Seven Challenges for the Undergraduate Statistics Curriculum in 2007

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Outline

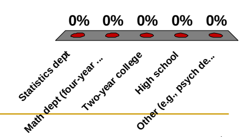
- Stat 100
- Stat 101
- Stat 101A
- Stat 102
- Stat 201
- Stat 201E
- Stat 499

Strategy

- "Nothing tunes the neurons like a little disagreement" – David Moore
  - I'll try to be provocative
  - Please, disagree with me often
    - In fact, keep track of how often you disagree
    - I'll probably disagree with myself more than once!
- Will barely scratch surface for each challenge
  - Could give 50-minute talk on each (have done so)
  - See handout for more details, references
  - Hope to generate conversations throughout conference

Which best describes your primary affiliation?

1. Statistics dept
2. Math dept (four-year college/univ)
3. Two-year college
4. High school
5. Other (e.g., psych dept, business school, …)



Challenge #1 (Stat 100)

How does statistical literacy / reasoning / thinking fit in?

GAISE goals for students in an introductory course

- Students should believe and understand why:
  - Data beat anecdotes.
  - Variability is natural and is also predictable and quantifiable.
  - Random *sampling* allows results of surveys and experiments to be extended to the population from which the sample was taken.
  - Random *assignment* in comparative experiments allows cause and effect conclusions to be drawn.
  - Association is not causation.
  - Statistical significance does not necessarily imply practical importance, especially for studies with large sample sizes.
  - Finding no statistically significant difference or relationship does not necessarily mean there is no difference or no relationship in the population, especially for studies with small sample sizes.

GAISE goals (cont.)

- Students should recognize:
  - Common sources of bias in surveys and experiments.
  - How to determine the population to which the results of statistical inference can be extended, if any, based on how the data were collected.
  - How to determine when a cause and effect inference can be drawn from an association, based on how the data were collected (e.g., the design of the study)
  - That words such as “normal,” “random” and “correlation” have specific meanings in statistics that may differ from common usage.

GAISE goals (cont.)

- Students should understand the parts of the process through which statistics works to answer questions, namely:
  - How to obtain or generate data.
  - How to graph the data as a first step in analyzing data, and how to know when that’s enough to answer the question of interest.
  - How to interpret numerical summaries and graphical displays of data - both to answer questions and to check conditions (in order to use statistical procedures correctly).
  - How to make appropriate use of statistical inference.
  - How to communicate the results of a statistical analysis.

GAISE goals (cont.)

- Students should understand the basic ideas of statistical inference:
  - The concept of a sampling distribution and how it applies to making statistical inferences based on samples of data (including the idea of standard error)
  - The concept of statistical significance including significance levels and *p*-values.
  - The concept of confidence interval, including the interpretation of confidence level and margin of error.

GAISE goals (cont.)

- Finally, students should know:
  - How to interpret statistical results in context.
  - How to critique news stories and journal articles that include statistical information, including identifying what’s missing in the presentation and the flaws in the studies or methods used to generate the information.
  - When to call for help from a statistician.

Some personal opinions/claims

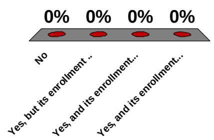
- This is a great list of goals
- These goals are hard to attain
  - “and understand why”
- You simply can’t achieve these goals in one course if you also teach a long list of methods
- Most students would be better served by a Stat 100 course than a Stat 101 course

Stat 100

- Focus on statistical literacy, conceptual understanding, “big picture”
- Much less emphasis on specific methods
- Aimed at *consumers*, not potential *producers*, of statistical analyses
  - *Statistics* (Freedman, Pisani, Purves)
  - *Statistics: Concepts and Controversies* (Moore and Notz)
  - *Seeing Through Statistics* (Utts)

Does your institution have a Stat 100 course?

1. No
2. Yes, but its enrollment is very small compared to Stat 101
3. Yes, and its enrollment is comparable to Stat 101
4. Yes, and its enrollment is much larger than Stat 101



I wonder …

- What percentage of students, after they graduate, ever …
  - Perform a *t*-test, or a chi-square test, or ANOVA?
  - Read an account of a study that involves sampling, or a randomized experiment, or statistical significance, or margin-of-error, or association, or causation, or confounding variables?

But can't we do it all?

- "Dogged attention to data analysis often comes at the expense of missing the bigger picture of statistical reasoning."
  – Dan Schafer

Comforting thought when I get discouraged about "and understand why"

- At least the mantras that students learn by rote now are better than when I started
  - Then
    - Order matters → permutations
    - Order does not matter → combinations
  - Now
    - Observational study → no cause/effect conclusion
    - Randomized experiment → possible cause/effect conclusion

Challenge #2 (Stat 101)

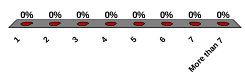
Do we really need umpteen flavors of introductory courses?

How many is "umpteen"?

- It depends on how you count (duh!)
- Any first course in stat, with no stat prereq
  - Cal Poly has eight
    - Liberal arts, social sciences, life sciences, agriculture, business, math/stat, engineering, computer science
  - If we exclude "Stat 100" courses: 7
  - Also exclude courses at post-calculus level: 4

How many is umpteen at your institution?

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. 7
8. More than 7



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Some personal opinions/claims

- We don't need so many different flavors
  - In fact, maybe one will suffice
- Offering so many only reinforces a mistaken and very unfortunate impression of statistics
  - Just a collection of tools
- Missed opportunity to present statistics as a unified discipline
  - Core ideas applicable across all applications

Some arguments for many flavors

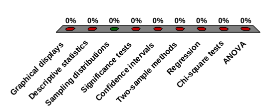
- Different application areas need different specialized topics
  - Life science: relative risk, odds ratios
  - Business: decision analysis, forecasting
  - Psychology: ANOVA
- Students will be more motivated, learn better if they see examples in their specialized field of study

My response

- Give me a break!
- But statistics is its own discipline with core ideas (yes, I'm repeating myself)
- Surely we can choose diverse examples likely to appeal to lots of students
- Students need to collaborate, communicate with those in other fields
- Those in client disciplines may not always know what's best

Which topic do faculty in client disciplines say can most easily be jettisoned?

1. Graphical displays
2. Descriptive statistics
3. Sampling distributions ✓
4. Significance tests
5. Confidence intervals
6. Two-sample methods
7. Regression
8. Chi-square tests
9. ANOVA



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I wonder …

- What percentage of students change majors between taking their intro stat course and graduation?
- What percentage of students become practicing professionals in the field of their major?

A pragmatic consideration

- I teach in a very special department
  - Statistics Dept with 14 full-time and 10 part-time faculty
    - University of about 18,000 undergrads
  - We'll teach 45 sections of undergrad courses in Fall 2007
    - About 35 students per section
    - Quarter system; about 120 sections for the year
- Why are we so lucky?
  - Because client departments like us
  - Why do they like us?
    - Because we teach (essentially) what they want
    - We do it well (their students don't complain)
    - I only say "give me a break" when I'm out-of-state

I wonder …

- What would a serious study of client discipline attitudes reveal?
- Is a compromise position tenable?
  - Perhaps one class meeting/week devoted to discipline-specific topics, examples, needs?

Challenge #3 (Stat 101A)

Should we re-center the Stat 101 universe?

Ptolemy vs. Copernicus

"We need to throw away the old notion that the normal approximation to a sampling distribution belongs at the center of our curriculum, and create a new curriculum whose center is the core logic of inference."

– George Cobb (2005)

You say you want a revolution?

"Computers have brought us opportunities for change as potentially revolutionary as the opportunities brought by rural electrification and the invention of the internal combustion engine, but to a greater extent than we realize, our curriculum is still mulishly pulling a tractor behind it, and our students are still going from room to room with a single light bulb."

– George Cobb (2005)

Example 1

- MythBusters: Is yawning contagious?
  - 50 subjects; random assignment

	Yawn seed planted	Yawn seed not planted	Total
Subject yawned	10	4	14
Subject did not	24	12	36
Total	34	16	50
Proportion	0.294	0.250	

- Contrary to what MythBusters claimed, this difference is not statistically significant
  - How to help students understand this?

One approach

- Calculate test statistic, p-value from approximate sampling distribution

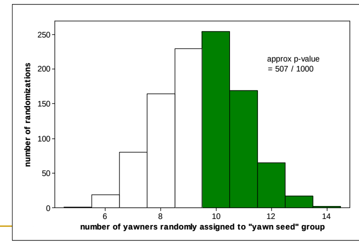
$$z = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}_c(1-\hat{p}_c)\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

$$= \frac{.294 - .250}{\sqrt{(.280)(.720)\left(\frac{1}{34}+\frac{1}{16}\right)}} \approx \frac{.044}{.136} \approx 0.324$$

$$p-value \approx \Pr(Z \geq 0.324) = 1 - .627 = .373$$

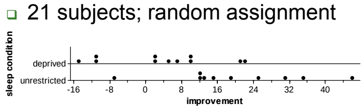
Another approach

- Simulate randomization process many times, see how often such an extreme result occurs



Example 2

- Does sleep deprivation have harmful effects on cognitive functioning three days later?
  - 21 subjects; random assignment



- Is such an extreme difference unlikely to occur by chance (random assignment) alone?

One approach

- Calculate test statistic, p-value from approximate sampling distribution

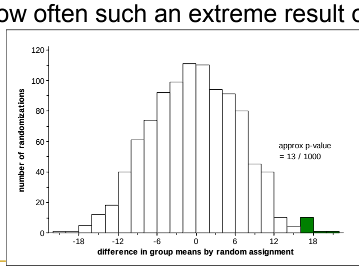
$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}}$$

$$= \frac{19.82 - 3.90}{\sqrt{\frac{(12.17)^2}{11}+\frac{(14.73)^2}{10}}} \approx \frac{15.92}{5.93} \approx 2.68$$

$$p-value = \Pr(t_? \geq 2.68) \approx .008$$

Another approach

- Simulate randomization process many times, see how often such an extreme result occurs



Potential advantages

- You can do this in week 1!
  - Spiraling could lead to deeper conceptual understanding
- Connects randomization in design to inference
- Emphasizes scope of conclusions to be drawn from randomized experiments vs. observational studies
- Very powerful, easily generalized
  - Flexibility in choice of statistic to be considered
- Takes advantage of modern computing power
  - Not just using software as *t*-table with more rows, columns
- Truer to what "founding fathers" (Fisher) envisioned

Still simple, but no longer so tedious

"The statistician does not carry out this very simple and very tedious process, but his conclusions have no justification beyond the fact that they agree with those which could have been arrived at by this elementary method." – R.A. Fisher (1936)

New project

- Concepts of Statistical Inference: A Randomization-Based Curriculum
  - NSF-DUE-CCLI #0633349 (Rossman, Chance, Cobb, Holcomb, Carlton)
  - Sample modules expected by end of summer
    - Randomization/permutation test for comparing 2 groups
      - Categorical response (2×2 table)
      - Quantitative response
    - Randomization/permutation test for matched pairs
    - One-sample test/interval for categorical response

Another resource

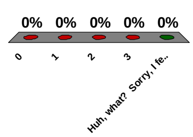
- Hesterberg, Moore, et al., *Bootstrap Methods and Permutation Tests*, supplemental chapter

I wonder …

- Which approach builds deeper student understanding of core concepts of inference?
- Which approach provides the better analysis?
  - Both are approximations
- Might statistics teachers welcome this approach?
  - What about faculty in client disciplines?

How many times did you yawn during that MythBusters example?

1. 0
2. 1
3. 2
4. 3
5. Huh, what? Sorry, I fell asleep and missed the example



Challenge #4 (Stat 102)

How do we deal with success in Stat 101?

Stat 101 enrollments

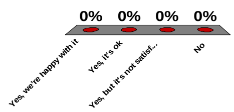
- Numbers of students taking introductory statistics courses in Fall 2005 (from CBMS Survey):
  - 148,000 in four-year college math dept
  - 117,000 in two-year college math dept
  - 54,000 in stat dept
  - 100,000 took AP Stat exam last week
  - Sub-total (under-estimate): 420,000

One reaction

"Please, sir, I'd like some more."
– Oliver Twist

Does your institution have a Stat 102 course, appropriate for students coming from Stat 101 or AP Statistics, without Calculus prereq?

1. Yes, we're happy with it
2. Yes, it's ok
3. Yes, but it's not satisfactory
4. No



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What should Stat 102 be?

- One approach: specialized courses
  - Regression
  - Time series
  - Experimental design
  - Multivariate methods
  - Data mining
  - …
- Another approach: identify core material, develop consensus for "ideal" second course

Some possibilities for Stat 102

- *The Statistical Sleuth* (Ramsey and Schafer)
  - "Statistics is like grout – the word feels decidedly unpleasant in the mouth, but it describes something essential for holding a mosaic in place."
- *Statistical Models: Theory and Practice* (David Freedman)
  - "At last, a second course in statistics that is serious, correct, and interesting." – Persi Diaconis

Some more possibilities for Stat 102

- Stat 2 Labs
  - Shonda Kuiper, Grinnell College
- CAUSEway workshop last summer
  - Julie Legler, St. Olaf College
- USCOTS pre-workshop
- Breakout session at 11:00 this morning
  - Robin Lock & Dick DeVeaux

Some personal opinions/claims

- This is *the* most important unresolved issue in undergraduate statistics education
  - We must offer good Stat 102 courses to students who get interested in Stat 101
    - Without requiring additional math prereqs
  - We must provide high-quality materials and support so that teachers can offer such courses without Herculean effort
  - Very good people are working on it

Challenge #5 (Stat 201)

Have we forgotten about math and stat majors?

Two options for math/stat majors

- Take Stat 101
  - Not challenging mathematically
  - Often perceived as "baby stat"
  - Often does not count toward major
- Take Prob / Math Stat sequence
  - Has emphasized math more than stat
  - Does not provide balanced view of discipline
  - Fails to recruit all who might be interested in statistics
  - Poorly prepares future teachers, even TAs for Stat 101

An alternative

- Adapt best features of Stat 101 / GAISE
  - Genuine studies, real data, activities, technology, simulations, conceptual focus
- Take advantage of students' mathematical abilities
  - Comfortable with functions, calculus
- Investigate mathematical underpinnings
  - Introduce probability "just in time"

An alternative (cont.)

- *Investigating Statistical Concepts, Applications, and Methods* (*ISCAM*)
  - Chance & Rossman, Duxbury Press, 2006
  - Supported by NSF-DUE-CCLI # 9950476, 0321973

Some mathematical applications

- Employ counting techniques for probabilities
- Derive least squares estimates
  - Univariate, bivariate cases
- Explore other minimization criteria
  - Sum of absolute deviations
  - Maximum deviation
- Consider M-of-E as function of π, n
  - Find π to maximize M-of-E (worst-case scenario)
- Analyze properties of linear, log transformations
- Investigate sampling distribution of log(odds ratio)

Other approaches

- Put more data, concepts, technology into Prob / Math Stat sequence
  - *Stat Labs: Mathematical Statistics Through Applications*, Nolan and Speed
  - *Modern Mathematical Statistics with Applications*, Devore and Berk
  - *Mathematica Laboratories for Mathematical Statistics*, Baglivo

A personal opinion/claim

- Math/stat majors are better served by working in the opposite direction
  - Put more math into Stat 101
  - Use spiraling approach so they encounter entire process of statistical investigations over and over

Challenge #6 (Stat 201E)

How should we prepare future teachers?

What's the problem?

"In most teacher preparation programs appropriate background in statistics and probability will not be provided by simply requiring a standard probability-statistics course for mathematics majors. It is essential to carefully consider the important goals of statistical education in designing courses that reflect new conceptions of the subject."

– CBMS *Mathematical Education of Teachers* report (chapter 5)

Some personal opinions/claims

- Teachers tend to teach as they were taught
- So, course should model effective pedagogy as well as present relevant content
  - Ideally, ask students to reflect on pedagogy, assessment, other teaching choices
- But I oppose multiple flavors of courses
  - So, offer Stat 201 to prospective teachers
  - With additional opportunities for reading and reflection on teaching practice

Some resources

- *Thinking and Reasoning with Data and Chance*, ed. Burrill, NCTM Yearbook
- *Developing Students' Statistical Reasoning: Connecting Research and Teaching Practice*, Garfield and Ben-Zvi (to appear)
- *Statistics Education in School Mathematics: Challenges for Teaching and Teacher Education*, upcoming ICMI/IASE study, conference, book

On second thought

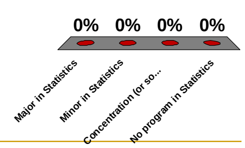
- Maybe I was wrong earlier
  - Maybe *this* is the most important unresolved issue in undergraduate statistics education
  - And I haven't mentioned the issue of training college teachers of statistics
    - Most of us have been trained on-the-fly
  - Or the related issue of TA training

Challenge #7 (Stat 499)

What do we want statistics majors / minors / concentrators to know?

Which of these undergraduate programs does your institution offer (choose "highest" one)?

1. Major in Statistics
2. Minor in Statistics
3. Concentration (or something like that) in Statistics
4. No program in Statistics



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Cal Poly Statistics major: student learning objectives

The graduate will

1. Have good working knowledge of commonly used statistical methods
   a. statistical modeling
   b. design of studies, sampling plans
   c. exploratory data analysis
   d. formal inference procedures
2. Have background in probability, statistical theory, and mathematics
3. Be able to synthesize and apply this knowledge and to tailor methods to the problem at hand, understanding the limitations of the procedures and the appropriate scope of conclusions
4. Communicate effectively (written and oral) with skills in collaboration (within and between disciplines) and teamwork
5. Have good mastery of several standard statistical software packages and facility with data management strategies
6. Have a focused concentration in an area of application outside the discipline of statistics

Cal Poly Statistics major: student learning objectives (cont.)

The graduate will have received:

1. Experience with real data and authentic applications
2. Frequent opportunities to develop communication skills
3. Capstone experiences for students
4. Frequent interaction with faculty and timely advising
5. Exposure to statisticians and statistical applications outside the Cal Poly community

Capstone course: Statistical consulting and communication

By the end of the quarter each student should be able to:

1. Understand the characteristics of an effective consultant, a satisfied client, and a successful consulting session.
2. Plan and implement a consulting session.
3. Facilitate effective communication with a client.
4. Ask appropriate questions in a consulting session.
5. Deal effectively with a variety of consulting situations.
6. Be aware of issues involving statistical ethics.
7. Find appropriate technical solutions to consulting problems, both individually and as part of a team.
8. Effectively present oral and written arguments.
9. Utilize professional publications and resources in statistics and other related fields.

Capstone course (cont.)

Course activities

1. Lectures and reading on technical statistical topics important in statistical consulting.
2. Lectures and reading on communication topics important in statistical consulting. Communication theories by Zahn and Derr are included.
3. Research in the field of statistical consulting obtained through published articles, textbooks, and interviews with practicing statistical consultants.
4. Multiple mock consulting sessions that will be recorded and reviewed.
5. Team-based project work including the development of statistical analyses and the development of written and oral presentations for different contexts. The presentations will be recorded and reviewed.
6. An individual consulting project including the development of a statistical analysis and the development of a written and oral presentation. The presentation will be recorded and reviewed.

Capstone course (cont.)

- Big challenge: helping students to put pieces together
  - Deciding which technique to use when
    - No longer have clear clue from name of course
    - Students think that data from a designed experiment can only be analyzed with ANOVA, not regression
  - Synthesizing knowledge from various courses
    - Not unrelated topics in list of requirements
  - Ensuring that knowledge of fundamental concepts is sound

Capstone course (cont.)

- Some resources
  - *The Practice of Statistics: Putting the Pieces Together*, Spurrier
  - *Statistical Consulting: A Guide to Effective Communication*, Derr

ASA’s Undergraduate Statistics Education Initiative (USEI)

- Developed, endorsed curriculum guidelines
- Articles about majors, minors
- Descriptions of exemplary programs

Summary of recommendations (exaggerated!)

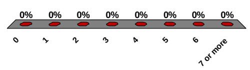
- Offer many more Stat 100 courses
- Offer fewer Stat 101 courses, of one flavor, and re-center around randomization tests
  - HW: Get buy-in from client disciplines
- Create canonical Stat 102 course
- Develop Stat 201 for math/stat majors, built upon Stat 101 but with more math
  - Make it appropriate for prospective teachers
- Think through learning goals of program
  - Implement capstone course to tie program together

Final thoughts

- Very exciting time in statistics education
  - Challenges are all *opportunities*
  - We stand on shoulders of giants
    - Moore, Scheaffer, Cobb, Garfield, Peck, Watkins, Utts, …
- USCOTS is living up to its “next level” theme
- Thanks for listening!

How many of my statements have you disagreed with?

1. 0
2. 1
3. 2
4. 3
5. 4
6. 5
7. 6
8. 7 or more



Where do you think I'm originally from?

1. Scotland
2. Ireland
3. Sweden
4. Canada
5. Minnesota
6. Brooklyn
7. South Carolina
8. Southern California
9. Mars
10. ✔ None of the above