Encouraging the Engineering Student to Feel the Importance of Statistics - Some Ideas

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1. Introduction

In Swedish universities of technology all students take at least one compulsory course in statistics. It may vary in length, depth, and content depending on what university of technology and what study programme you consider. Luleå University of Technology is young, 19 years, and fairly small, about 2000 engineering students. It comprises seven study programmes. In Luleå all students get a basic course of statistics of 48 classroom hours. Some students go on with reliabilty, quality control, regression analysis, survey sampling, time series analysis, or stochastic processes, depending on what study programme they are taking. Every second year the PhD students in engineering subjects are offered a course based on Box, Hunter and Hunter (1978), where experimental design is emphasised. We are currently working on introducing a course in quality technology for all engineering students including quality management, quality control, reliability, and experimental design.

Too many engineering students start the basic course in statistics with the attitude that statistics is of no interest to them, it is boring, and probably useless. Furthermore, they have a limited amount of time to spend on the course. They usually study two or three other courses in parallel, courses that they may feel are more relevant in their education. The duration of each course is a study period of eight weeks.

With these facts as starting points I will discuss ideas I have found fruitful when trying to encourage the students to feel the importance of statistics. I will draw on 15 years' experience of teaching engineering students in Luleå within different study programmes.

2. The importance of real-world data

Many teachers and authors have stressed the importance of introducing a course using real-world problems, preferably from the field of interest of the students. I agree with that and find it of the utmost importance. It does not matter if the problems are a little "too difficult" for the students, although the ideal situation is that it will be possible to find solutions to the problems during the course. I prefer to present problems involving data sets and to ask a lot of questions, focusing on the importance of trying to draw conclusions and exploring new features. See, for example, Chapter 1 in Vännman (1990) and Vännman (1983).

The examples can be taken from the local newspaper as well. I have found that discussing a mixture of some problem connected with the students' subject area, something from the newspapers, and some data that they generate themselves during the first lesson, is usually a good start. To generate data in the class I might ask the students to estimate my height (see Dunkels, 1987). I have found that this little exercise helps them to get acquainted with me and to feel comfortable, and so I usually start with this activity. We go on and analyse their estimates of my height using a stem-and-leaf display and a box-plot, focusing on what conclusions can be drawn, and the variability.

Whenever possible in a course I think one should use real data from real-life situations, the earlier in the course the better. My experience is that real data and problems arising from engineering departments affect the students' attitude to statistics a lot. Furthermore it is important not only to focus on the statistical technique itself but also spend time on interpreting the results. From school the students are fed up with small invented data sets, drawing a histogram, or calculating a mean without seeing what it is good for.

It is not always an easy task to find relevant data. Those involved in statistical consulting usually find examples. Different statistical and engineering journals may also provide examples and case studies. Within the area of experimental design, the *Journal of Quality Technology* (1988) and Snee, Hare and Trout (1985) are useful. Suggestions on experiments designed and performed by students are found in Hunter (1977). There is a book (Andrews and Hertzberg, 1985), full of data sets gathered from many different situations. It would be valuable to have an annotated list of books and journals with real-world data, both small and large data sets, suitable for teaching engineering students. With such a list easily available I think more teachers would base their courses on examples with real data. I agree with Hogg et al. (1985) that most teaching should be done by examples. Theory should be less stressed than in a theoretical course but not completely abandoned.

There are different ways of introducing real-world problems in the classroom. One way that I have tried is to use short video programmes. The Open University, UK, has produced 16 short (about 25 minutes) videotapes in connection with their course 245 Probability and Statistics. Several of these tapes consider interesting real-world problems, like "How many parking meters should you expect to repair per day in a town with 2400 meters?" or "How do you know that the expected volume of coke cans is not less than 330ml, which is the bound set by the EEC regulations?". With the video the students see things I cannot show as a teacher, for example, how the volume of coke cans is measured in the factory. It is also a welcome interruption to the usual teaching.

It is always good to have variation also in the way you teach. My experience is that the students appreciate seeing these videos, but there should not be too many in a short course. There are other videotapes, for instance, the American *Against All Odds : Inside Statistics*, which unfortunately do not run on our Swedish video system.

3. Exploratory data analysis and graphical techniques

When I came across John Tukey's *Exploratory Data Analysis* (Tukey, 1977) towards the end of the seventies, I became really fascinated by these simple and efficient tools as well as the attitude behind them. Since 1980 we have taught simple EDA methods, such as stem-and-leaf displays and box-plots in all our basic courses. The students have two small projects right at the beginning of their course, where they analyse data using EDA as well as traditional descriptive methods. They work in groups of two students and are supposed to spend about 4 hours' work on each small project. In the first project they generate their own data by investigating how readable different books and newspapers are. In the second project they get data generated from engineering situations and use computers to analyse the data. My experience is that the inclusion of EDA has made the students grasp the concept of variability earlier in the course. Since box-plots are so convenient for comparison we can discuss problems like the following very early in the basic course.

Some years ago researchers from Luleå University were involved in evaluting the effects of automatic speed limit signs. If you exceeded the speed limit of 30 km per hour, the signs told you with big letters *You are driving too fast. Remember those with defective vision.* The signs were located near a school for students with defective vision. The speed of passing cars was measured at several points just before the signs were installed. Then the researchers measured, at the same points as before, the speed of passing cars one week, three months, and one year after the signs were introduced. The results, shown as box-plots, can be seen in Figure 1. The small line on the outside of the box indicates the mean, and the cross indicates the 85th percentile. Here questions about how to gather the data, how many cars to check, what quantities are of interest, how to interpret the results, can be discussed early in the course.

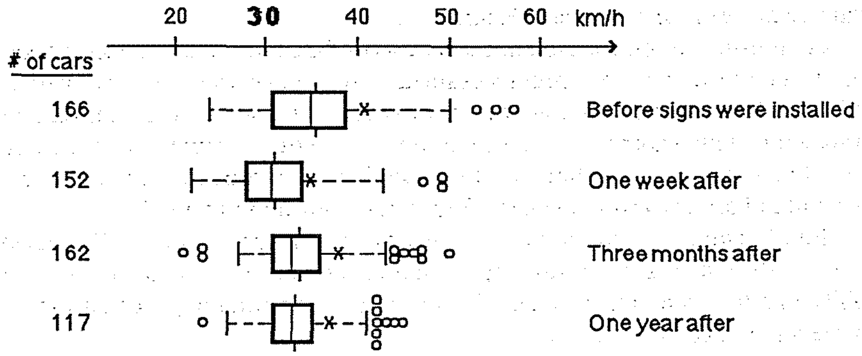

FIGURE 1
Comparing the speed (in km/h) of cars, where the speed limit is 30 km/h

I believe that the use of graphical methods encourages the students to be involved in statistics. Regardless of how plots or diagrams have been drawn, by hand or by computer, you cannot avoid looking at them and so you get a visual impression of your results. When you only calculate a statistic it is easy to do the calculation and then forget about the interpretation and what the result tells you.

Let me mention the use of probability papers to check distribution assumptions. When the students encounter this simple graphical tool the the phrase "distribution assumption" becomes something meaningful. They can also investigate, in the course where they consider ball bearings, if the lifetime of a studied ball bearing seems to follow the Weibull distribution by using Weibull probability papers. Since the graphical methods are easy to use and understand the students continue using them after the statistics course has ended.

Experimental design is an area which is becoming popular in industry today, especially the simple 2^k design, both full and fractional designs. The use of normal probability paper when interpreting the results is very convincing. The engineering students appreciate it both since it is easy to interpret and since it is easy to use when communicating the result to others.

As an example let me show the two normal probability plots of Figure 2 and Figure 3 from Vännman and Varbanova (1989). They arise from a study of the epitaxial thickness of an epitaxial layer on silicon wafers used in IC fabrication (see Kackar and Shoemaker, 1989). Eight design factors were considered important in controlling the thickness. The eight design parameters were each tested at two settings. The chosen design for the experiment was what Box, Hunter and Hunter (1978) call a 2^{8-4}_{IV} fractional factorial design. The thickness was measured at five places on each of 14 wafers, giving a total of 70 measurements from each of the 16 experimental runs. These measurements reflect the effect of noise. For each experiment the mean and the logarithm of the variance were recorded.

The objective of the experiment was to find the design factors and the settings which would make the variance of the epitaxial thickness small and make the mean thickness close to 14.5 micrometers.

To find the design parameters that have the largest effect on the variability, we will consider the logarithm of the variance as our response variable and estimate the main effects and the interaction effects using the standard method for 2^{k-p} fractional factorial design (see Box, Hunter and Hunter, 1978).

All the estimated effects are linear contrasts of the same kind. If a factor does not give rise to an effect, then we expect its estimated effect to behave as an approximately normally distributed random variable with zero mean. By plotting the estimated effects on normal probability paper we can distinguish the real effects from those that occur by chance, which will fit reasonably well to a straight line through zero, while the real effects will fall far away from the line. The result is shown in Figure 2.

From Figure 2 we can see that, in order of importance, factor H (Hydrochloric acid flow rate) and factor A (Susceptor-rotation method) have real effects on the variability and to some extent factor D (Deposition temperature). But all the other effects seem to be due to chance alone.

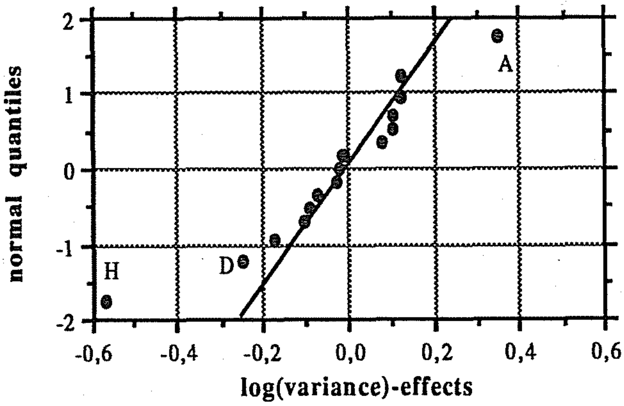

FIGURE 2
Normal probability plot of the effects of the logarithm of the variance

In order to find the design factors that have the largest effect on the location, we will consider the mean as our response variable and estimate the main effects and the interaction effects as above. From the normal probabilty plot of the effects of the mean in Figure 3 we see that there is one very dominant adjustment factor, namely the deposition time D, and all the other effects seem to be due to chance only.

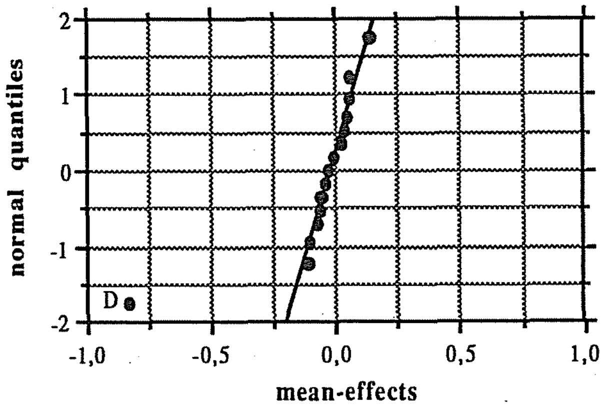

FIGURE 3
Normal probability plot of the effects of the mean

After having found the factors of interest we may summarise their effects in other illustrative plots, for example in a location-dispersion plot and a factor-level effects plot (see Vännman and Varbanova, 1989).

Much more can be said about the importance of using graphical methods in teaching. An example of the use of graphics in regression is found in Denby and Pregibon (1987).

4. The use of computers

In Luleå all statistics courses include the use of computers. Four rooms, each with 15 IBM compatible AT machines, are available to all students around the clock. The students are already acquainted with computers (from other courses) when they start the basic course in statistics. We use the software Statgraphics, STSC Inc (1986–1988), since it contains most of the methods we need, is easy to use, is menu-driven, has good graphics, and uses colours. According to my experience, colours and good graphics have an encouraging effect on the student. It is important to have software which is easy to use, since the short valuable teaching time should be spent on statistics and not on programming. It is also important to have students' manuals that are well designed for the course. I have found that, for each small project with computers, a separate self-instruction manual has meant that the students can concentrate on the statistical problem. There are no more complaints about too much time being spent on finding the correct buttons to press.

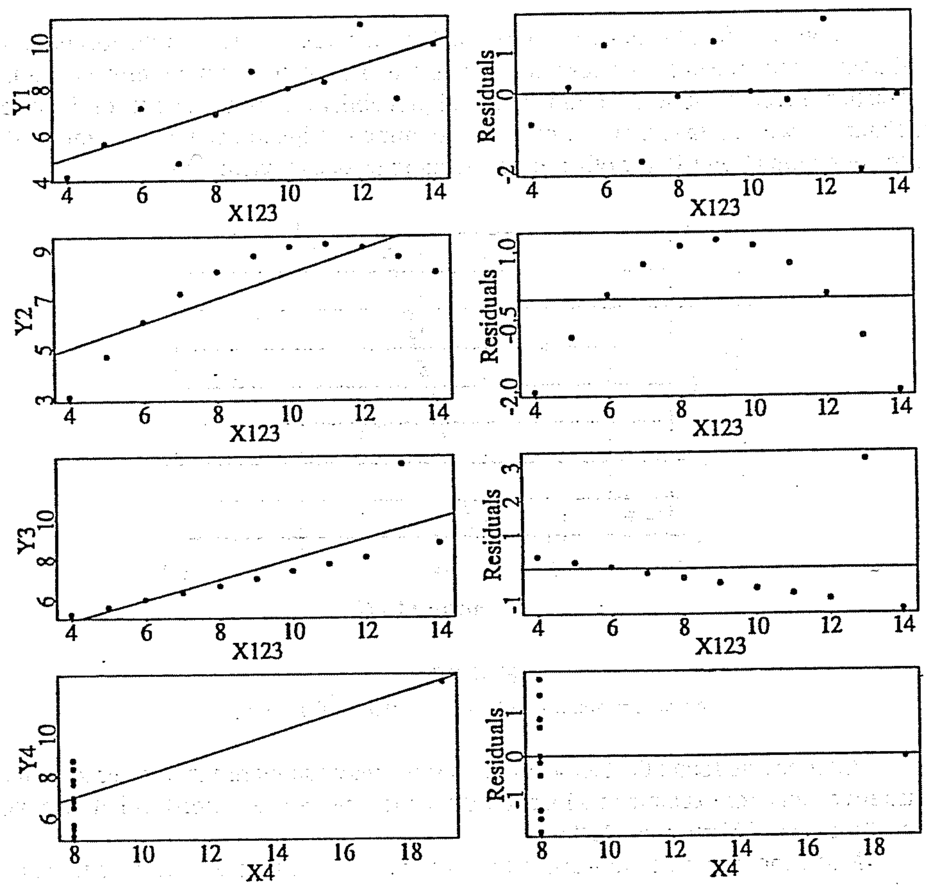

FIGURE 4
Data and residual plots for four fictitious data sets from Anscombe (1973)

It is important to use real data, but invented data can be very useful as well. Starting up courses in regression analysis I introduce Statgraphics by giving the students the four fictitious data sets by Anscombe (1973) to enter in Statgraphics. Then they are asked to explore the regression command and the plots using these four data sets. The data sets differ considerably and are designed to give the same regression line and the same analysis of variance table. Many students have had aha-experiences when having seen the plotted data and the corresponding residual plots. See Figure 4 to understand why. The importance of plots and analysis of the residuals in regression analysis is evident after this little exercise.

When teaching regression analysis or analysis of variance I consider the computer indispensable. Earlier I gave the students the data sets they were going to analyse on disks, anxious that they should not spend their precious time on entering large data sets. However, the small projects they handed in did not seem to have engaged them, despite the fact that the data sets consisted of real data. One year the circumstances forced me to give them the data on a piece of paper instead, and the students turned out to be much more concerned about the data. And no-one complained about the time needed for entering the data. Of course, it is best if students can collect their own data, which is usually difficult to administer with large groups of students. But at least entering the data in the computer gave them some sort of feel for it.

Apart from using the computer in the work with the small projects, where the students work in pairs, they are encouraged to use the computers on their own. I have prepared handouts with suggestions on how to simulate data and explore methods and theory discussed during the lessons. One handout is about plotting simulated data on probability papers to get an understanding of how normal and non-normal samples may look on a normal probability paper. Such experience is valuable.

We have now got a portable computer with an overhead projector screen, and I have found that the class discussion is invigorated when I bring it to the classroom now and then. I have used it, for example, when introducing the concept of an estimator, its distribution, and properties. When discussing the estimation of the expected value of a symmetric distribution the students may come up with the following three suggestions of estimators: the mean of the observations, the median and the mean of the smallest and largest observation. Using Statgraphics it is very simple to generate samples from different distributions, calculate the estimates, and compare their distributions using box-plots. Figure 5 shows what the students might see. After simulations like these we could have fruitful discussions about what an estimator is, how it may vary, that it can be efficient in one situation, but need not be in another, and so on. We could also try other estimators suggested by the students during our discussions.

Statgraphics has a facility to prepare diagrams, save them, and then replay them on the screen. I once replayed some prepared diagrams in the classroom with no success. I could as well have brought overhead transparancies of the diagrams. When, instead, the students could see me typing in the different commands, including my typing errors, they were more involved in, or even in charge of, the discussions.

My experience is that bringing the computer into the classroom, using it for shorter periods, encourages the students. It is important not only to present formulas and procedures to the engineering students but to spend time on developing the statistical concepts, and the computer is a very useful tool for that also.

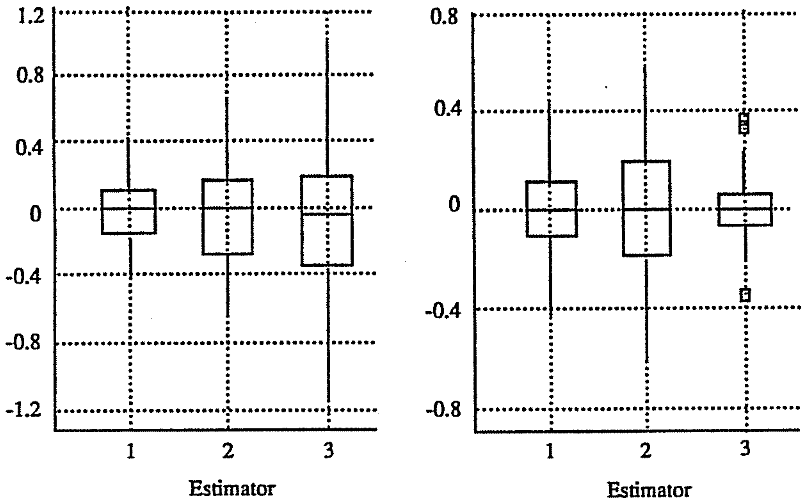

FIGURE 5
Comparisons of the estimators (1) the mean, (2) the median, and (3) the mean of the smallest and largest observation, using box-plots of 100 estimates based on simulated samples of size 10 from a normal distribution to the left and a uniform distribution to the right

5. Encouraging activity

Real-life data, EDA, graphical methods, and the use of computers are all important ingredients when encouraging the engineering student to feel the importance of statistics. But we have to be aware of the fact that the students have limited time and that they may feel one of the parallel courses to be more relevant in their education. So I think it is important to encourage the students to make the most of classroom time.

In Luleå the students are taught, in classes of about 30, in a student-activity kind of way. This means that the teacher tries to avoid talking constantly and instead presents examples and theory in the form of a dialogue. We believe that teaching the students in smaller groups is more efficient than lecturing, and that activity of the learner is essential for a positive learning environment.

I have found it to be most important to start every lesson by not talking. Instead I present a small problem to the students on a prepared overhead transparancy, and they immediately begin to solve it on their own. The problem is often a review of the previous lesson or has some connection with the new ideas to be discussed during the lesson. The most important thing is that the lesson begins with student activity rather then student passivity. One such problem is described in Vännman (1983). The students appreciate the "small problem starter" very much. They say it supports them in their effort to study the subject continously and keeps them up-to-date with what is going to be discussed.

Unfortunately, due to lack of teachers, we have sometimes been forced to give lectures in larger groups. It is more difficult to get instant feedback in a large lecture group than in a group of 30 students. To overcome that problem, and to let the students influence the ongoing course, I have adapted to my circumstances the excellent idea from Mosteller (1988), called the muddiest-point-in-the-lecture. At the end of each week I have handed out a paper where I have asked the students a few questions like: Should the lecturing speed increase, decrease, or be the same next week? Should the time for discussions and questions increase, decrease, or be the same next week? Which of the last week's problems or areas do you find difficult or have questions on? The course where I have used the weekly evaluation has 6 hours' lecturing plus 2-4 hours' lessons in smaller groups per week. After discussing with the students we have decided to make the evaluation once a week instead of every lecture, as Mosteller has done. They have felt they would not answer it if it was given too often and, furthermore, they wanted to study the course book and try to solve some problems at home before answering.

I took the answers into consideration and changed the lecturing speed if they wanted me to do so. Furthermore, every Monday I started to discuss some of the problems or areas that several students had commented on. In a sense I reviewed the past week's topics. That was regarded as beneficial. Furthermore, several students said that they made a short review the evening before they were to answer the weekly evaluation. The students also appreciated the possibility of affecting the time spent on questions as well as the lecturing speed during the on-going course. One interesting thing to be observed here is that at one of the courses where I used this weekly evaluation many students said at the end-of-course evaluation that the lecturing speed had been too high. But when looking through the weekly evaluations I found that only in one week, out of eight, they had asked me to slow down. That was in the sixth week. But obviously they remembered that week the most when they answered the end-of-course questionnaire.

The way I teach will, of course, affect the activity of the students as well as the encouragement the students get. I think that there are no two teachers who are alike, and that there is not one good way of teaching only. I have found several useful ideas in Mosteller (1980). And I always feel that I get new insights and ideas for every new group of students I meet and whenever I discuss teaching aspects with other teachers. That is why I find conferences like ICOTS so important and rewarding.

6. Some final remarks

There are two points I have not touched in this paper. One is the essential question "Who should teach the statistics courses?". I recommend the article Moore (1988) with subsequent discussion, for valuable views. The other, no less important, is the content of the statistics courses. I have suggested that real-world data, EDA, graphical methods, and the use of computers, should be included. But much more could be said. Let me recommend the excellent report by Hogg et al. (1985) and urge all teachers of engineering students to discuss the report in their own departments.

I have presented some points which I have found useful when trying to encourage the students to feel the importance of statistics. I know that I am not alone having these thoughts and I know that many other interesting and useful ideas are around. I am convinced that we can learn a lot by sharing experiences and discussing at a big international conference like ICOTS. I am positive that the talks in this session will give us many stimulating discussions and ideas for improving the teaching of statistics and the statistical education for engineering students.

7. References

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