Biological Data Analysis (BIOL 250)

Fall 2018

Version date: August 26, 2018

"Knowledge is power." Francis Bacon (1561-1626)
"To measure is to know." Lord Kelvin (1824-1907)
"Heavier-than-air flying machines are impossible." Lord Kelvin (1824-1907)
"Knowledge is good." Emil Faber. Founder of Faber College (see documentary: Animal House, 1978)
"Knowledge comes from collecting, analyzing, visualizing, and interpreting information correctly." Gregg Hartvigsen

Item	Course details
Meetings	MF 2:30 - 3:45, ISC 115
Dr. H's info	Geneseo Safe Zone Office = ISC 360 Office phone = 245.5448 Email = hartvig@geneseo.edu Office hrs: M 4 - 5pm, Tues 11am - 1pm, W 3:30 - 4:30pm
TA info	Angela Kubik. Email = ajk21@geneseo.edu Briana Kubik. Email = bck3@geneseo.edu Office hours: TBA in ISC 343
Required textbook	Hartvigsen (2014). Bringing this to class is up to you but it might help.
Required laptop	Bring this to all meetings, unless otherwise instructed. Also, bring a power cord.
Required software (free)	`Excel` (or similar), `R` (version 3.5.0 or later), `RStudio` (version 1.1.456 or later), and LaTeX.
Required backup (free)	You are required to keep all files from this class in a folder that automatically syncs in the cloud. This can be through Google Drive (recommended), Dropbox, OneDrive, or iCloud.
Calculator	Not needed.

Note that this course fulfills a requirement for the biology BS, biochemistry BS, and biomathematics minor and an elective for the biology BA degree.

Course Resources

1. **Book**: The required book (Hartvigsen, 2014) was written based on my teaching of this course. It is a brief introduction to biological data analysis and visualization using `R`. Each chapter has problems that you should be able to complete on the day the chapter is due. The book was written using `RStudio` and LaTeX, skills you will have by the end of the course!
2. **Post-lecture notes**. After lectures I'll post the notes on Canvas.
3. **ICEs**. These are in-class exercises, provided on Canvas, that will have background information for a specific topic, instructions, sample code, and problems to complete. These are integral parts of the course and your knowledge of these will be rewarded on exams.
4. **Old exams**. Some old mid-term and final exams are available in my Geneseo "Outbox" in the `BDA` folder. For help on boxes see `https://wiki.geneseo.edu/display/cit/Inboxes+and+Outboxes`.
5. **Help using R**.

(a) Your TAs and me! The TAs (Angela and Briana) are experienced and will likely be able to answer any question you have. They will not tell me you asked an especially tragically stupid question. Note that I do not mind answer tragically stupid questions because they're the ones I probably can answer! So, ask away. The only thing that matters is that you get answers to your questions. We're here to make that happen.
(b) Your book (e.g., see section 1.3, "Getting help with `R`", in your book.
(c) You can Google search questions pretty effectively.
(d) A quick entry to the breadth of the `R` software packages can be found through the Cran Task Views.
(e) Please ask me or the TAs for help before emailing a list or people you find online.

6. **Let's do lunch!** This is an opportunity to chat about anything - the course, undergraduate research, life, jobs, juggling, hitchhiking, motorcycling, music, tennis, racquetball, squash, nature, cycling, the next exam, whatever. Please gather a group of two or more. The venue is your choice. We each pay for ourselves (i.e., "Dutch treat"). Note: I'm a vegetarian.

Overview

This is a course on empowerment and discovery in biology. It's designed to be an introduction to the management, visualization, analysis, and interpretation of biological data. The process of understanding what data are telling us requires proficiency in a range of fundamental procedures, from the design of experiments through the generation of results to the interpretation of biological information to the presentation of data and ideas. Your ability to challenge ideas with data should be helpful and inspiring to you. If you seek to understand and solve problems in science or critically assess the meaning of biological information (e.g., as a doctor, PA, ecologist, or reader of the news and interpreter of statements by politicians) then you are in the right place.

In this course you will survey a variety of statistical approaches which should help you be able to think more creatively. Biological data analysis is, however, an ever-expanding area of inquiry. New methods are being developed daily. New data also are creating the need for new types of analytical tools. You will be learning to use the program `R` to perform your analyses and create professional-quality visualizations because all new analytical procedures are being developed in this environment.

My goal is for you to learn how to solve problems. This will require that you push yourself to solve your own problems. The TAs and I are glad to help but part of your learning will involve figuring out how to find answers to your questions.

You, no doubt, will forget how the data are supposed to be entered for a particular test or how to do something cool when making a graph. But you don't have to remember everything because you'll develop *many* script files that you can simply reuse. Be sure to name your files appropriately (do not name your work on a t-test "`lab7.r`"). What I hope you get (or keep) is the attitude that you can figure anything out.

A peek at what happens during a typical class

We often begin discussing a few basic principles for the day regarding statistics, visualizations, experimental design, and/or the interpretation of information. We then apply this information to solve an in-class exercise (ICE) using `R`. The most common suggest on my SOFIs is that I should lecture more. I like lecturing but I think you'll learn more by doing.

Expected Learning Outcomes

If you successfully complete this class your ability to critically assess commonly encountered biological information will improve. To accomplish this you will need to be able to:

1. find, save, organize, manipulate, and access data using `Excel` and the `R` statistical and programming language;
2. identify correctly basic experimental design principles that are used to answer a variety of biological questions;
3. correctly develop and test hypotheses statistically using data;
4. understand the differences between parametric and non-parametric statistical tests;
5. create appropriate publication-quality visualizations of results;
6. correctly identify and report, in appropriate scientific format, the results of a statistical test;
7. write a professional-looking report using `Sweave` and LaTeX (pronounced lay-tech);
8. explain the meaning of quantitative results (and accompanying visualizations), whether done by you or others (e.g., in books, papers, presentations, and news media).
9. collaborate in a team conducting original work that requires gathering, analyzing, and graphing data using `R` that assesses a comprehensive biological problem and culminates in an oral presentation;
10. write and use your own functions;
11. write computer programs in an object-oriented programming language, including "for" and "while" loops, and "if" conditional statements.

These outcomes are aligned with the report "Scientific Foundations for Future Physicians" produced by the Association of American Medical Colleges and the Howard Hughes Medical Institute, 2009. This report states that

> ...biology students must be able to "apply quantitative reasoning and appropriate mathematics to describe or explain phenomena in the natural world."

and:

> "It is essential not only to read the medical and scientific literature of one's discipline, but to examine it critically to achieve lifelong learning. These activities require knowledge and skills in critical analysis, statistical inference, and experimental design."

Additionally, Schwartzstein et al. (2013) state that students taking the new (2015) MCAT are required to demonstrate

1. "scientific reasoning and problem solving by reasoning with scientific principles, theories, and models and by analyzing and evaluating scientific explanations and predictions;
2. reasoning about the design and execution of research by demonstrating their understanding of important components of scientific research and by reasoning about ethical issues in research; and
3. data-based and statistical reasoning by interpreting patterns in data presented in tables, figures, and graphs and by reasoning about data and drawing conclusions from them."

We can achieve these outcomes by working together. You are more likely to achieve these if you actively ***play*** with data analysis and modeling techniques. You should work to solve all problems posed in the ICEs and your book. Those questions may appear on an exam. Use `R` in your other classes to solve problems, too. And write up lab reports using `Sweave` from within `RStudio`. These skills will come back to reward you. The evidence of others using this platform are found in leading scientific journals, including *Science*, *Nature*, and *PNAS*. It also is an important analytics program used extensively by a variety of organizations, including Pfizer, Merck, Google, Facebook, Mozilla, Microsoft, NY Times, Shell, and others. Also, the data skills you learn in this class will help you get into med school (see the MCAT test) or graduate school (see the GRE test) and help you succeed when there.

Finally, by the time you successfully complete this course you should be able to counter the following misguided thinking:

> **Why do we need to use statistics and mathematics in biology? If the hypothesis is clear, the experiment is designed correctly, and the data carefully collected, anyone should be able to just look at the data and clearly see whether or not the hypothesis is supported. Statistical procedures and mathematical tricks are simply safety nets and smoke screens to cover up sloppy science.**

Expected Learning Shortcomings (things you won't likely learn)

Biology is an extremely broad and rapidly changing, data rich discipline. Techniques used to understand and visualize biological information are being developed and implemented continuously. This course introduces you to the most widely used platform for understanding biological information but you'll see only the most basic principles and procedures. You will need to seek out new methods, practice, read, and implement techniques on your own as you work to be a part of modern biology. Still, you can look at the latest issues of the journals *Science* and *Nature* and find analyses and visualizations that you will do in this class.

Grading

Below are the basic assessment tools for this class. Most of the points will be earned through two exams and the semester-long research project. There is some flexibility in how many points will be available due to the unknown number of pop quizzes and homework assignments. The number of these is inversely related to a vague quantification of in-class participation and engagement. Feel free to encourage me to provide these opportunities. Your grade will be determined by dividing your points earned by the number of points that were available. Your final grade will be converted from a numerical value to a letter grade using the following rules. The values below are proportions of possible points earned.

Score		Letter Grade		Score
0.933	$\leq$	A		
0.900	$\leq$	A-	$<$	0.933
0.867	$\leq$	B+	$<$	0.900
0.833	$\leq$	B	$<$	0.867
0.800	$\leq$	B-	$<$	0.833
etc.				

Note that I will round your proportion grade UP to three decimal places using `Excel`'s function `CEILING(number, 0.001)`. The college rounds grades DOWN (truncates) when calculating your GPA (see page 39, 2016-2017 College Bulletin). In the Bulletin the college tells you that a student earning a GPA of 2.728571 will have a GPA = 2.72! They probably round down your GPA for your cumulative GPA, as well! To help counter this I will take a grade of, say, 0.832105, which would be a B-, and round it up to 0.833, making it a B. Note, too, that the college gets you again by making a a B+ 3.3 "quality points" instead of $3.\overline{3}$. You get a GPA boost for getting a grade with a minus (e.g., A- = 3.7 instead of $3.\overline{6}$). So, maybe it's a wash, but you might go look at your grades. If you have more grades with a "+" then you're getting stiffed.

Assessments

Item	Description	Points
Quizzes	Quick, likely unannounced challenges assessing competencies with concepts and `R` coding. Number unknown	5 pts ea
Homework	Problems with strict due dates/times. May be to just submit answers to ICE and/or book questions	10 pts ea
Group assignment	Working in Groups	10 pts
Mid-term exam	Written and computer	100 pts (total)
Final exam	Cumulative written and computer	150 pts
Semester project	Includes progress reports	120 pts

Quizzes. These are opportunities to reward you for preparing for class. You are expected to be able to complete basic, rudimentary tasks performed in recent classes and understand the reading for the current week. These may include function calls from `R` and basic concepts. They are to be answered using pen and paper. A sample question might be "Provide the `R` code that would read in a data file called `datafile.csv`."

Exams. Exams are cumulative. They will have two parts. The first will be a written part that takes about a third of the time. Once you hand that in you can proceed to open your computer and do the computer part. The written exams are closed book. The computer exams are open (book, notes, computer, and internet). For all exams you are not allowed to communicate with anyone (chatting, talking, texting, or emailing, unless otherwise instructed). The computer part will be worth 60% of the grade and is emailed to me when you are done (attaching just the `.rnw` file). Gmail attaches a time stamp for when you send it to me. It's tempting to stop working when "time" is called and then try to send it. Each minute the exam is late costs 5% of the overall exam grade.

Semester project

This is a project you should feel comfortable discussing with someone when you want to get a job, do research with someone, or show someone who might consider funding you as a grad student or accept you into medical school. Working in groups you will present a deep analysis of an original hypothesis, or hypotheses using real data (e.g., from journals, your own research, or using data found on the internet; e.g., CDC). All the files for this project need to be emailed to me before the closing date/time. You must provide the data *and* the `R` script files used to complete *all* the analyses from your presentation and produces your graphs so that I can simply run the script file. Each 24-hour period after the due date/time accumulates a 10% grade deduction for your project. If the `R` script file doesn't work expect to lose 20% of the points for the project. The presentation should be 12-minutes long and then allow three minutes for questions.

Group presentations will be completed during the final exam time slot (see schedule below). Attendance throughout all presentations is required else risk losing 50% of your presentation grade.

For this project you will need data. Be warned: good science is hypothesis driven. You always should

1. develop a question;
2. phrase the question as a testable hypothesis;
3. get the appropriate data to answer the question;
4. answer the question.
5. share the result with clean data analysis and beautiful, revealing visualizations.

You should not build a project around whatever data you can find. This paper raised an important issue about whether people who analyze other people's data are just scientific parasites. An interesting rebuttal to that paper can be found here: **"The one true route to good science is..."**. Do check these out before spending a lot of time on your project.

Here are some rules to keep in mind for this project. Ignore these at risk of losing an indeterminant number of percentage points from your project.

1. **Submit one zip file**. All the files must be in one zip file. Name the zip file Lastname1-Lastname2-Lastname3.zip, assuming those are the three presenters. The pdf file, which you'll present, also should have the same name but ending in .pdf. Do **not** name a file "presentation1.pptx" or "BDAproject.r". If you don't follow this you're giving me permission to subtract 5% of your grade from the project before seeing it.
2. **Data analyses must work**. You can't get a passing grade with analyses that don't yield your statistical results and visualizations used in your talk. If you have strange `R` packages then include one or more lines like this at the top of the file:

   ```
   # install.packages("packagename")
   ```

   If necessary I will simply uncomment those lines and install the packages myself.
3. **Talk structure**. A good project presentation will flow much like a good scientific paper:
   (a) Title slide. The first slide should show your project's title and your names.
   (b) Probably have an outline slide, which reappears at the beginning of each new section. This can help you make sure your talk is well organized.
   (c) An Introduction. Introduce the problem and why your audience should care.
   (d) Methods. Describe how the data were collected and what you did to analyze the data. A normality test, if necessary, would go here because it justifies why you did a particular test. If showing how the data are distributed is a result then it belongs in the results section.
   (e) Results. Share what you found. There should be graphs and results from statistical tests (e.g., the ANOVA table).
   (f) Discussion. What do your results mean? Pull together the significance of your results.
   (g) Acknowledgments and citations.

Check out this article on the Ten Simple Rules for Making Good Oral Presentations. There are ideas to consider but not all are appropriate for your data-rich, visually intensive presentation for this course.
Finally, here's the basic rubric for your presentation evaluation:
The presentation:

(a) was professionally presented by the group members (thoroughly practiced);
(b) was appropriately organized (Intro, methods, results, discussion, citations);
(c) included publication-quality visualizations;
(d) showed a diversity of statistical routines;
(e) demonstrated correct and appropriate statistical tests;
(f) asked and answered appropriate questions for this class;
(g) group found adequate data for project/statistical tests;
(h) members seemed to be necessary (no drifters/lost souls); and
(i) the depth of the presentation matches the number of group members.

Please note that all files are to be delivered to me by 11:59pm the night before your presentation (final exam time slot). Late fee = 20%. The code you provide should be in one file and run without errors, generating the statistical results and visualizations that you have included in your presentation. You will present the pptx/pdf file you send me.

4. **Project dates/times** for presentation components:

Date	What's Due
9-7	Form group and decide on topic. All members names are on this with their signatures.
9-24 (beginning of class)	Project title and one paragraph proposal. Paper copy only. All members names are on typed on this along with their signatures.
10-25 (Thurs., 5pm)	Group project mini-presentation to be given on 10-26 (~ 7.5 minutes). This is a shortened version of your final presentation. Be sure to demonstrate that you have data, have made at least one thorough analysis of your data, and have graphs showing clear results. Provide title slide, intro, three visualization slides showing data, at least one formal hypothesis test, and a brief discussion of what these results mean. The slides you present must be emailed to me (hartvig@geneseo.edu) with BDA in the subject. Preferably provide a pdf file. Name your file with your last names in alphabetical order.
11:59 pm on the day before your presentation	Email me your properly named presentation file (preferably a pdf). Attach data files opened with your single, complete R script file. The R script must be named like you presentation file - include all your last names. I'm flexible about the due date: you can hand it in **any time before** this deadline. You can deliver it after this time but will be charged a late fee of 10%. The presentation file you hand in will be on my computer waiting for you on presentation day. It is your job to know the fonts and formatting are fine on a Windows 10 machine.
Final presentation	See schedule below. Miss this and flunk the class.

Project Ideas

Wow. So many possibilities! Projects have ranged from creating a simple stochastic model of logistic growth and analyzing the data to very large-scale, comprehensive analyses of different disease incidence rates across different countries.

One thing to keep in mind is that, at this point in time, R has become ubiquitous in scientific data analysis, particularly in biology. It is possible to find all sorts of data sets with associated R script files that will crunch the data in a variety of ways and produce amazing visualizations. You, however, will be evaluated on your creativity, difficulty, and the work you do. This is like an Olympic diving competition - it's a combination of difficulty and execution. If you lift a project then your learning and grade will suffer. Each group member is expected to understand all of the project code and analyses and be able to explain these, upon request. Do NOT have someone who is "The Codemaster" and certainly do not have someone who is the "PowerPoint person." The other extreme is that each person doesn't their own piece and then slides are combined 15 minutes before the project is due. This usually works out poorly, as well.

Keep in mind the TAs Angela and Briana and I can *usually* help you. Sometimes, however, other faculty members in the department will be great resources for understanding the system you're studying. I'm an ecologist so can usually be somewhat helpful in this area. If you find ecology revolting that's OK! But I might not be a lot of help with the biology of your particular system. Also, keep in mind that if you choose a project that is way over your head, and it remains that way until the end, your grade will suffer! Given all this, here are few ideas:

1. Talk to a professor and, possibly, develop a research project with them that involves helping them analyze some of their data.
2. You are in a lab doing independent research already and want to "double-dip" so you can better understand the data. You may NOT use someone else's analysis for this project. But if this is something you're working on and hope to present at GREAT Day, for instance, you're in business, as long as your group is unanimous in agreeing to do this! Also, clear this with me.
3. Check out data online, of course, such as Dryad Data Outlet, state cancer profiles State Cancer Profiles, Ecological Data Wiki or Nature Serve, the Ecological Society of America's data archive site, and Blast genomic data.
4. Most add-on packages in `R` come with data sets (e.g., see `R` data sets). Type `> data(data)` at the console and a file will be opened and available. These are not appropriate for this project since code is provided for analyzing these data.

Note that proceeding without talking to me is not recommended. There always seems to be a group that goes off in a direction with the best of intentions but without realizing they have no oars, no rudder, no life vests, no nothing. Don't be that group! Use the resources available to you. Consider me and TA Angela and Briana members of your group.

Building and working in groups

Doing group projects is *always* difficult and, in this class, required. The training you get in this class involves developing collaboration skills. Unfortunately, allowing folks to form their own groups does not necessarily maximize joy and/or productivity. In this class groups will be assigned randomly. Everyone, I suspect, is in the class because they need it for some reason. These reasons should suffice for everyone to act collaboratively. Projects are graded and then individual contributions are assessed so that individuals can receive wildly different grades. Work hard and collaboratively and you'll be rewarded accordingly.

Non-compliance of group members

Every so often a group is unable to reach its potential. It appears from experience that some people find working collaboratively challenging. Not making meetings is one complaint I hear about some folks. Individuals have been voted off the island. If that happens those folks will likely get to form their own group so I recommend everyone make a special effort to pull their weight (not just appear to pull their weight). Keep in mind, too, the needs of *all* members. Some folks may have kids at home to take care of so it's not a given that group meetings on Friday night at 11pm should work for everyone. Feel free to keep me informed about how things are going for you.

Work handed in late

All work excluding exams will be charged a value of 20% per 24-hour period the work is late. Submitting exams late will cost 5% per minute on the time stamp of mail in which the file(s) are sent.

Religious observances

It is my responsibility, as outlined in the College's Undergraduate Bulletin, to accommodate religious observances. No exams have been scheduled to occur on notable observance days. However, as stated in the 2016-2017 Bulletin, I am "to comply in good faith with the provisions of... " section 224-a of the Education Law of New York State. I am happy to meet your needs if you inform me of any such absence at least one week prior to the conflict. Without you providing me this information I may not be able to meet your learning expectations for the class.

Schedule

Note: bring your computer unless otherwise instructed. Also, the first day survey should be completed by 11:59pm on the first day of classes.

Date	Day	Activity.Topic	Prep.for.Class
8/27/2018	Mon	Introduction to class + data analysis	Chapt. 0 - the book's introduction.
8/31/2018	Fri	Introduction to Excel and R. Getting data into R	Chapt. 1 + 2. Have installed R and Rstudio. Complete "Getting Started Using R" ICE. Don't hand in but check yourself against solution set.
9/3/2018	Mon	Labor Day - No Class	
9/7/2018	Fri	Form groups, hand in proposed topic, discuss Working in Groups assignment	HW: All probs for Chapt 1 + 2. BRING candidate topics for your semester project. Find out if there are data available. At end of class hand in topic.
9/10/2018	Mon	Crash course in statistics for the project	Quiz - What are the major tests and what do they test? Skim through the entire book looking at chapters and section headings
9/14/2018	Fri	Working with data	Chapt. 3 + discuss "Working in Groups" assignment
9/17/2018	Mon	Introduction to Sweave/LaTeX	Make sure that Sweave works (in Rstudio try File -> New File -> R Sweave. Type some words, and click on "Compile PDF")
9/21/2018	Fri	Tell me about my data	Chapt. 4. HW: all chapt 4 problems, using Sweave
9/24/2018	Mon	Visualizing data	Chapt. 5 - Group proposal.
9/28/2018	Fri	Data challenge 1 (previous work). Begin probability	Organize code for data challenge
10/1/2018	Mon	More probability	
10/5/2018	Fri	R Challenge (20 min) + Intro to statistical thinking	Chapt. 6, sections 6.1-6.3
10/8/2018	Mon	October Break - No Class!	
10/12/2018	Fri	Experimental design	Chapt. 6, sections 6.4-6.5

10/15/2018	Mon	Intro to statistical inference, p-values, and errors	Chapt. 6, sections 6.6-6.8
10/19/2018	Fri	Mid-term exam	Written (15 minutes) and computer (1 hr).
10/22/2018	Mon	One-sample tests	Chapt. 7, sections 7.1-7.2
10/26/2018	Fri	Group project update - presentation (~ 5 minutes using my computer)	Send by Thurs. 10-24 @ 5:00pm: Powerpoint file with 7 slides: title slide (include names!), intro slide, one methods slide (analyses used), three slides showing visualization with data analysis results, one discussion slide stating significance of results.
10/29/2018	Mon	Two-sample tests	Chapt. 7, section 7.3
11/2/2018	Fri	More than two samples	Chapt. 8, sections 8.1-8.2
11/5/2018	Mon	Visualizing sample data, error bars, and post-hoc tests	Chapt. 11, sections 11.2-11.3
11/9/2018	Fri	Two-factor analysis	Chapt. 8, section 8.3
11/12/2018	Mon	Quiz, statistical analyses, visualizations, and interpretation	
11/16/2018	Fri	Correlation	Chapt. 9, section 9.1
11/19/2018	Mon	Linear regression	Chapt. 9, section 9.2
11/23/2018	Fri	Thanksgiving - No Class!	
11/26/2018	Mon	Categorical data + writing your own functions	Chapt. 10 + Chapt. 11, section 11.1
11/30/2018	Fri	Non-linear regression	Chapt. 11, section 11.5
12/3/2018	Mon	A little programming and the central limit theorem	Chapt. 12
12/7/2018	Fri	Final - Written	
12/10/2018	Mon	Final - Computer	
12/12/2018	Wed	Final Presentations 12:00-2:30	

1 Electronic distraction devices, drugs, and other disabilities

In my classes we both agree not to text, chat, "do" Facebook or Instagram, recreationally watch YouTube videos, message, or do similar electronic gaming or distracting activities during class. Why? It's respectful and these activities are distracting to those around you. I think we both deserve respect in the classroom. If you ask me a question you certainly expect and deserve my full attention.

We also agree not to consume alcohol or other recreational drugs during class or come to class impaired by such activities. If either of us finds scheduling these activities (e.g., texting or doing drugs) around class time difficult then we should seek professional help (e.g., through the Lauderdale Center for Student Health & Counseling).

Additionally, those of us who teach at SUNY Geneseo will do our best to make reasonable accommodations for students with documented physical, emotional, or cognitive disabilities. In addition, we will do our best to accommodate challenges brought about through pregnancy, parenting, or care giving. Students should contact Assistant Dean Buggie-Hunt in the Office of Disability Services (tbuggieh@geneseo.edu or 585-245-5112) and me to discuss needed accommodations as early as possible in the semester. Note that I happily will help you to take exams in the Test Center (`https://www.geneseo.edu/is/testcenter/main`) during the regularly scheduled exam times. Please do not try to move the test day.

References

Hartvigsen, G. 2014. A primer in biological data analysis and visualization using R. Columbia University Press.

Schwartzstein, R. M., G. C. Rosenfeld, R. Hilborn, S. H. Oyewole, and K. Mitchell. 2013. Redesigning the MCAT exam: balancing multiple perspectives. Academic Medicine, **88**.