Teaching Large Classes of Science and Engineering Students

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1. Introduction : the importance of service courses

This paper is about teaching large service courses in introductory statistics, with particular reference to engineering students and science students not majoring in mathematics. Identification with the requirements both of the service subject and the large class helps in making the subject successful and rewarding for students and lecturer. "Rewarding"? Yes, because service courses are an essential aspect of the influence of the statistical profession on the use of statistical techniques. From the students in such courses come the statistical users, those who will consult with statisticians and, perhaps, those who will employ statisticians. If statisticians do not teach them, opportunities are lost to establish communication with potential and even with current users, through liaison with other departments and professional areas.

Service teaching in statistics contributes also to the visibility of the statistical profession with students. Because of the diverse nature of statistical applications, the statistical profession does not have such a highly visible profile as areas like engineering, commerce and business, medicine, or computer science. Such areas often attract mathematically-inclined students who are drawn either to readily identifiable careers or to areas perceived as essentially practical. Students in a statistics service subject may and do become interested in statistics and pursue it, sometimes changing to specialise in it. It is important that statistics departments allow for, and recognise the desirability of, attracting students to statistics through service teaching.

Lastly, not only are such subjects an integral part of the tapestry of statistical usage and consulting, but, like consulting, they are part of the bread and butter for the statistical profession. To be able to afford jam, we need to take care of our bread and butter.

For reasons of space, this paper can discuss only some aspects of statistics service subjects and large classes. Teaching students with few mathematical (even arithmetical) skills, combining disparate backgrounds, assessment procedures, can be mentioned only briefly here. Use of statistical packages opens up enormous possibilities for teaching statistical methods, for discussion, and for understanding concepts, but I have had to set this topic aside completely.

My comments are based on my experiences with biological and physical science, and engineering students in classes of sizes 140-300 at the University of Queensland, where I took approximately sixteen such courses in about ten years. In particular, my comments are based on feed-back from the students themselves, through questionnaires and other means. They are as general as possible, and will apply not just to science and engineering students. Individual differences between students will always mock generalisations, but generalisations are still valuable and necessary in the interests of discussion.

2. Large class teaching

2.1 *Components of quality*

Quality teaching is more than a simple negation of bad teaching. It is not easy to identify what contributes to quality teaching, because different factors are not independent, and because it is also a highly individual and everchanging activity. However, a broad analysis is that quality tertiary teaching is made up of quality in (a) organisation and management; (b) content and course structure; (c) knowledge, understanding, and love of subject; (d) communication and vitality: caring.

Quality and level of explanation come into (b), (c) and (d). In small classes, quality in (c) and (d) can often compensate for lack of quality in (a) and (b), but in large classes, inadequacies in (a) or (b) can actually prevent quality in (c) and (d) shining through. A large class magnifies effects, and therefore every aspect of the course requires care and thought. The quantity of time per student may be small, *but* it is the quality not the quantity of time that is important. The key to handling both these aspects is planning and management. Identification of goals and potential problems may sound like today's buzz words, but it does help in maximising quality and efficiency.

The usual accusation against large classes is that they are passive learning situations and that there's not sufficient interaction. My own worst experiences of passive learning were in classes of fewer than ten students. Large classes are certainly challenging, but also exciting. Indeed, isn't there more rather than less opportunity for interaction with a large class? Again and again, students' comments on questionnaires stress two main aspects of what they appreciate: one concerns course organisation and management, and the other is the feeling that the lecturer cares about the students and "every aspect of the course". Such comments come from both science and engineering students, but for engineering students in particular, recognition of the pressure under which they work goes a long way towards producing an effective course for them. In return, their need to efficiently manage their study makes them highly appreciative of similar qualities in their lecturers.

2.2 *Interaction in lectures and tutorials*

Both students and lecturers in a large class need an interactive relationship, and this can be provided. Again, the key is the quality of the use of the lecturer's time and not the quantity. Efficient management aims to meet the students' information needs within lectures and tutorials. A large class magnifies the effect of any lack of information, confusion, misprints, mistakes, or lack of clarity. Conversely, keeping the class constantly informed on the what, how, when, and why of the course, makes them feel part of the whole process. Tutors need a similar level of information to avoid any confusion and subsequent time wasting. Solutions to exercise sheets for tutors are essential so that their explanations fit the lecturer's.

All lectures are performances: a large class simply means that good preparation shows more, and that greater concentration is needed during the actual performance to establish contact with *all* the class. Preparation should be enough to let the lecture flow, but not inhibitive, as vitality is essential to a good performance. When the total organisation of the course is under control and running smoothly, and the lecturer is completely at ease with the subject, interaction with a large lecture class is easily achieved (sometimes more easily than with small), with some similarities to the style of theatre that relies on audience participation. Even though knowing names in a large class is almost impossible, recognising faces in lectures is unexpectedly easy. It is interesting how surprised students are that you know their faces from lectures, and it helps enormously in interaction and hence control. In science classes it can be an effort to get students to respond, but it is worth the effort. Engineering classes always respond; their overall vitality is as rewarding as it is challenging.

Interaction with a large class requires a certain amount of stage management, so it is essential that tutorials provide the back-up. I prefer to run my tutorials more as practice classes, in largish groups with a number of tutors per group plus myself. This arrangement also translates naturally to the computing lab situation, and has the advantage of smoothing over variabilities in tutor experience. Attending tutorials maximises my contacts with the students in group situations as well as individually, establishes an atmosphere of interaction between students, tutors, and myself, and minimises the need for contact outside lectures and tutorials. Creating an atmosphere of availability and willingness to help will actually help decrease the urge to contact the lecturer outside lectures and tutorials, but only if associated with an overall management strategy. In general, engineering students tend to be efficient with their queries, while science students sometimes need a little firmness to establish the ground-rule: no tutorials, no extra privileges.

2.3 *Organisation*

From a practical point of view, unless a textbook is such that the course can be centred on it and that every student has access to a copy, it is little use as a text. However, it may serve as a reference for optional supplementation to lectures that should then be self-sufficient. Printed notes tend to be both more efficient and enable better use of precious class time, but are worthwhile only if their use enhances lectures. For example, omitting the actual working of chosen examples until class is not only the best way to discuss the material, but also helps solve the problem of combining printed notes with class attendance. Optional references open the possibility of different reference books for different groups of students, but it must be emphasised that they are references only and *not* texts. For any large class, a summary is of enormous benefit, and, if a statistical package is used, handouts reproducing in full, sessions using the package, are essential. An interesting contrast is that science students tend to like full notes, while engineering students seem to cope better with a mixture of handouts and their own notes, although they do want clear, well-defined, and plentiful headings.

There are many ways of organising exercises, worksheets, and assignments. Full information on due time and place should be clearly marked on the assignment. Full solutions to assignments for all students reduces questions and marking problems. Numerical answers on exercise sheets also reduce queries; I prefer full solutions to exercise sheets to be available during tutorials, with sets in the library for photocopying purposes. Marking coordination can be controlled centrally with marking schemes and marker guidance and training, or done by moderation over fixed groups. I prefer the former because it gives better feedback to students during the course, because the assumptions of moderation do not necessarily apply to small groups, and because I have more control. Assignments are part of the learning process, and so the most important aspect is to get students to do them. I have found that counting a small percentage each is enough incentive to do them, but still allows students to receive some help. Submission security is a must, preferably using a locked box.

In a large class, assessment should have enough to get the workers through, with a small component of extra to sort out the top. One necessity in assessment is again to give as much information as possible for the students: how it's marked, coverage of course, any bookwork, comparison with level of assignments. Comments on past papers will pre-empt endless questions.

3. Course structure

3.1 *Syllabi and the serviced departments*

Syllabi should be decided through consultation between servicing and serviced departments. Just as statisticians need to know the wishes and requirements of the serviced areas, so too we should not hesitate to (diplomatically) voice suggestions and concerns based on our teaching and consulting experience. I have found a considerable number of serviced departments a delight to work with, but I have also found that non-statisticians' views on teaching statistics are sometimes highly coloured by their own learning experiences which may not translate to the current situation of their students.

Undergraduate students need and appreciate emphasis on the essential threads linking various statistical techniques. Messy or over-ambitious case studies, and practical problems that rely too much on understanding of the area of application, can cause misery in an introductory subject, and can actually leave permanent confusion. Of course, extensive examples and teaching through examples are essential; and at the introductory level, students seem to need a great variety of contexts and examples. A golden rule is that *every* example should be firmly context-based, with the emphasis on identifying what is known, what the question is, and answering in context.

Syllabus descriptions for introductory statistics courses often tend to sound the same, but the actual content and structure for the particular situation require considerable thought, planning, and talking with the serviced department. Serviced departments very much appreciate such information as statements of the aims of the subject, lecture diaries, use of examples and statistical packages, and feedback on students. In their turn, updated feedback from serviced departments provides valuable background information. Students also appreciate statements of aims; for them I add that, as well as aiming to give them a sound basis on which to build, I also aim to get them and me through the course as smoothly as possible.

3.2 *Some general comments on content*

Since one of the aims is to give the student confidence in basic statistics, the lecturer should be completely at ease with his/her explanations; hesitancy is quickly interpreted as indicating the material is "too hard". Perhaps a good motto for subsidiary material is, if in doubt, leave it out. Another important aim which results in the same motto is to work towards what is important to *them*. For example, I do not know of any service subjects that cannot omit *all* mention of coins, cards, and combinations. It is very easy to demonstrate probabilities and their uses in relevant contexts. For example, because engineers often deal with variables in complex situations, it is important to immediately put the emphasis for them on random variables and distributions and deal with probability in the context of distributions.

For all students, it is important to identify random variables in applied contexts, recognise situations in which the basic distributions are appropriate (whether or not they see the distributions or just use tables), and discuss measures of location and dispersion. All students benefit from seeing data generated from various distributions, and this plus considerations of combining random variables, lead naturally to samples and statistics and data presentation.

No matter how modern are the aims of the course, confidence intervals and tests for one and two sample normal situations provide an ideal framework for introducing the use of statistics and their distributions. They also provide opportunity to fight the "learn it to death" syndrome by using examples almost exclusively, avoiding as much as possible anything that looks like a formula, and emphasising "similar technique, different statistic". If the emphasis is placed on assessing assumptions by comparing observed values of statistics with their distributions under the assumptions, formal hypothesis testing becomes a by-product with jargon. Once again, every example should be context-based, and as much like a miniature case study as possible. Once the basic ideas are established through the above, the building blocks are there. If regression, ANOVA, and experimentation are done using a package such as MINITAB, examination of residuals opens a whole vista of discussion of model assessment.

Another general comment is that the whole course should be integrated, and consistent in its themes. Students appreciate an integrated approach, in which lectures, exercise sheets, tutorials, and assignments all play their allocated and *stated* roles. Particularly to first-year science students (except perhaps to computer science students who often remind me of engineering students), I need to emphasise again and again that *doing* is part of the learning process, that exercises are not testing but teaching, and that learning lecture notes by rote is a waste of brain power. In contrast, engineering students are usually better at getting stuck into exercises and using lecture notes for reference, although I sometimes remind enterprising individuals that slightly closer reading of one's notes can help, and that perhaps exercise sheets were designed to be worked through forwards rather than backwards.

4. Explanation and mathematical level

Consistency and conciseness of explanation are worthy goals in this type of subject, and clarity of explanation is essential for a large class. It comes from emphasising the essence of the statistics, letting each component of explanation play its role in the overall "story", and tailoring the explanation to the audience, not vice versa.

Although statistics service subjects should use mathematics only where the students will need it themselves, it can be just as damaging to underuse mathematical ability and background as to foist too much mathematics on an inadequate background. Wherever possible, students with grossly disparate mathematical backgrounds should not be artificially combined in one subject, but a moderate range of backgrounds is not a problem because a statistics service subject relies on convincing rather than proving, and the two are not necessarily the same.

The effect of the mathematical emphasis in engineering courses depends largely on the timing of their introduction to statistics. If this occurs at second or third year level, the solidarity of the mathematical background can be of assistance, but there may be some peculiar effects due to an over-exposure to deterministic mathematics. This can also be observed in physics students, although usually at a more sophisticated level. For example, engineering students often have difficulty in accepting that something is only estimated when it is "measured". Engineering and physical science students often do not get enough statistics but at least they should be introduced to basic statistical concepts in parallel to deterministic modelling.

Science students, especially in biological and life sciences, often have a better understanding of the need for statistics, and sometimes even of the different sources of variability. However, many need frequent reassurance that confidence in using basic statistical techniques does not necessarily depend on confidence in mathematics. Indeed, in teaching students with no calculus at all, negligible algebra, and shaky arithmetical skills, the main battle is to get rid of fear. There is no need to speed-teach calculus for statistics. On the other hand, it is also important not to frustrate the more mathematically able and inclined students; a little extra attention goes a long way in meeting their needs.

5. Conclusion

Service subjects are both challenging and rewarding. Positive feedback from past students as they use statistics in their own areas is part of the reward. Statistics can be an exciting area to teach at all tertiary levels, provided the subject is appropriate for the audience. In service subjects, the need to explain the essentials of statistical techniques with little or no recourse to mathematical proofs, and to relate them to practice, has the positive aspect that matters of current relevance to consulting and research can colour discussion even at the introductory level. The management challenge of large classes is obvious. But a bigger audience means greater appreciation of performance. As with all teaching, the aim should always be one of overall quality and efficient management.