 9 12 17 17 ...
#> - attr(*, ".internal.selfref")=<externalptr>
```



```
str(airquality)
#> 'data.frame':   153 obs. of  6 variables:
#> $ Ozone   : int  41 36 12 18 NA 28 23 19 8 NA ...
#> $ Solar.R: int  190 118 149 313 NA NA 299 99 19 194 ...
#> $ Wind    : num  7.4 8 12.6 11.5 14.3 14.9 8.6 13.8 20.1 8.6 ...
#> $ Temp    : int  67 72 74 62 56 66 65 59 61 69 ...
#> $ Month   : int  5 5 5 5 5 5 5 5 5 5 ...
#> $ Day     : int  1 2 3 4 5 6 7 8 9 10 ...

str(air_quality)
#> Classes 'data.table' and 'data.frame':   153 obs. of  6 variables:
#> $ Ozone   : int  41 36 12 18 NA 28 23 19 8 NA ...
#> $ Solar.R: int  190 118 149 313 NA NA 299 99 19 194 ...
#> $ Wind    : num  7.4 8 12.6 11.5 14.3 14.9 8.6 13.8 20.1 8.6 ...
#> $ Temp    : int  67 72 74 62 56 66 65 59 61 69 ...
#> $ Month   : int  5 5 5 5 5 5 5 5 5 5 ...
#> $ Day     : int  1 2 3 4 5 6 7 8 9 10 ...
#> - attr(*, ".internal.selfref")=<externalptr>
```

4.9 R only does what you tell it

Healy [2019a] offers this advice for specific things to watch out for:

- Make sure parentheses are balanced—that every opening (has a corresponding closing).
- Expect to make errors and don't worry when that happens. You won't break anything.
- Make sure you complete your expressions. If you see a + in the Console instead of the usual prompt >, R thinks your expression is incomplete. For example, if you type the following and try to run it,

```
str(air_quality
```

the output in your Console reports:

```
#> str(air_quality
+
```

The plus sign indicates that the expression is incomplete...in this case a missing closing parenthesis. To recover, hit **Esc** or **ctrl C**. Then correct the code.

As you work through the MIDFIELD tutorials, we'll introduce syntax by example from both base R and the `data.table` package. There can be subtle differences that we will attempt to avoid by consistent usage.

For example, to subset a column from a data frame but keep it as a column (not

a vector), the base R syntax is

```
# base R subset one column
airquality[, "Ozone", drop = FALSE]
#>      Ozone
#> 1      41
#> 2      36
#> 3      12
#> 4      18
#> 5      NA
#> 6      28
#> 7      23
#> 8      19
#> 9       8
#> 10     NA
#> ..., etc., truncated for brevity
```

In `data.table` syntax, the same operation is as follows. Note we are using the `air_quality` `data.table` object we created earlier.

```
# data.table extract one column
air_quality[, .(Ozone)]
#>      Ozone
#>      <int>
#> 1:      41
#> 2:      36
#> 3:      12
#> 4:      18
#> 5:      NA
#> ---
#> 149:     30
#> 150:     NA
#> 151:     14
#> 152:     18
#> 153:     20
```

If we want the same information extracted as a vector, we would:

```
# base R subset one column as a vector
airquality[, "Ozone"]
#> [1] 41 36 12 18 NA 28 23 19 8 NA 7 16 11 14 18 14 34 6
#> [19] 30 11 1 11 4 32 NA NA NA 23 45 115 37 NA NA NA NA
#> [37] NA 29 NA 71 39 NA NA 23 NA NA 21 37 20 12 13 NA NA
#> [55] NA NA NA NA NA NA NA 135 49 32 NA 64 40 77 97 97 85 NA
#> [73] 10 27 NA 7 48 35 61 79 63 16 NA NA 80 108 20 52 82 50
#> [91] 64 59 39 9 16 78 35 66 122 89 110 NA NA 44 28 65 NA 22
#> [109] 59 23 31 44 21 9 NA 45 168 73 NA 76 118 84 85 96 78 73
#> [127] 91 47 32 20 23 21 24 44 21 28 9 13 46 18 13 24 16 13
```

```
#> [145] 23 36 7 14 30 NA 14 18 20

# data.table subset one column as a vector
air_quality[, Ozone]
#> [1] 41 36 12 18 NA 28 23 19 8 NA 7 16 11 14 18 14 34 6
#> [19] 30 11 1 11 4 32 NA NA NA 23 45 115 37 NA NA NA NA
#> [37] NA 29 NA 71 39 NA NA 23 NA NA 21 37 20 12 13 NA NA NA
#> [55] NA NA NA NA NA NA NA 135 49 32 NA 64 40 77 97 97 85 NA
#> [73] 10 27 NA 7 48 35 61 79 63 16 NA NA 80 108 20 52 82 50
#> [91] 64 59 39 9 16 78 35 66 122 89 110 NA NA 44 28 65 NA 22
#> [109] 59 23 31 44 21 9 NA 45 168 73 NA 76 118 84 85 96 78 73
#> [127] 91 47 32 20 23 21 24 44 21 28 9 13 46 18 13 24 16 13
#> [145] 23 36 7 14 30 NA 14 18 20
```

In each case, you will note that the square bracket operators include a comma `[i, j]`. In general, the comma separates row operations `i` from column operations `j`. When there is no row operation (as in the examples above), the `i` position is empty.

In data table syntax, we go one step further and add a grouping index, that is `DT[i, j, by]`

This can be read as “Take DT, subset/reorder rows using `i`, then calculate `j`, grouped by `by`.” You don’t have to go into it any more deeply than this for now—we will illustrate it by example in the `midfieldr` tutorials.

4.10 To get help

Online resources

Tutorial

- Getting Started in R: Tinyverse Edition. Highly recommended. An 8-page introduction to R using `data.table` and `ggplot2`.

Online Q & A

- Stack Overflow R section. A question-and-answer site.

Cheat sheets. Compact (information dense) summaries of features.

- RStudio
- `data.table`
- `ggplot2`

Package main help

For a package’s main help page, `help(package = "name_of_package")`, to obtain a list of all the functions (and possibly some data objects) in the package.

```
# type in the Console
help(package = "midfieldr")
```

In the Help pane, click through any of the links for details on the function.

Package vignettes

Some packages come with vignettes, articles explaining how to use the package for specific tasks. For example,

```
# type in the Console
browseVignettes(package = "data.table")
browseVignettes(package = "ggplot2")

# to see a listing of all vignettes in all your installed packages
browseVignettes()
```

Function help

A number of times so far we’ve shown how to get the help page for a function when we know its name, e.g.,

```
# type in the Console
? str()
```

If you recall only a part of the function name, use `apropos()` to search packages that are currently loaded. “Loading” a package is what we do when we use the `library()` function at the top of a script.

For example, `midfieldr` has functions with “timely” in their name because they involve timely completion. `apropos()` reports two functions:

```
# type in the Console
apropos("timely")
#> [1] "add_completion_timely" "add_timely_term"
```

Examples

There are often examples at the end of an R function help page. You can run them using the `example()` function. For example,

```
# base R function examples
example("mean")
#>
#> mean> x <- c(0:10, 50)
#>
#> mean> xm <- mean(x)
#>
#> mean> c(xm, mean(x, trim = 0.10))
#> [1] 8.75 5.50
```

try one of the `midfieldr` function examples,

```
# midfieldr function examples
example("add_institution")
#>
#> add_ns> # Extract a column of IDs from student
#> add_ns> id <- toy_student[, .(mcid)]
#>
#> add_ns> # Add institutions from term
#> add_ns> DT1 <- add_institution(id, midfield_term = toy_term)
#>
#> add_ns> head(DT1)
#>           mcid  institution
#>           <char>         <char>
#> 1: MID25783939 Institution M
#> 2: MID25784402 Institution M
#> 3: MID25805538 Institution M
#> 4: MID25808099 Institution M
#> 5: MID25816437 Institution M
#> 6: MID25826223 Institution M
#>
#> add_ns> nrow(DT1)
#> [1] 100
#>
#> add_ns> # Will overwrite institution column if present
#> add_ns> DT2 <- add_institution(DT1, midfield_term = toy_term)
#>
#> add_ns> head(DT2)
#>           mcid  institution
#>           <char>         <char>
#> 1: MID25783939 Institution M
#> 2: MID25784402 Institution M
#> 3: MID25805538 Institution M
#> 4: MID25808099 Institution M
#> 5: MID25816437 Institution M
#> 6: MID25826223 Institution M
#>
#> add_ns> nrow(DT2)
#> [1] 100
```

4.11 Keyboard shortcuts

If you are working in RStudio, you can see the menu of keyboard shortcuts using the menu *Tools > Keyboard Shortcuts Help*. The shortcuts we use regularly include

Windows / Linux	Action	Mac OS
<code>ctrl L</code>	Clear the RStudio Console	<code>ctrl L</code>
<code>ctrl shift C</code>	Comment/uncomment line(s)	<code>cmd shift C</code>
<code>ctrl X, C, V</code>	Cut, copy, paste	<code>cmd X, C, V</code>
<code>ctrl F</code>	Find in text	<code>cmd F</code>
<code>ctrl I</code>	Indent or re-indent lines	<code>cmd I</code>
<code>alt -</code>	Insert the assignment operator <code><-</code>	<code>option -</code>
<code>ctrl alt B</code>	Run from beginning to line	<code>cmd option B</code>
<code>ctrl alt E</code>	Run from line to end	<code>cmd option E</code>
<code>ctrl Enter</code>	Run selected line(s)	<code>cmd Return</code>
<code>ctrl S</code>	Save	<code>cmd S</code>
<code>ctrl A</code>	Select all text	<code>cmd A</code>
<code>ctrl Z</code>	Undo	<code>cmd Z</code>

Lastly, any time you want a fresh start in your working environment,

- Use the pulldown menu *Session > Restart R*

4.12 Next steps

That concludes our brief introduction to R. To continue, return to your starting point (links below) and from there, select the next link in your progression.

- New to R?
- Familiar with R?
- After the workshop

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Chapter 5

Graph basics

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5.1 Introduction

This tutorial is an introduction to ggplot2 adapted from Chapter 3 from [Healy, 2019a]. If you already have R experience, you might still want to browse this section in case you find something new.

Prerequisites should be completed before proceeding. After that, the tutorial should take about an hour.

Create a new script for this tutorial.

- See Open an R script if you need a refresher on creating, saving, and running an R script.
- At the top of the script add a minimal header and install and load the packages indicated.

```
# Graph basics
# name
# date

library("gapminder")
library("ggplot2")
```

If you get an error like this one after running the script,

```
Error in library("gapminder") : there is no package called 'gapminder'
```

then the package needs to be installed. If you need a refresher on installing packages, see Install CRAN packages. Once the missing package is installed, you can rerun the script.

Guidelines

- As you work through the tutorial, type a line or chunk of code then *File* > *Save* and run the script.
- Confirm that your result matches the tutorial result.
- **Your turn** exercises give you chance to devise your own examples and check them out. You learn by doing (but you knew that already)!

5.2 Data structure

Data for analysis and graphing are often laid out in “block record” or “long” form with every key variable and response variable in their own columns [Mount and Zumel, 2019]. We use this form regularly, for example, in preparing data for graphing using the ggplot2 package.

The `gapminder` data frame is tidy. We use `glimpse()` to get a look at the structure.

```
# glimpse(gapminder)
```

And we can just type its name to see the first few rows,

```
gapminder
#> # A tibble: 1,704 x 6
#>   country      continent  year lifeExp      pop gdpPercap
#>   <fct>        <fct>    <int>   <dbl>    <int>    <dbl>
#> 1 Afghanistan Asia      1952    28.8  8425333    779.
#> 2 Afghanistan Asia      1957    30.3  9240934    821.
#> 3 Afghanistan Asia      1962    32.0 10267083    853.
#> 4 Afghanistan Asia      1967    34.0 11537966    836.
#> 5 Afghanistan Asia      1972    36.1 13079460    740.
#> 6 Afghanistan Asia      1977    38.4 14880372    786.
#> 7 Afghanistan Asia      1982    39.9 12881816    978.
#> 8 Afghanistan Asia      1987    40.8 13867957    852.
#> 9 Afghanistan Asia      1992    41.7 16317921    649.
#> 10 Afghanistan Asia      1997    41.8 22227415    635.
#> # ... with 1,694 more rows
```

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Chapter 6

Data basics

This tutorial is an introduction to ...

Prerequisites should be completed before proceeding. After that, the tutorial should take no longer than 50 minutes.

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Chapter 7

Designing effective displays

7.1 Stuff

7.2 More stuff

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