Experience Early, Logic Later

K. L. Weldon
Simon Fraser University
Canada

Statistics educators have been trying to improve undergraduate statistics instruction for decades. Some progress has been made but the forces of the status quo are formidable. One of the most frustrating constraints relates to the economics of textbook publication: few publishers will accept a script that is much different from the current market. Another constraint is the human effort required by both instructors and students to blaze a new path. Moreover, the disincentives to teaching effort, especially at influential universities, are well known. In spite of these impediments to reform, a small group of reformers is motivated to keep trying.

If students as a group had a keen interest in statistics, both teaching and learning would be more successful. In this paper, I want to encourage course designers and instructors to focus on the student motivation for the subject, even at the expense of shortchanging the student with the usual list of inferential tools. I will argue that guided immersion in real data-based problems, in contexts of interest to students, is a more effective way to produce useful learning of statistics basics than to present a logical sequence of techniques, even if the techniques are illustrated with applications as they are introduced.

The organization of the paper is as follows: The first section considers an overview of the progress of statistics education over the last quarter century. Next, the style and content of textbooks is used as a proxy for the teaching style and course content of many undergraduate courses in statistics – that the advances in textbooks have not solved the pedagogical problems. The important role of context-based motivation, "experience-based instruction", is then discussed. Next, some suggestions are presented concerning the year-levels at which context-based instruction is appropriate, and the related issue of class size is considered. Three examples of context-based teaching of statistics theory are then outlined. The final sections of the paper discuss the implications of context-based instruction for both undergraduate and graduate statistics courses.

Reform in Statistics Education

The ICOTS conferences that began in 1982 initiated a continuing international focus on the issues of teaching statistics. OZCOTS, USCOTS, ICME, and the ISI/IASE Satellite Conferences have also been a part of this activity. An unofficial theme of all the early conferences seems to be that instruction in the subject had not adapted appropriately to the expansion of statistics audiences from math majors to all majors. An additional theme of the more recent conferences seems to be that the changes associated with statistical software availability have not been adequately absorbed into undergraduate curriculum and pedagogy. In fact, an overarching theme is the lack of adaptation to changes in statistics instruction to reflect the changing practice in the discipline. As a participant in ICOTS 2, I joined the rising voices asking for change, and there were many good ideas being proposed in 1986. Consider the following quotes from ICOTS 2 in Victoria, BC, 1986:

"The development of statistical skills needs what is no longer feasible, and that is a great deal of one-to-one student-faculty interaction ..." (Zidek 1986)

"The interplay between questions, answers and statistics seems to me to be something which should interest teachers of statistics, for if students have a good appreciation of this interplay, they will have learned some statistical thinking, not just some statistical methods." (Speed 1986)

"Using the practical model [of teaching statistics] means aiming to teach statistics by addressing such problems in contexts in which they arise. At present this model is not widely used." (Taffe 1986)

"To take advantage of these developments, one must recognize that, while most statistics professors like statistics for its own sake, most students become interested in statistics mainly if the subject promises to do useful things for them. I believe that even the seemingly limited goal of developing "intelligent consumers of statistics" is best attained if students try to produce statistics on a modest scale. Only then do most students seem to become sufficiently intrigued with statistics to want to learn about statistical theory." (Roberts 1986)

These ideas span different parts of the problem: the need for interaction of students with experts in statistics, the need for students to learn the whole process of statistics from verbal questions to verbal answers, the need to incorporate context into students' experiences in statistical analysis, and the need to excite students about applications before presenting the theory. As an index of the extent to which these suggestions have been adopted, consider their impact on current textbooks. I suggest that the impact has been very slight, partly because the suggestions all relate to the process of teaching rather than the techniques to be learned. In fact, it is hard to imagine how a textbook would be written that would help the instructor with the above recommendations. One might conclude that a good start to implementing the recommendations is to contemplate abandoning the dependence on a textbook, at least for the sequencing of course topics. For undergraduate courses, the current textbooks could be used as a reference resource for students, rather than as a course outline. The text assigned to the course could remain as in a traditional course, but the instructor could change completely the role of the text.

I cannot summarize all the recommendations of the series of ICOTS, ISI, and ICME conferences any better than to quote from Brian Phillips report of David Moore's Invited address to the ICME 1996 conference (Phillips(1996)):

> In discussing what helps students learn, [David Moore] listed the following:
>
> Hands-on activities
> Working in small groups
> Frequent and rapid feedback
> Communicating results
> Explaining reasoning
> Computer simulations
> Open questions real settings
> Learning to work co-operatively

Even though many of these ideas were discussed in earlier statistics education conferences, they were still "new" in 1996 as they are today. The question I wish to ask readers to consider is how well modern textbooks incorporate these strategies, and also whether it is possible for a textbook to provide for all these strategies. I suggest experiential learning of the kind proposed in this paper is one way to incorporate all these strategies, and that textbooks should pursue an important but limited role as reference agents for students, and not as lecture guides for instructors and students.

More than Textbook Reform

Lovett and Greenhouse (2000) review and update the psychological research on course design in statistics to make recommendations for curriculum reform. The reforms they highlight are listed in their paper as "Collaborative Learning, Active Learning, Target Misconceptions, and Use of Technology". "Collaborative learning" refers to learning in teams and peer discussion. "Active learning" includes exploratory investigation and data collection, the "target misconceptions" item is described more fully as "confront students with their misconceptions", and "use of technology" means allowing students to use statistical software for both calculations and exploration. Few instructors would find these suggestions startling. However, it should be noted that textbooks do not help much with any of these reforms. What do textbooks say about teamwork, learning based on exploration, or confronting students with their misunderstandings? More and more textbooks do encourage "use of technology" although even in this reform area, exploratory use of software is less often proposed than are demonstrations or prescribed calculations with software. The implementation of the recommended reforms requires much more than reforming the textbook.

Moving away from the textbook, or a sequenced curriculum based on a list of techniques, raises many questions for the course designer. Some of the things we want students to experience are unobservable, and the final examination that tests the outcome may not be, by itself, the perfect instrument for guiding the learning. One suggestion to improve the situation has been proposed by Wessa (2008): providing an archive that captures students calculations as well as their calculation outcomes. In fact, the facility provided by Wessa facilitates communication between instructor and student, and among students as well, about the actual calculations under discussion. This removes the concern about arithmetic, and replaces it with a focus on method and interpretation. A pedagogical benefit is that the instructor does not have to force the student into one particular mode of calculation, and this recognizes that there are often a variety of ways to extract information from data. Wessa's facility is based on R but the user does not need to know R to use it. There is no charge to use the facility. To fully understand the potential of the Wessa facility, it is necessary to explore the website www.wessa.net. However, Wessa(2008a) has reported informally some quantitative evidence that involving students in discussion of quantitative strategies does actually improve their score on objective examinations, in which the examinations aim to assess conceptual understanding.

Another way to assist the instructor in moving away from the textbook as a lecture outline, is to provide a reference-friendly electronic textbook for student access. Students depend increasingly on clickable sources. One excellent example of this is the freely downloadable text called CAST (Sterling (2006)). With searchable key words and a detailed table of contents and index, this provides easy access to text material. Because it is electronic, optional links for further information are available. Another benefit of the electronic source is the multitude of java-based animations and parameter sliders. It is just more fun to use than a paper text!

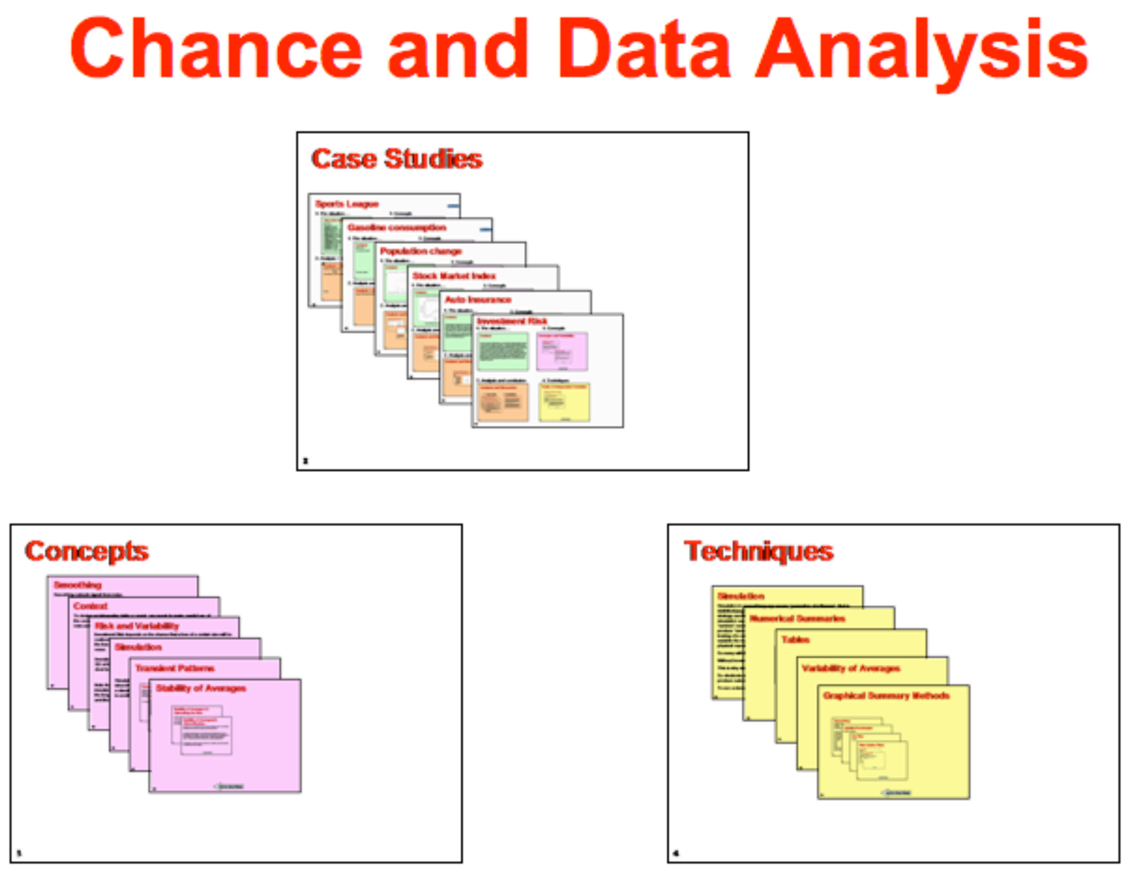


Fig. 1   Display from Roadmap Tools version of STAT 100 (Weldon and Carr (2008)). Each icon provides links to a more detailed display, and cross links are facilitated.

An interesting development making an experience-based course feasible is the Excel-based Roadmap Tools (Carr 2008). This software allows the instructor to prepare notes outlining the "experiences" and at the same time capturing the techniques and concepts illustrated as they are met in the explorations of the experiences. Fig. 1 gives a hint of the display: imbedded slides are brought forward by clicking, and communication with the instructor or other links are also enabled through this medium. In reviewing a technique, it is possible to return with a click to the case study in which the technique was introduced, or more than one case study if appropriate. Similarly for the concepts arising in the case studies. Or , if the student wants to know what techniques and concepts were supposed to have been learned from a case study, the linkage is there to provide the information. Students can use the display initially to access the case studies, and subsequently to ensure that they have mastered the intended techniques and concepts. This is one way technology can help students stay organized within a case-study or experiential approach.

An example of an electronic textbook designed for reference rather than as a lecture guide is the handbook provided jointly by NIST and SEMATECH at http://www.itl.nist.gov/div898/handbook/
With such a helpful electronic resource, students should be less dependent on a traditional textbook.

The benefits of experiential learning have been recommended for many years, notably as a common theme of ICOTS 4 (1994) sessions in Marrakesh. Don Bentley's "Hands-On and Project-Based Teaching" (Bentley, 1994) was so popular that it had to be broken into three sessions. However, the adaptation of this strategy into the current curriculum context seems to be problematic, since it is still not a common strategy at the tertiary level. An example of the creative atmosphere surrounding these sessions is the following quote from an abstract of Allan Rossman (1994): "In this presentation, I describe a project which takes this approach to the extreme of abandoning lectures completely". His abstract of the paper titled "Learning statistics through self-discovery" concludes with "The goals of these activities are to create a more enjoyable and productive learning environment as well as to deepen student's understanding of fundamental statistical ideas." However, university traditions seem to require lecture schedules and student-faculty interaction, and so a practical problem is how to incorporate the widely-recommended project device into a traditional lecture course. The proposals of this paper suggest a way of incorporating experiential learning into the undergraduate statistics curriculum.

Experience-based instruction

To a mathophile, logic is beautiful, but most practitioners of statistics are not mathophiles. We need to keep that in mind when we are directing our pedagogical efforts toward students of statistics. We want to attract future practitioners of statistics to our statistics courses. What device can we use to show the charm of statistics without losing the underlying logical structure? I will argue that the logic of statistics can be instilled subversively by seducing students through immersion in the process of context-specific, data-based "discovery", and only later providing the logical framework that is more generally applicable.

Of course, this approach is not new. Not only the ICOTS 4 concentration on the idea in 1994, but an intriguing compilation of student-conceived projects is recorded in the locally published volume in 1997 by MacGillivray and Hayes "Practical Development of Statistical Understanding". The report records the results of student-selected projects which satisfied the criteria for an problem-based statistics course. Although each student would have primary responsibility for only one project, and not a sequence of projects, the resource does suggest the richness of student-selected problems for motivating learning of the entire process of statistical analysis.

Even earlier, Tukey (1977) emphasised the importance of involving students in data analysis unencumbered by assumptions of parametric models. His emphasis on visualization and an exploratory approach was revolutionary at the time. He felt that students needed experience with data more than knowledge of formal methods of parametric inference. But the project-based approach that would provide this experience tends not to be used – most undergraduate courses still follow closely textbooks organized by parametric technique. When the project-based approach is used in a text-dependent course, it is thought to be an add-on rather than the main driver of exposure to statistics. The suggestion here, as it was in Rossman(1994), is that with adaptation, it can be the main driver, and that there are compelling reasons to consider doing it this way.

The mathematical culture of statistics instruction is pervasive. In this culture we think it is obvious that, to teach statistics, we need to start with basic definitions, follow up with basic tools, and build on these basics to construct the commonly used strategies of statistics practice. However, if we apply this seemingly obvious approach to other disciplines, it does not seem so obvious. For example, to teach conversational Spanish, we would start with vocabulary, grammar and pronunciation, and after a long period of becoming familiar with these skills, encourage students to converse. But immersion programs show that the formal phase of instruction works best after a lengthy immersion in motivated oral practice. Likewise, English grammar is best taught to children after they can speak English! Or, as another example, consider the math approach to teaching social geography: start with definitions of urban, climate, transportation corridor, enumeration area, etc. and get to the human impacts much later. To engage students' interest, it might work better to talk about human impacts first, and get to the formal definitions later. This same approach might not work for mathematics instruction, but it may well work for statistics instruction.

Whether a statistics course is designed as a service course or a mainstream course, the content tends to be technique-based rather than problem-based. Textbooks encourage this approach, and both students and instructors find textbooks a useful guide. Within the style of technique-based courses, many strategies have been devised to increase interest in the presentation of the techniques: data-collection projects, personal-data comparisons, in-class presentations, computer-based games, computer-quizzes with feedback, and simulation by applets or statistical software programs. These strategies certainly improve the likelihood that students will learn the techniques, and in some cases will increase interest in the techniques. But absent from these many strategies is the thrill of discovery: unexpected findings or anomalies that may have a bearing on the information gained from the data. What is often missing from traditional courses is the opportunity to use general intelligence, in combination with techniques learned from past experiences, to uncover information from data. How many students of statistics are aware of the fact that most applications do not use the "standard" techniques without adaptation?

An alternative to the technique-based course is the project-based course. The obvious argument against a project-based course is that the students will find the collection of techniques associated to be a jumble of unrelated tricks, rather than a logical sequence of strategies. But just as with geography or language, the formalities are a lot more useful to students after the students have an in-depth exposure to some examples. If students have been motivated to wonder what it takes to decide if a differential group effect is consistently reproducible, or transient, then they will be interested in the concept of a hypothesis test to tidy up the confusion. But the understanding of the information dilemma really needs to be internalized before this tidying is appreciated. Most instructors would agree that both theory and application need to be covered in a statistics course for the course to be useful to students. However, the mathematical approach of theory-first, application-after may not work as well as application-first, theory-after. The reason is that for the vast majority of students, it is easier to arouse interest in an application than in a theoretical concept.

Some instructors routinely use application examples to introduce statistical techniques, which is a reasonable way to motivate theory. But if the guiding theme of such a course is a series of application-technique pairs, this has not really deviated from the technique-oriented course. For application immersion, one needs an application that engages students for several days or weeks, with data to analyze, external background information to track down, feedback on analytical techniques suggested by students, opportunities to verbalize what the question is and what the findings are, and time to read up on similar studies that have been done. Classes are an opportunity for the instructor to suggest multiple approaches, invite criticisms, provide feedback from past suggestions of students, and ask questions for students to work on outside class. Only after two or three such projects are completed (maybe over 15 hours of instruction) would the instructor have enough technique material to outline the logical links among the techniques: types and numbers of variables, formal and informal analyses, estimation vs testing, prediction vs modeling, experiments vs experiences. The theory would be presented as a *simplifying* device rather than as an perplexing abstraction.

Students in "mainstream" courses of statistics (courses that would not be called service courses) generally have some tolerance for a mathematical approach to statistics. In particular, students of engineering, natural science, business, or psychology are required to have some math basics in their programs. But do these students actually like the mathematical, logical approach to their subjects? Is the chemistry student more interested in the periodic table or the relationship of sugar and alcohol? Is the business major more interested in the definitions of credits and debits or the earnings growth rate of Google? Mathematically-oriented students might actually be more interested in the periodic table and definitions of debits and credits, than the more applied topics, but such students are a small minority of the ones we want to introduce to statistics. As Cleveland (1993) says:

"A very limited view of statistics is that it is practiced by statisticians. … The wide view has far greater promise of a widespread influence of the intellectual content of the field of data science. "

If we accept that the target audience, even in mainstream courses, is users of statistics, rather than the statisticians that are a subset of this group, then we need to think about how to make statistics courses attractive to future users. While some advantage can be had from making the course process a pleasant social experience, with team assignments, and convenient venues, an important draw is to have very interesting content. To say that the logical, sequential approach to the introduction of statistical techniques is the only viable one is to deny the importance of motivation in learning. It is important to make the introduction of statistical ideas fall out of stimulating investigations into real data-based questions. The logical structure of statistical strategies can come later.

Improved learning as a result of heightened motivation is just one reason to use in-depth exposure to applications. Another reason is that students need to learn the *process* of statistical investigation, and not only the strategies and tools. This process involves many attitudes that need to be learned: the presumption that more subject-matter knowledge may help; the realization that modeling and analysis is to some extent a trial-and-error process, the appreciation of the dangers of overfitting or overanalysis, the importance of graphical methods for identifying anomalies and summarizing results, the availability of resampling methods when standard methods fail, and the appreciation of power in summarizing findings. These things are hard to reduce to single lessons – demonstration and repetition are required. Guiding students through immersion in real data analysis exercises, right from the problem formulation stage to the ultimate report of findings, is one way to "indoctrinate" students in this process.

The efficacy of experiential learning has support from the psychological literature. The "constructivist" approach to learning involves social collaboration and communication and individual responsibility and experimentation. Although the concept of constructivism is quite old, course designers are still working toward courses which incorporate all the aspects identified by recent researchers. (Moreno, Gonzalez et al (2007)). Another recent example of support for this approach comes from Konold (2007). He argues for "bottom-up" instructional design rather than "top-down". The idea is that for effective teaching, we need to start with the student's current context, and use this as a starting point for introducing new ideas. Experiential learning, including exploratory data analysis, student-choice projects, and verbal reports, does seem suited to bottom-up instruction.

A recent and extensive bibliography of the contribution of educational psychology to pedagogy in statistics is given by Garfield and Ben-Zvi (2007). In reviewing this bibliography, one is struck by the long list of difficulties experienced by students in learning from traditional technique-based courses. It does seem that experience-based pedagogy deserves a greater emphasis than has been usually practiced so far.

An important contribution to the role of experiential learning in the computer age is explored extensively in the series of articles recently published in the International Statistical Review. A lead-in to this series is provided by Seneta and Wild (2007). Although the emphasis is on computer-based learning environments, the important role of experiential learning is highlighted.

Integrating Experience-Based Courses into Undergraduate Education

Where does such an "experience" course fit in the undergraduate curriculum? I think the approach can be used at all levels. In recent years I have initiated a few new courses into the offerings at my university. Although they were proposed for various levels of student, they all have the feature that they are a series of examples rather than a logical sequence of techniques. I'll give a brief overview of these courses, since their style is close to the style I am recommending.

STAT 100: "Chance and Data Analysis". At the first year level, data relating to accidents by young drivers, sports leagues, blue whales, and the stock market, and others introduced ideas of causality, time series smoothing, simulation, sampling surveys and survival analysis. Of course, the basic definitions of means and standard deviations, frequency distributions, sampling variation, and scatter diagrams are introduced and repeated many times, in the context of the examples discussed. By the end of the course, the student has had all the techniques normally included in a first

course although perhaps less drill than usual.
STAT 300: "Statistics Communication". After two years of basics, students can begin to comment verbally on what they have learned. More specifically, they should be learning how to explain why certain techniques are appropriate in a particular data analysis, and what the analysis really shows. This course asks students to critique or defend criteria like "unbiasedness" or "minimum variance", to comment on the use of hypothesis tests when the sampling frame is uncertain, to discuss how to report anomalous data, and how to present orally or in writing what the real findings are in an instance of data analysis.
STAT 400: Data Analysis. The approach in this course is to ask students to suppose that the information in the data is more important than the techniques normally used to analyze the data. This helps the student understand that statistical practice is problem-based, and students are expected to use all their knowledge and intelligence to get at the information in the data. Of course, it helps if the content of the examples is of intrinsic interest to students. I have used a badly designed internationally funded agricultural study to draw attention to the value of good design as well as to provide an opportunity for students to try to rescue some information from the study in spite of its bad design. Another example uses a profit maximization strategy for a wholesale distribution network, in a situation where demand data is censored by inventory. Other examples use the data sets from Cleveland's *Visualizing Data* Book for which multivariate graphing provides a visual approach to information retrieval. Creativity in analysis is encouraged. These experiences lead to the use of resampling techniques, simulation to assess trial and error solutions, graphical smoothing in one or more dimensions, context-guided strategies to avoid the pitfalls of stepwise regression, and more.

Students find these courses both challenging and rewarding, judging from the feedback provided as part of the department's routine evaluation procedures. They are challenging because they require the student to move away from mere textbook knowledge, and they are rewarding because they confirm that a student can integrate their intelligence with the techniques they have learned to produce useful information from data.

Of course, the big question concerning this type of course is: When do the students find out about the logical structure of the discipline? There are different approaches for students with different needs. For students who take only one course, it may be futile to try to convey the logical structure. Perhaps for this group it is better to convey an appreciation for the utility of statistical strategies, rather than the basic tools and concepts themselves. For students who take more than one course, the subsequent courses can supply the logical structure – if the students appreciate the utility of the subject from the problem-based course, they will be both motivated and receptive to the more formal approach. However, an alternative is to include this step within a problem-based course. For example, each module of say, ten contact hours, can be followed by a "what tools have we learned" session with the logical structure emphasized. As mentioned earlier, this phase can be described as a simplification of the apparently chaotic collection of tools introduced for a particular problem. The website for STAT 100 at www.stat.sfu.ca/~weldon includes some examples of this approach. STAT 300 and STAT 400 are imbedded in course sequences that include more formal courses, and so the logical structure is, to some extent, left to these other courses.

The Class Size Constraint

The ideal of 1-1 instruction is clearly impractical at the undergraduate level. But small classes that allow discussion can sometimes be afforded. Over the last few decades, with the ubiquitous spread of data-based research into most disciplines, undergraduate class sizes have grown to one hundred and more, making discussion during a class meeting a rare event. How can students be exposed to the whole process of data analysis in a setting of large-class lectures? The efficiency of large classes may be an illusion in the case of statistics.

Various strategies have been used to try to solve the lack of student-faculty interaction that occurs with large classes. Small group tutorials is one common approach. Tutor-assisted group projects such as the ones documented by MacGillivray (1997) is another. Group assignments in which students help each other and thus reduce the need for faculty help is a third approach. But the guidance in the complete process of data analysis is most effective if an instructor experienced in both tools and applications has frequent interaction with students. Instructor-to-student lectures, as are common with large classes, do not provide this interaction. Strategies involving group work outside of lectures (as just mentioned) do provide some benefit. But the small class ideal would be best at allowing the instructor to balance the motivation of student exploration with the provision of guidance in the most effective tools and strategies.

One recent report (Carnell (2008)) which attempted to gauge the impact on learning of a single project in an introductory stats course, found that this project addition did not make an appreciable difference in learning outcomes. Perhaps several projects are necessary. If a project is seen as an extra, it may not be treated the same way as if projects are the main drivers of the course.

In a world of large classes in statistics, how does one move in the direction of experience immersion as a teaching device? One way is to have whole courses that are taught to smaller classes at the advanced stage (like STAT 400). Another is to try to create the experience in the large class by abandoning the "technique-coverage" approach and instead describe for students the process of development from idea to report. In such an approach, the assumption is that enough tools and strategies will be covered incidentally to the case-studies described to satisfy the programs that require one course in statistics. (like STAT 100). The justification for this shotgun approach is that it is better to have an understanding of a few common tools, than little understanding of a complete toolkit. However, it may be necessary to convince university administrations that the best statistics education requires small classes. For this to happen, the public view of the discipline of statistics may have to change from a necessary evil to that of a creative and vital subject! If students become excited about the small-class statistics course they are taking, then perhaps the message will get through to administrators that the subject is worth the higher price. So this is another reason to focus on drawing students into the subject matter with material that seems immediately interesting and useful.

Exploratory Contexts:

These days the internet provides a wealth of good examples for teaching material. In fact, there are some conventionally published sources as well: the text mentioned previously, MacGillivray and Hayes(1997), details the teaching experiences in 19 different application scenarios: from fishing to motorcycle accidents to Murphy's Law. The availability of ideas for projects is useful, but the pedagogic effectiveness of an example really depends on how it is presented. Consequently, the instructor's role is still key to the learner's outcomes.

The suggestion in this paper is that exploratory data analysis, suitably guided, will lead a student to understand basic statistical strategies, and the student will learn the basic statistical strategies more thoroughly in a given time frame than if the same strategies are presented in the more conventional way. The reason is that the student will be motivated by the obvious relevance of the strategies since they will be introduced as the data exploration requires them. But will the student be able to apply the strategies to new contexts? This is where the instructor's role is crucial. After several data exploration examples have been worked through, the instructor needs to make sure that the student has the big picture. This is where the logical relationships of the techniques need to be presented.

For students to be able to use their learning of statistical tools and concepts in new contexts, they do need the logical structure clearly in mind. For example, they need to be aware of the different scales of measurement, of the different ways comparisons can be made, and of the difference between parameter estimation and testing parameter credibility. But, as we have argued, to try to teach these in a sequence of techniques has not worked well – better to have them as a framework for techniques motivated by data-based projects, when there is a readiness for aggregating the pieces learned.

To further illustrate the potential of teaching techniques through experience immersion, I will briefly describe three examples. The first one should appeal to students since they get to choose an activity from their own lives. The second one has the advantage of relating to local conditions. The third one relates to a personal characteristic that students hold subconsciously and would often be of interest to a student in comparison with others. All of the examples could be used in a first course, or in an advanced course. Of course, statistics courses with a subject area focus (e.g. life sciences, business, engineering or psychology) would likely include examples more closely related to the subject area, and would build on a more specialized student background. But these examples will suffice to illustrate the point of conveying useful statistical theory through comprehensible applied projects with real-world contexts.

Example 1: Sports Leagues

Students often have at least one sport they are interested in, either as a participant or a spectator. Team sports have the feature that game results are accumulated throughout the season and teams are repeatedly ranked using some points system. Suppose students are given the task of finding the accumulation table of a currently operating league, and commenting on the relative quality of the teams suggested by the table. Students should be advised to choose a sport that interests them, if possible. Questions for discussion might be:

1. If team A has more points than team B, does team A have a better than even chance of winning the next contest with team B?

2. Is there any evidence of a home team advantage?

3. If all the teams have the same chance to win each game, what would the league ranking look like?

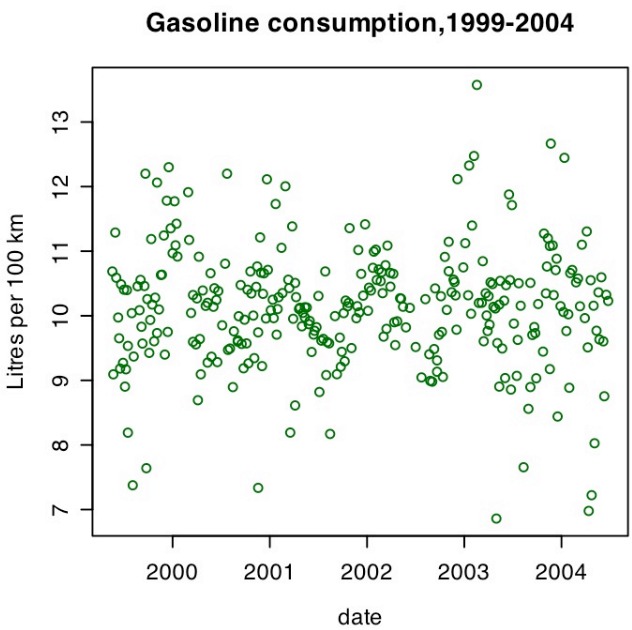
Note that many students will have an opinion regardless of their statistics knowledge so far, so a discussion should be easy to stimulate. Where would the discussion lead? Here are just a few of the possibilities:

a better understanding of "better than and even chance"
a realization that current rankings are, at least in part, subject to "luck" or "random variation"
an opportunity to test a hypothesis by observing data
consideration of conditional probability
an appreciation that randomness can deceive and often does
an opportunity for answering a question via simulation (by coin or computer)
a need to define a measure of variability (in point status)

The point of this example is that a context of interest to students can be the platform for introducing many important statistical tools and strategies, and because the answers to the questions are of interest to the students, the tools and strategies that help to get at the answers will also be of interest to the students. The motivation for learning statistics is based on a genuine interest and not only on the need for a good mark in the course. The learning will include the entire process of data-based study and not only an artificially simplified context. Moreover, the freshness of the discussion should make the process stimulating for both student and instructor.

Example 2: Auto Fuel Consumption

An example that I like to use is based on some personal data I accumulated on gas consumption for my car during a five year period. The graph shows the data:



Students are asked if they find any interesting or useful information in this graph, and are asked to analyze the data to see if there are any "trends" or anomalies. The initial response is usually negative. It turns out that fitting ordinary polynomial regression reveals nothing much, just as a visual scan would suggest. But any kind of nonparametric smoothing, even a moving average, shows a nice sinusoidal pattern in sync with the annual seasons. This pattern raises the question of the likely cause, and the many potential explanations include usage, temperature, precipitation, traffic, and tire pressure. Note also the likelihood of a negative serial correlation as a result of the way gas consumption is measured. What does the student learn from this experience?

not all regular patterns in time can be discerned by eye
a correlation can have many causes, and often further data collection is suggested
nonparametric smoothing is a useful exploratory technique
not all interesting data is a sample from a population (time series)
the measurement context must be examined as part of the analysis

Example 3: Crossing of Arms and Clasping of Hands

Macgillivray (2007) reports a project in which a large class of students were asked to report their normal way of crossing their arms and clasping their hands. Students are intially surprised that there is a "natural" way to do these things that is personal for each student. There is the question of whether gender, or handedness, explain the differences, and whether arm crossing is related to hand clasping. An advantage of this example over the other two is that, even if one is an unusual student with no interest in sports or driving, one is still likely to practice arm crossing and hand clasping. The referenced paper gives the full detail of this example, but some of the obvious lessons one learns from the experience are:

the procedure of developing an idea into a data-based study is a non-trivial exercise
careful definitions and protocols need to precede data collection
two features can be related even when exceptions exist
categorical data is summarized by frequencies
descriptive techniques need to be used before inferential techniques
descriptive techniques can often reveal unexpected findings
"obvious" relationships are sometimes not confirmed by data
apparent relationships can be deceiving and require testing for reproducibility

Looking over the twenty "lessons learned" from these three examples, even though they are a partial list, should suggest the richness of the learning experience with respect to statistical practice. Are these lessons as useful to students as the ability to fit a line to x-y data, or test if two groups have the same mean? While students do need to learn about the calculation methods, they need these meta strategies as well to have a useful education in statistics.

These three examples suggest the broad spectrum of statistical tools and strategies that can be conveyed through immersion of students in stimulating applications. One only has to consider how the lessons-learned from the examples would be taught one-at-a-time in a logical sequence to see that the logical approach would lack the charm of the experience immersion. If we want to attract and retain students' interest in statistics, we need to consider charm! And, if we want students to understand the whole process of data analysis, we need to give them experience with the whole process of data analysis.

Target Audience for Statistics Strategies

The mathematics model of teaching statistics is a product of the 20th century, math-based history of statistics. It seems to work for those few students who relish mathematical abstraction, and the current cadré of statistics instructors are mostly drawn from this group. But today modern statistics is practiced by a wide spectrum of engineers, scientists, and social scientists, and these users need more than a superficial knowledge of statistical strategies. STAT 100 does not adequately prepare these users. These users must be able to identify opportunities for data-based studies, plan data collection, explore data, extract valid information from data, and defend what they have done in words. It is this large group of future practitioners of statistics that needs the most attention at the undergraduate level, not the stat major. The stat major can benefit from math courses, even math courses with little statistical overlap. But the future statistics practitioners need to know how to use statistical software to explore data, and how to allow for study design shortcomings in coming to conclusions.

Practitioners educated in applied disciplines will not be able to handle all data-based problems they meet, and will find it necessary to seek the help of expert statisticians. However, to take advantage of this expertise, they must recognize the opportunity. Do the technique-based courses give students the insight needed to know when an expert can help? A student who has met a situation in which the perfect test is unknown, such as would be likely to happen in an exploratory study, may be willing to admit the need for expert help in later practice.

To become expert statisticians, graduate work would usually be required. This is where the full confluence of mathematics and statistics should be explored. Instead of designing a special undergraduate education for stat majors (future statisticians), it might be efficient to give all the statistical practitioners the same undergraduate education in statistics, but require further mathematical statistics in graduate courses. With this approach, undergraduates learn to appreciate statistics as a vital subject relevant to many careers, and are not deceived into thinking of statistics as a specialized form of mathematics; and graduates will not arrive at the serious study of statistics with a naive view that statistics is a bundle of calculation tools, and will realize that the role of mathematics in statistics is to allow adaptation of available methods to suit particular application contexts.

Mathematics is a powerful technology for clarifying complex ideas, and is essential for expertise in many "applied" disciplines. Theory in engineering, management science, environmental science, and many other fields is assisted by mathematics, but these theories are not only mathematics. The same is true of statistics. It is now clear that statistics is a separate discipline from mathematics, even though this was not always recognized in the past. We need to judge statistics expertise by its relevance to the extraction of useful information from data, and not by the mathematical expression of its tools. Our teaching of statistics should reflect this criterion.

Summary

The content of undergraduate courses in statistics has not changed very much in spite of the reform movement of statistics educators. Better textbooks, and the provision of computer software, have changed the tasks of the student, but objectives as revealed through tests and examinations have not kept up with the recommended reforms. What seems to be missing is the immersion of students in the entire process of data-based research along with frequent interactivity with the instructor. The motivation provided by interesting projects (suggested by the instructor or the students themselves) is an important factor in shaping the image of the discipline, as well as being a powerful stimulus to learning. It may be necessary to depart from large classes to accomplish a useful exposure to statistics: higher education administrators need to see undergraduate statistics as concepts and strategies rather than procedures and formulas. Statistics courses need to include more experience and creativity and less coverage and dogma.

Of course, balance of the old with new is probably the optimal strategy, but change has been so slow that extreme measures need to be contemplated. The basic recommendation in this paper is to provide students with exciting experiences in extracting information from data, and after the student is completely amazed by the many surprising and useful strategies of statistics, proceed to provide the formal structure of the techniques used, including the mathematics as required. We need to recognize that the main audience for statistics at the undergraduate level is future practitioners of statistics, and the principal secondary market is for statistics appreciation courses. The training of future statisticians should not be considered and undergraduate mission. Future statisticians need the practical knowledge of the undergraduate education, as well as graduate work in mathematical statistics. Our focus in undergraduate education should be on experiential immersion in data-based discovery. The conveyance of the logical structure of formal statistical inference will to some extent be achieved simultaneously, but in any case should be relegated to the status of a secondary goal.

References:

Bentley, D. (1994) Sessions 4A,B,C in Proceedings of the Fourth International Conference on Teaching Statistics. Vol 1: pp 17-31. The National Organizing Committee of the Fourth International Conference on Teaching Statistics. Rabat, Morocco.

Carnell, Lisa J. (2008) The Effect of a Student-Designed Data Collection Project on Attitudes Toward Statistics, Journal of Statistical Education v16/n1 www.amstat.org/publications/jse/

Carr, Rodney (2008) Roadmap Tools for Excel. www.deakin.edu.au/~rodneyc/roadmaptools.htm

Cleveland, W.S. (1993) *Visualizing Data*. Hobart Press, Summit, NJ.

Garfield, J. and Ben-Zvi, D. (2007) How Students Learn Statistics Revisited. A current Review of Research on Teaching and Learning Statistics. International Statistical Review, 75(3) pp 372-396.

Konold, C (2007). Designing a tool for learners. In M. Lovett & P. Shah (Eds.) *Thinking with data* (pp 267-291). New York, Taylor & Francis.

Lovett,M.C. and Greenhouse, J.B. (2000) The American Statistician: 54(3) 196-206.

MacGillivray, Helen, C. Hayes (1997) Practical Development of Statistical Understanding: A Project Based Approach. Queensland University of Technology. Brisbane.

MacGillivray, Helen C. (2007) Teaching Statistics: 29(2): 49-53.

Moreno, L., Gonzalez, C. et al (2007) Applying a constructivist and collaborative methodological approach in engineering education, Computers & Education, 49 (2007), 891-915

Phillips, B. (1996) Plenary Lecture Given By David S. Moore (USA) "New pedagogy and new content: The case of statistics". Proceedings of ICME 8, Seville, Spain.

Roberts, Harry V. (1986) Data Analysis for Managers. ICOTS 2. pp 410-414. Victoria, BC.

Rossman, Allan (1994) "Learning Statistics Through Self-Discovery". Abstract in Proceedings of the Fourth International Conference on Teaching Statistics. Vol 1: p30. The National Organizing Committee of the Fourth International Conference on Teaching Statistics. Rabat, Morocco.

Seneta, E and Wild, C. (2007) Preface. International Statistical Review v75(3) 279-280.

Speed, Terry (1986) Questions, Answers, and Statistics. ICOTS 2 pp 18-28. Victoria, BC.

Sterling, Doug (2002) Computer Assisted Statistics Teaching (Version 2.1) and for an up-to-date version go to cast.massey.ac.nz/

Taffe, John (1986) Teaching Statistics: Mathematical or Practical Model. ICOTS 2 pp 332-336. Victoria, BC.

Tukey, J.W. (1977) *Exploratory Data Analysis*. Addison-Wesley. New York.

Wessa, P. (2008), Free Statistics Software, Office for Research Development and Education, version 1.1.22-r5, URL http://www.wessa.net/ See also www.freestatistics.org/index.php?action=10 for more information.

Wessa, P. (2008a) Personal Communication.

Zidek, James V. (1986) Statistication: The Quest for a Curriculum. ICOTS 2 pp 1-17, Victoria, BC.