A POST-CALCULUS INTRODUCTION TO STATISTICS FOR FUTURE SECONDARY TEACHERS

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We describe our experiences with developing and teaching a new introductory statistics course for prospective teachers of secondary mathematics. The course emphasizes statistical concepts through their applications in the context of recent scientific studies, and it uses an interactive technology-enhanced pedagogical approach that models recommended practice for teachers. A concurrent seminar course introduces students to seminal articles and research findings in statistics education, and encourages them to reflect on their learning experiences in the course as a way to prepare for their own teaching of statistics. Feedback and evaluation from students will be discussed.

INTRODUCTION

Statistics teachers at the secondary level typically begin their own study of statistics while pursuing an undergraduate major in mathematics or mathematics education. These students have traditionally been presented with two options for studying statistics: take the introductory, algebra-based service course (that we will call "Stat 101") or take a two-course sequence in probability and mathematical statistics (that we will call "Math Stat"). We see several problems with both options. The "Stat 101" course is aimed at a completely different, less mathematical, student audience. This option does not challenge these students mathematically, and it frequently does not count toward fulfilling the requirements of their major program. On the other hand, the "Math Stat" option usually presents only the mathematical aspects of statistics and does not provide students with a balanced view of the discipline. Since this class often focuses on probability rather than data analysis, it may not motivate students interested in statistical applications to study more statistics. Moreover, the "Math Stat" option does not present the fundamental ideas of statistical practice that the prospective teachers will be asked to teach if they lead an Advanced Placement course or follow the NCTM Guidelines. Nor does it typically employ pedagogical tools, such as activities and technology, that would provide effective models for future teachers to follow in their own courses.

In response to these concerns, we have developed an alternative introduction to statistics at the post-calculus level. We have taught this course three times for mathematics majors at Cal Poly who intend to pursue secondary teaching. We believe that this course provides an effective introduction to statistics for all mathematically inclined students, but we find the course to be especially valuable for prospective teachers. We described early development of this course at ICOTS-6 (Rossman and Chance, 2002) and at the IASE Roundtable on Curriculum Development (Rossman and Chance, 2004), and we have now published the curricular materials for the course in a book titled *Investigating Statistical Concepts, Applications, and Methods* (*ISCAM*, Chance and Rossman, 2006). In this paper we give an update on the *ISCAM* course and then describe a concurrent seminar course that we have developed for prospective teachers.

COURSE PRINCIPLES

The pedagogical principles on which we have developed this *ISCAM* course are:

1) *Put students in the role of active investigator*. Our materials are intended for use in a course that emphasizes active learning and asks students to construct their own knowledge of statistical concepts and methods. They consist primarily of investigations that present directed series of questions that lead students to explore and apply statistical ideas.
2) *Motivate with real studies and genuine data*. Almost all of the *ISCAM* investigations center on genuine data from real studies. The contexts come from a variety of scientific disciplines and also from popular media. Some of the questions that students investigate include:

a. Is there a relationship between the lighting conditions in a child's room and whether that child develops near-sightedness?
b. Does sleep deprivation have a detrimental effect on a visual discrimination task, even after two nights of unrestricted sleep?
c. Does a river downstream from a commercial hog operation have a dangerous level of dissolved oxygen?
d. Just as most people are right-handed, do kissing couples tend to turn to the right?
e. Is letrozole an effective treatment for women recovering from breast cancer?
f. Are popular diet plans effective, and is one more effective than another?

3) *Experience the entire statistical process over and over*. From the outset we ask students to:
   a. consider issues of data collection,
   b. produce graphical and numerical summaries,
   c. consider whether inference procedures apply to the situation,
   d. apply inference procedures when appropriate, and
   e. communicate their findings in the context of the original research question.

   Students consider all of these aspects of a statistical investigation in the very first chapter of the book. This pattern is then repeated over and over as students encounter new situations, for example moving from categorical to quantitative responses or from two to several comparison groups. We hope that this frequent repetition helps students to see the entire story, to appreciate the "big picture" of the statistical process, and to develop their confidence for "doing statistics." The following outline of the course content illustrates this "spiral" approach to sequencing:

	Chapter 1	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Data Collection	Observation vs. experiment, confounding, randomization	"	Random sampling, bias, precision	Pairing	Independent random samples	Bivariate
Descriptive Statistics	Conditional proportions, segmented bar graphs, odds ratio	Quantitative summaries, transformations	Bar graph	"	"	Scatterplots, correlation, SLR
Sampling/ Randomization Distribution	Randomization distribution	Randomization distribution	Sampling distribution of X, $\hat{p}$	Large sample $\hat{p}$, $\bar{x}$ sampling distribution	Sampling distribution $\hat{p}_1-\hat{p}_2$, $\bar{x}_1-\bar{x}_2$, $\hat{OR}$	Chi-square statistic, F statistic, regression coefficients, correlation
Model	Hypergeometric	"	Bernoulli, binomial	Normal, *t*, bootstrapping	Normal, *t*, log-normal	Chi-square, *t*, LINE
Statistical Inference	p-value, significance, FET	"	Binomial tests, CIs, type I/II error	*z* procedures for proportions, *t* for means, bootstrap	Two-sample *z*, *t*, bootstrap, CI for *OR*	Chi-square for homogeneity independence, ANOVA, regression

4) *Emphasize connections among study design, inference technique, and scope of conclusion*. Issues of study design come up early and recur throughout the materials. From the opening chapter we lead students to examine:
   a. why we can draw cause-and-effect conclusions from randomized comparative experiments but not from observational studies,

b. the importance of randomness in collecting data, distinguishing between *randomization* of subjects to treatment groups and *random sampling* of individuals from a population,
c. the concept of a sampling/randomization distribution, which allows us to assess whether the observed data could reasonably be explained by the randomness in the study design.
d. use of simulation to approximate a sampling/randomization distribution, followed by studying exact probability models and occasionally approximate probability models for those distributions

5) *Use variety of computational tools.* We expect that students will have frequent access to computer software as they work through our materials. We ask students to use technology both to analyze data and to explore statistical concepts. Our guiding philosophy is to choose the appropriate software tool for the task at hand. When the task is to analyze data, the appropriate tool is a statistical analysis package. We've chosen Minitab for its ease of use, but other packages could be used as well. When the task is to develop understanding of a concept, the tool is often a Java applet specifically designed for that purpose, typically with a premium on interactivity, context, and visualization. For a few tasks, such as examining the effect of changing a parameter value, the appropriate tool might be a spreadsheet package. We've chosen Excel as the spreadsheet package, but its use is minimal. We also ask students to do some calculations with a hand calculator, when that seems to be the most appropriate tool.
6) *Investigate mathematical underpinnings.* The primary contrast between this course and a "Stat 101" course is that we often ask students to use their mathematical training to investigate some of the underpinnings behind statistical procedures. An example is that students examine the principle of least squares and other minimization criteria in both univariate and bivariate settings. Probability models form another example, as students develop and apply the hypergeometric distribution to model a randomization test with a 2×2 table, and they use the binomial distribution to analyze data from a Bernoulli process. Students also examine functions symbolically and numerically to investigate issues such as sample size effects.

CONCURRENT SEMINAR

As we mentioned above, we have developed both the content and the pedagogy of this course with an eye toward what prospective mathematics teachers will be asked to do in their own secondary classrooms. The content focuses on fundamental ideas of collecting, analyzing, and drawing conclusions from data. The pedagogy emphasizes an investigative spirit of discovery throughout. As we taught the course for the first time in Spring of 2004, we realized that these points are often lost on prospective teachers. We needed to draw attention to these points and ask students to reflect on them and how they might pertain to their own future careers as teachers, so we developed a concurrent seminar course.

This one-unit seminar course asks students to read articles about various issues related to teaching statistics, to discuss those readings and issues with each other and with their instructors, and to reflect on those readings and issues through a series of journal writings. For these journal reflections we asked students to focus specifically on their own learning styles and experiences and also on their anticipated teaching style.

We offered this seminar for the first time in Spring of 2005. Eight students enrolled in the seminar, and the three of us (two statisticians and one mathematics educator) selected the readings, led the discussions, and read the students' journal writings. We met once per week for one hour (in addition to the four hours per week for the statistics course). That hour consisted of students discussing the reading for that week and answering questions posed by the professors and students. We often tried to stimulate discussion by asking students to write informally on specific questions at the beginning of class.

SEMINAR TOPICS, READINGS

The weekly topics and readings of this seminar were:

Week 1: Differences between statistics and mathematics (Moore and Cobb, 1997). We asked students to consider the importance of non-mathematical aspects of statistics, such as the crucial role of context and the substantial role of data collection strategies. Students also reflected on differences in their own experiences as students between mathematics courses and the concurrent *ISCAM* course that they were all taking.

Week 2: Educational psychology, pedagogy (Garfield, 1995). We introduced students to some of the research literature on constructivism and its implications for teaching and learning statistics. Students reflected on how the *ISCAM* course was implementing constructivist principles and whether they found that conducive to their learning.

Week 3: Statistical literacy (Utts, 2003). Students read and discussed this article that lists the most important statistical idea for educated citizens to understand. Some of the ideas discussed are fairly subtle, such as the difference between "normal" and "typical," and the distinction between "significant" and "important." Since the students were concurrently taking an introductory course, they were just becoming comfortable with these ideas themselves.

Week 4: Assessment (Wild, Triggs, and Pfannkuch, 1997; Cobb, 2004). We think that students were surprised to see how much thought and effort goes into developing exam questions and other forms of assessment. Students reflected on whether assessment methods are always closely aligned with course goals.

Week 5: Technology as a teaching tool (Mills, 2002). We asked students to read this survey article about the literature on using computer simulation as a teaching tool. Students reflected on their experiences using technology in mathematics courses as well as the concurrent statistics course. Students expressed very different opinions; some firmly believed that one must do calculations by hand in order to understand them; other felt that technology could be an important tool if used appropriately.

Week 6: Research studies in statistics education (Ben-Zvi and Arcavi, 2000). Students read an account of one research study done with elementary school children in Israel. Students came to realize how challenging it is to do educational research and how much insight can be gained from paying careful attention to students as they learn a new topic.

Week 7: Active learning (Keeler and Steinhorst, 1995). This article examined ways to implement active learning even in large lecture classes. This may not have been the best choice on our part, because prospective secondary teachers do not face the prospect of teaching large lecture classes. Nevertheless, we hope that the article helped students to realize that they could be creative in devising activities rather than constantly lecturing.

Week 8: Professional standards for teaching statistics. We asked students to read both the NCTM Standards as they pertain to data analysis and also the California State Standards. These readings engendered much spirited discussion. Students noticed how very different the two documents are, for the California Standards take a much more traditional, less reformed approach than the NCTM Standards. Students also reported that their eyes were opened as to the possibilities of teaching and learning substantial aspects of data analysis throughout the K-12 curriculum, whereas their own K-12 experience was quite limited with regard to studying data analysis.

STUDENT REACTIONS

At the end of the term, several students agreed to be interviewed about their reactions to the statistics course and seminar. These students were uniformly positive about both. Some of their comments about the *ISCAM* course include:

- I really like the examples and I really liked where we had the opportunity to predict something and then actually apply it and see how our predictions compared so I think that's neat because that to me gets me thinking more in depth about what something is actually going to do and then I am going to remember it longer because I actually had to stop and think, oh what is that going to do to what I am doing? So, I really liked that concept of it.
- When I think of statistics now I think of it as a way to analyze studies and experiments.

- The best was how it was very interactive.
- (Statistics) is interesting and it definitely has a lot of applications and there is logic behind it and not just a bunch of formulas and I could understand the logic behind it now.
- I enjoyed (simulation) because it kind of helped me see what was going on and help me believe certain ideas like the central limit theorem … it helped in convincing me because I like to be able to be convinced so before I apply anything.

The following quotes reflect students' general feelings about the benefits of the discussions that took place in the seminar:

- Some of the things we talked about I never really thought about…. I think a lot of technology talks we had and a lot of the discussions whether technology would help or not just made me want to make sure when I'm using technology in the class that I teach that I'm really careful … I think something else that was really um really cool to talk about was just all of the talk that we did on different learning styles and different teaching styles.
- Getting a perspective on public school teaching. Different philosophies … gave me an idea of how I would teach because I hadn't really thought about that.
- I found that it opened up ideas on how I would approach teaching methods … it was helpful to listen to other people's views and what they thought, especially reading through some of the materials and studies that were conducted.
- I found the discussions to be kind of helpful because they gave me a glance into how the teaching world is… I just think its nice to explore and think about cognitive issue and what helps students learn statistics and what helps me learn statistics.

The following quotes reflect students' answers to the question about which reading(s) they found most memorable:

- The one that was difficult to get into but was interesting was the study with the two boys and they were talking about how the teacher addressed them and that one was interesting to think about just because it was interesting to think about the experiments they did.
- The more memorable reading was the Standards papers for like second grade or so to first grade or so to the end of high school… since it gives us some sort of guidelines as for what children would need.
- I think it was also interesting to look at the Standards that we just did because that was different. Just to see what was expected.
- The experimental one with the two boys kind of stuck with me… they picked two random samples and not really random students… And then the last one the Standards, I presented on the Standards for one of my senior project classes and I discussed it there too and it talks about all of these standards and expectations.
- I think the reading that was most memorable was the one about (assessment) fairness. I also thought the one that I liked the second most was the Israeli one with the students.

All of the students interviewed said they recommend these classes to other students interested in teaching.

CONCLUSIONS

We think that the *ISCAM* course fills a very important gap in the undergraduate curriculum by providing an introduction to statistics for mathematically inclined students, adopting an investigation-centered pedagogy and emphasizing experiences with genuine studies and data. We believe that this course is especially valuable for prospective teachers. We also contend that the seminar course on teaching issues is very worthwhile, as it forces prospective teachers to reflect consciously on the process of learning statistics while they are taking an introductory course themselves.

Considering the students' positive reactions, we may ask them to read more actual research studies in the future, as students found it empowering to realize that many issues

involved with teaching and learning are open not only to debate but also to empirical investigation.

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This course is an introduction to the fundamental principles of statistical science. It does not rely on detailed derivations of mathematical concepts, but does require mathematical sophistication and reasoning. It is an introduction to statistical thinking/reasoning, data management, statistical analysis, and statistical computation. Concepts in this course will be developed in greater mathematical rigor later in the statistical curriculum, including in STAT 515, 516, 525, and 535. It is intended to be the first course in statistics taken by math majors interested in statistics.Â MATH 490A: Intro Abstract Algebra for Future Teachers. George Avrunin TuTh 11:30-12:45. Prerequisites