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# Teaching Statistics to Engineering Students – An Australian Experience of Using Educational Technologies

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**ABSTRACT:** Engineers require scientific methods whereby models are developed to explain real phenomena. Model building, data collection, data analysis, and data interpretation form the very core of any sound engineering practice. Therefore statistical methodologies are vital components in engineering curricula and engineers should have the ability to think statistically when dealing with data. They should learn how to design and conduct well-planned experiments to improve the efficiency of the process and the quality of products, and must learn to deal with data, and interpret results produced as a part of their data analysis skills. Statistical methods are vital in engineering practices such as process monitoring by control charts, process optimization by response surface methodology, determining important factors by hypothesis testing, process modelling by regression analysis, initial pilot plant operation by design of experiments and laboratory recommendation. This paper shares some of the experiences of teaching statistics to undergraduate engineering students in an Australian University, focusing on the appropriate content, teaching technique, educational technology, software package, online support and evaluation in an engineering problem solving course. Results from an online survey of students are also presented.

**Keywords:** Distance learning; Problem-based learning; Teaching statistics; Screencasting; Web-based teaching; On-line survey; Educational technology.

**تدريس الإحصاء لطلبة الهندسة – تجربة أسترالية باستخدام التقنيات التعليمية**

**شاهجهان خان ، محمد كاظم و سوجان باياه**

**الملخص:** يتطلب المهندسون أساليب علمية لتطوير نماذج شرح الظواهر الحقيقية. بناء النموذج، وجمع البيانات، وتحليل البيانات، وتفسير البيانات تشكل محور الممارسة الهندسية . لذا فإن المنهجيات الإحصائية هي مكونات حيوية في المناهج الهندسية، وينبغي أن يكون لدى المهندسين القدرة على التفكير إحصائيا عند التعامل مع البيانات. وينبغي أن يتعلموا كيفية تصميم وإجراء تجارب جيدة لتخطيط و تحسين كفاءة وجودة المنتجات، ويجب أن يتعلموا التعامل مع البيانات، وتفسير النتائج التي تنتج كجزء من مهارة تحليل البيانات. الطرق الإحصائية هي حيوية في الممارسات الهندسية مثل مراقبة العمليات من خلال مخططات السيطرة، وايجاد الحلول المثلى، وتحديد العوامل الهامة من خلال اختبار الفرضية، وعملية النمذجة من خلال تحليل العلاقات الهندسية، و تصميم التجارب والتوصيات المختبرية. تشارك هذه الورقة بعض من خبرات التدريس الإحصاءات لطلبة الهندسة الجامعية في جامعة أسترالية تركز على المحتوى المناسب، وتقنية التدريس، والتكنولوجيا التعليمية، حزمة البرامج، والدعم عبر الإنترنت والتقييم في دورة حل المشاكل الهندسية. وتقدم أيضا نتائج من استطلاع الطلاب الكترونيا.

**الكلمات المفتاحية:** التعلم عن بعد، التعلم القائم على المشاكل، الإحصاءات التعليمية، التدريس، التدريس على شبكة الإنترنت، المسح عبر الإنترنت والتكنولوجيا التعليمية.

## 1. Introduction

Teaching introductory statistics to undergraduate students is quite challenging, and it is more so if the students are from non-mathematical disciplines. In general, service teaching, including teaching of statistics, is under threat due to increasing apathy from disciplines that require intense statistical knowledge in their profession. The traditional service teaching principle of teaching by experts in the discipline is not universal anymore. In engineering disciplines there has been a shift to recognise the crucial need of statistics, but the decision makers are, with a few exceptions, reluctant to allow as much space in the curriculum as required to cover adequate statistical content and allow adequate teaching time. According to Lindgren and Zetterqvist [1] the Mathematical Statistics Division at Lund University teaches 8 core and 13 elective statistics courses within 14 different engineering programmes leading to Master of Science in Engineering. But this seems an exception in Australian universities, rather than the rule.

Statisticians should accept some of the responsibility for statistics not being very well received by students of other disciplines. Some of the self-criticisms for statistics poor reception by others include "there continues to be a severe shortage of statisticians competent to deal with real problems" [2]; "We have historically done a very poor job of teaching statistics. … The problem is compounded because most people who teach statistics have never practiced statistics."[3]; and "For too long we in the statistics profession have tolerated poor statistics teaching, which produces courses that are often rated as the worst course or the most useless course that graduates in other fields claim they have ever taken. We too often teach what appears to the students a collection of unrelated methods illustrated by examples taken from coin-tossing, card-playing and dice-rolling."[4]. We don't use the language of the discipline and touch the variables inherent to the learners' degree program. Generic methods do not appeal to the students learning from within. At the end we want students "to improve their ability to communicate statistical information in oral and written form, to improve interaction skills and to appreciate the fact that in real life an answer must (usually) be found, however imperfect" [5]. Bisgaard [6] emphasised the essence of statistical skills for engineering professionals.

The statistics curriculum in Engineering should emphasise what the students are able to learn and apply in their workplace [7]. Professional skills are acquired mainly by "doing" and by "seeing what others do." The learning process is basically a personal task, where the protagonist is not the teacher but the student. The teacher must be a generator of resources and facilitator of acquiring knowledge in the learning contexts, but the student is the person who is learning. Active participation of students in all steps of the learning process would better prepare them for their career needs. To encourage the students' active participation, we have reduced the time spent in lecture classes and increased individual work and discussion. The role of the teacher has changed from that of "source of information" to "facilitator of learning" [8]. Recently, the importance of cooperative learning in Engineering has been further emphasised by [9].

The knowledge of basic methods is important, but creating a positive attitude and interest towards statistical methods in the minds of students is more crucial. We must convince students of the great value of these methods as tools for data analysis and decision-making in real problems that will arise in their future professional work. The only way to succeed in this is through the formulation and solution of real, or at least realistic, problems of direct interest to students. This must be done using the scientific method appropriate for the level of the students and sharing the teacher's experience in real projects.

Applying appropriate educational technologies in teaching is absolutely crucial to make sense of statistics. Computer and internet provide us with endless opportunities to analyse real data more efficiently than we formerly could; therefore, it is essential to integrate suitable statistical software into the teaching of statistics. Students should carry out laboratory practical tasks and hands on activities as an essential part of their learning process. They must have a feeling for what they are doing, why it is done, and what the benefit of doing so is.

## 2. Role of Statistics in Engineering Problems

Like most of the other scientific disciplines, engineering problems deal with variation, error, and uncertainty. Engineering experiments produce data which are the key to solving engineering problems. Real data exhibit variability and is subject to errors which obscure the criteria needed to make sound decisions. All decisions based on real data involve risk and uncertainty. Statisticians could reveal the sources or causes of variability. Discovering these sources and removing them are often the keys to engineering success. As a result, statistical methods are essential to address those issues.

Examples of some engineering variables are the coating thickness of a panel produced by a paint operation, the breaking strength of a plastic, the time/age of radial tires until the thread wears, the running time for fuses, the pressure required to separate the cap from a bottle, the power requirement for cutting metal with ceramic tools, or the annual rainfall in a city. Only statistical methods can help analyse data on those or any other engineering variables.

Often engineering problems require a fundamental modelling approach for solving real life problems, which consists of the following steps: (1) specify the problem clearly (2) identify the factors that influence outcome variables (3) formulate a working model for the underlying relationship (4) produce data through an appropriate experiment (5) estimate/fit the working model (6) determine the important factors and test the adequacy of the model (7) revise the working model as appropriate and (8) collect additional data via a confirmatory experiment, and repeat the steps if required.

As an example consider the study of the strength of a new polymer filament that is later spun into yarn. The filament's elastic strength (S) depends on the (i) amount of catalyst (C) used, (ii) polymerization temperature (T), and (iii) pressure (P). Therefore, for an engineer, the working model of the phenomenon is of the form S = f

(C,T,P). A statistician would suggest a regression model to predict the strength based on the varying level of the predictors:

$$S = \beta_0 + \beta_1 C + \beta_2 T + \beta_3 P + \varepsilon$$

This model represents a linear relationship between the response (strength) and the three factors - catalyst, temperature, and pressure as the predictors. It helps the engineer to determine appropriate settings for the three factors that optimize the strength. For further details see Vining and Kowalski [10].

How can we determine the exact impact of the three factors on the filaments strength? Which combination of the factor levels produces the optimum strength? The statistician systematically changes the amount of catalyst, the polymerization temperature, and the polymerization pressure. The engineer then conducts the experiment for each possible combination of these factors, and takes a sample of filaments and measures their strengths. This produces essential data that are key to the solution of the problem. The estimated model gives the statistician an appropriate basis for determining the important factors. The statistician will determine which of the estimated coefficients is really different from zero. If the coefficient associated with the amount of catalyst is zero, then no matter what we do with the amount of the catalyst, it has no effect on the filaments strength. The engineering method continues in this manner until the engineer finds an adequate solution that produces the optimum strength.

## 3. Problem-Based Learning

Bringing any real problem from the engineering area and apply statistical techniques to solve it is a great way to introduce the discipline to the students. Problem-based learning (PBL), pioneered in the medical school program at McMaster University in Hamilton, Ontario, Canada in the late 1960s by Howard Barrows and his colleagues has now been adopted in many other disciplines to achieve this goal. It is a student-centered pedagogy in which students learn about a topic in the context of complex, multifaceted, and realistic problems. The goals of PBL are to help the students develop flexible knowledge, effective problem solving skills, self-directed learning, effective collaboration skills and intrinsic motivation [11]. Working in groups, students identify what they already know, what they need to know, and how and where to access new information that may lead to resolution of the problem. The role of the instructor (known as the tutor in PBL) is that of the facilitator of learning who provides appropriate scaffolding, guidance and support for the process, modelling of the process, and who monitors the learning [12]. The tutor must build students' confidence to take on the problem, and encourage the students, while also stretching their understanding [13].

In collaboration with Aalborg University of Denmark, PBL was introduced at University Tun Hussein Onn Malaysia (UTHM). Since then the PBL was widely used among engineering as well as humanities lecturers at UTHM [14]. Recently many Malaysian universities are going for PBL, purposely to improve the quality of the graduates produced. Other examples are given by Romero et al. [15], Woods [16], Schmidt et al. [17], Perrenet et al. [18], Viali [19], Bland [20], Vidic [21], and Schmidt and Yew [22].

The PBL method of teaching has been in practice for engineering courses at the University of Southern Queensland (USQ), Australia for several years, under the title of Engineering Problem Solving courses. The second course of the series of 4 courses contains the application of statistics for engineering data analysis. Every year an engineering topic relating to a present day problem (e.g. Solar power generation or flood water management in Australia) is selected by the teaching team of about 15 academics from the Faculties of Engineering and Sciences. The problem must provide scope for students of different branches within the Engineering faculty. Each member of the teaching team facilitates a number of groups of students and helps guide them through to completion of the final group report and assesses them under a strict common marking rubric. The class is divided into groups of 8 students with a leader and a deputy leader from among the group members. This is done separately for external and on-campus students in the two different campuses of USQ (Toowoomba and Springfield). In the assessment a significant weight is allocated for team work and the group report while there are also marks for individual work. The groups meet weekly to work on various engineering aspects of the problem as well as on the statistical analysis of relevant data. The group leader makes sure that the meetings are held on a regular schedule and according to agreed codes of conduct, such that everyone completes assigned tasks and contributes to the group discussions and preparation of the final report. Minutes of such meetings are kept for future reference. Lecture and tutorial support on selected topics is provided when needed. Within each group the students also conduct peer reviews of their personal portfolios which also contribute to their final grades.

Recently, within the Engineering Problem Solving and Data Analysis course four weeks of the second semester were exclusively devoted to the teaching of statistics, to help students analysing the data to acquire relevant statistical skills required to solve the engineering problem. Two hours of lectures and two hours of tutorial time weekly were offered to all on campus students. Recordings of the lectures and tutorials were provided to the external and on-campus students via the StudyDesk portal. The statistical package SPSS was used to analyse the data. Support for learning SPSS was provided by pre-recorded online video snippets.

## 4. Online Teaching Support

About three quarters of all USQ students are external and they are located all over the world. Traditionally USQ has one of the best online support systems in the world for external students. This, coupled with the state of the art educational technology and ongoing research in teaching technology, enables USQ to provide very effective support to our external students. We provide pre-lecture/tutorial notes to the students via the StudyDesk which are accessible from anywhere in the world. Recorded live lectures, tutorials etc, including screencasting, are also made available to all students. Lecture theatres are equipped with audio and screen recording facilities, but some lecturers use Tablet PC to record lectures/tutorials using TechSmith (Camtasia) Relay. Khan et al. [23] use the screencasting to bridge the divide between external and on-campus students. This makes it easy for students to watch the recordings at their own pace and in their own time, either online or after downloading. Further support is provided via various discussion forums, newscasts, and consultancy. There is provision for students to post messages/questions to the whole class or just to the group members, and to respond to the postings of other students. Students can post any questions related to the topics of the course or a response to /explanation of others' questions. The facilitators make sure that the discussions are on track and directed to the learning goals of the students.

Online quizzes are provided both for practice and assessment. The questions in the quizzes are randomised for each student from a bank of questions on all topics covered in the course. Online exams are also conducted similarly. All online assessments are marked by computer and followed by automated feedback. The final group report is submitted online via the StudyDesk near the end of the semester. The teaching team members can access the allocated reports online and mark them for final assessment. A combination of individual assessments and group performance determine the final grade of each student.

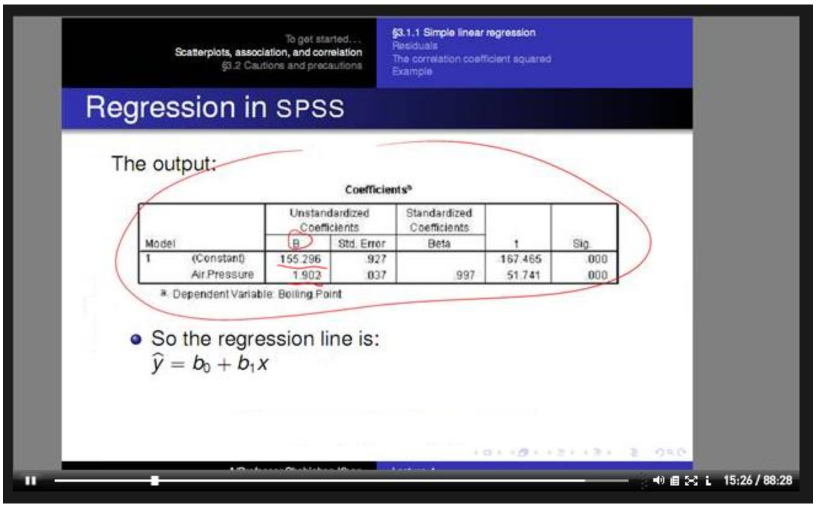


**Figure 1**. Screencasting of a slide for an introductory statistics class

Screencasting allows the lecturers to record the content of lecture slides on the computer screen along with the audio discussions and explanations. Using the Tablet technology lecturers are able to write equations or draw graphs on the computer screen which is instantly shown on the display screen. Camtasia Rely allows them to record the intended part or whole of any lecture and saves it in a central depository. Students are able to access the recorded screencast via the link on the StudyDesk online. They are able to watch the recordings in their own time and at their own pace either online or by downloading them in various static or mobile formats such as MP4, IPod, etc.

## 5. Students' Survey Results

The teaching team conducted an on-line survey to find the students' opinion on various aspects of the statistics module in the course and the teaching of related topics. The survey consisted of 10 online questions of which the first 9 were multiple-choice type with answers provided in a Likert scale. The last question was open ended, seeking suggestions on how the statistics content might be better presented to assist students' learning. Please see the appendix for the survey questionnaire. The summary of the survey results are provided in Table 1. The survey was conducted after 4 weeks of teaching of the statistics module and after two online exams. The teaching involved two hours of lectures and two hours of tutorials in weeks 2-5. Out of a class of about 450 students, 203 responded to the online survey. The responses to question 3 clearly demonstrate the important role of statistics in the course as 11.44%+54.23% ≈ 66% agree or strongly agree, whereas less than 15% disagree. The formal lecture/tutorial was supported by 27.86+39.80% ≈ 68% in question 1. In contrast, the self-learning of statistical content was favoured by less than 12% and not supported by 42.29%+33.33% ≈ 76% in question 4. These figures strongly justify formal teaching of the statistics module in the course. As such 15.42%+33.83% ≈ 49% suggested retaining this module whereas 15.42%+18.41% ≈ 34% disagreed in question 9. The module did provide adequate skills for data analysis according to 13.93%+48.76% ≈ 62% of students in question 2. All this evidence reinforces the crucial role of statistics in the course and the need for formal teaching as opposed to independent self-learning by students while doing the course.

**Table 1.** Percentages of responses in the student survey

| Brief question/ Student response | S Agree | Agree | Undecided | Disagree | S Disagree |
|---|---|---|---|---|---|
| Q1 Lecture/tutorial assisted learning | 27.86% | 39.80% | 12.94% | 13.43% | 5.97% |
| Q2 Better equipped for data analysis | 13.93% | 48.76% | 17.41% | 16.92% | 2.99% |
| Q3 Appreciate crucial role of statistics | 11.44% | 54.23% | 19.40% | 9.95% | 4.98% |
| Q4 Prefer self-learning of statistics | 3.98% | 7.96% | 12.44% | 42.29% | 33.33% |
| Q6 Had adequate math foundation | 23.88% | 55.72% | 10.45% | 8.96% | 1.00% |
| Q8 Online assessment effective | 6.97% | 34.83% | 20.40% | 16.42% | 21.39% |
| Q9 Retain statistics module for future | 15.42% | 33.83% | 16.92% | 15.42% | 18.41% |

Some sample responses to the open-ended question 10 are noted below:

- This course has been compressed far too much; it should be spread out over 7 or 8 weeks.
- I strongly agree with the inclusion of statistics in Engineering.
- I am actually surprised that this is the only statistical component of the engineering degree.
- I think the statistics component should be a stand-alone subject.
- Statistics is a very important subject in Engineering and therefore I think it should have more hours allocated in this course.
- The statistics section needs to be placed as a totally separate course.
- I would have mastered Statistics if it were separate unit.
- Lectures were a great way to learn.
- I found the tutorials good.
- The lecture notes were nice and clear; they were a good help.
- I learned more on this course because of statistics which I think should be run as an independent course

## 6. Statistics Teaching in Engineering at other Universities

A survey of engineering curricula of some of the leading universities in the USA shows that every university has at least one course on statistics [24]. Some universities offer it as a stand-alone separate course while others are offering it in combination with probability as “Probability and Statistics”. In some of the programs of those universities, for example in industrial engineering (IE) programs, statistical concepts and methods are included in a number of courses including “Quality Control”, “Simulation”, “Operations Research”, “Research Methodology” and “Engineering Statistics”. A similar practice exists among the best universities in the Gulf Cooperation Countries (GCC) region, where most of the engineering programs are accredited by ABET. ABET emphasises outcome based learning with continuous improvement. The learning outcome may come from a program, a course or specific part of a course. The Industrial Engineering program at Sultan Qaboos University, Oman has incorporated statistical skill in many courses, such as Statistical Quality Control, Probability and Statistics. The program is accredited by ABET and based on the contents of these courses the outcomes include: i) an ability to apply knowledge of mathematics, science, and engineering, ii) an ability to design and conduct experiments, as well as to analyse and interpret data, and iii) an ability to identify, formulate, and solve engineering problems. Such applications of statistics are widespread in all branches of engineering. The course content, delivery plan and method of assessment to check the proficiency of students in statistics is then prepared in such a way that these components ensure achieving the course outcomes. The course materials are provided to the students through an online system (on Moodle platform) before they are discussed in the classroom. For each of these courses there are two lecture hours and two hours of tutorials each week, throughout the semester of 14 weeks. Apart from solving textbook problems and exercises in the classroom, tutorials consist of some specific number of lab sessions where students engage themselves in hands-on experience using statistical software (e.g. Excel, Minitab) to solve engineering problems involving data analysis using statistical techniques. Students are then assessed multiple times within the semester to check their proficiency in achieving the learning outcomes of the course. The assessment includes multiple quizzes, term tests, assignments and a group project. In their project work, students are encouraged to work on real world engineering problems where they have to perform statistical analysis very similar to the PBL approach. These courses are further linked to advanced courses such as Quality Control, Six Sigma, Simulation, Stochastic Operations Research etc. At the end of every semester a student survey is carried out to discover their point of view on the course. Following is some of the typical feedback received for the courses on statistics:

- This course is applicable for the real world problem and is interesting.
- The most interesting part of the course is hypothesis testing and design of experiment.
- Project work is very interesting as it deals with real problem.

- Very useful subject in the real life and industry.

## 7. Conclusion

The survey revealed consistent opinions regarding the two main directions for the future statistics module of the course. The majority of the students think that the course allowed less than sufficient time to teach statistics. They felt that the duration of 4 weeks is not enough to learn the statistical content of the course. Interestingly, most of the students suggested a stand-alone statistics course for Engineering. Some students were surprised that this was the only statistical component that they had seen in the whole engineering program. Many of the USQ students are of mature age and have long industrial experience and value statistical knowledge more than the fresh graduates who enter university directly from the colleges do. Giving due weight to statistics within the engineering curriculum would benefit the profession enormously, including augmenting the employability of our new graduates. Statistical methods are becoming an indispensable part of many scientific disciplines and engineering is no different. The views of the teaching team and the survey outcomes reinforce the need for increased formal teaching of statistics for engineering students. Therefore, this emphasizes the necessity of offering statistics as a stand-alone course and to include it as a learning outcome for the program. The idea is to include statistical concepts and methods in as many engineering courses as possible within the program, including setting and conducting experiments and hands-on analysis of experimental data using computing software and group projects to solve real engineering problems. Active participation of students and interaction among fellow colleagues [8] are essential to enhance students' learning, and ensure hands-on statistical support in the process of teaching statistics to help solving diverse engineering problems.

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## Appendix – Survey Questionnaire

1. Do you consider the inclusion of traditional lectures and tutorials has assisted your learning of Statistical concepts? Likert scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

2. Do you consider yourself better equipped to contribute towards the data analysis part of the set problem after formally learning basic statistical skills?
Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

3. Have you gained a better appreciation of the crucial role of Statistics in Engineering and Spatial Sciences? Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

4. Would you have preferred to acquire this statistical knowledge through independent research and study instead of formal teaching?
Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

5. How many hours per week (on average) have you spent in mastering the statistics content?
☐1-2; ☐2-4; ☐4-6; ☐6-8; ☐8-10; ☐>10

6. At the start of this statistics module, were your mathematical skills an adequate foundation?
Likert scale : ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

7. How did you find the level of support from the statistics teaching team on the Study Desk, and the effective delivery of the content?
☐Poor; ☐Inadequate; ☐Acceptable; ☐Good; ☐Excellent

8. Do you consider that the on-line exam/test was an effective way to assess your learning?
Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

9. Based on your learning experience and support received from the teaching team, would you recommend that the Statistics module be retained in ENG2102?
Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

10. How might this the statistics content be better presented to you to assist your learning?
Likert Scale: ☐Strongly Agree; ☐Agree; ☐Undecided; ☐Disagree; ☐Strongly Disagree

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