

**TEACHING MODERN ENGINEERING STATISTICS:
THE CONTRIBUTION OF COLLABORATION AND SHARED VIEWS
OF THE ROLES OF MATHEMATICAL STATISTICS IN ENGINEERING**

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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. This paper uses cases to analyse the combination of ingredients that seems to make the difference between success and otherwise in design of curriculum for engineering programmes. The key aspects underpinning the efforts seem to be collaborative curriculum development, and a joint view from both engineering and statistics of the role of mathematics and statistics in technology and engineering. This respect and high regard for mathematical statistics from the engineering side, often arising from research or other collaboration, changes them from clients to partners. This paper is an attempt to systematize what we see as the important success factors in an engineering statistics education.

BACKGROUND

The Faculty of Engineering at Lund University educates about 4400 students in 14 different 4,5 year programmes leading to Master of Science in Engineering. Some of the programmes are classical engineering programmes, like Chemical, Civil, Computer, Electrical, or Mechanical engineering; others are of new design, based on societal/student demand or strong research, like Environmental engineering, Risk management and Safety engineering, Industrial management and engineering, Engineering mathematics, and Engineering nanoscience. All Masters Programmes have a basic statistics course in the 2nd or 3rd year, to the extent of 13-15% of a full academic year. Formally there are 8 different courses with between about 60 and 180 students taking the respective courses. The courses can be grouped together in five groups, depending on subject emphasis and mathematical sophistication.

After the basic course, students can choose between 13 elective courses, in stochastic processes and time series (4 courses), safety analysis and extremes (2 courses), financial statistics (2 courses), special courses in experimental design and chemometrics, image analysis, statistical genetics, and Monte Carlo based methods. In total, 350 students take the elective courses every year. The division has 16 teachers with PhD qualifications, 11 with a degree in engineering and 5 with a science degree. About 20 PhD students take part in the teaching, up to 20% of full time. The division is also responsible for the teaching of mathematical statistics at the Faculty of Science at the university.

The problem of how to teach statistics to engineers has been studied by several authors. Romero et al. (1995), Acosta (2000) and Lambert (2000) are just some examples of papers which give tangible proposals or/and more fundamental ideas within the subject. After working with this large amount of courses for many years you get a pretty good feeling of what ingredients are necessary to make a statistics course “successful.” This paper is an attempt to systematize these ingredients.

We shall exemplify our discussion with two courses in Mathematical Statistics, which we consider as success courses: the compulsory *Basic course for Environmental engineers*, taken by about 60 students each year, and the elective course in *Stationary stochastic processes*, which is taken by about 100 students from many different programmes. It is also a required course for students in Engineering mathematics and for those who choose Mathematical modelling in the Industrial management programme.

How do you decide whether a course is successful or not – apart from the “knowing” by teachers and students? For the two courses we discuss students’ results on the exams and their apprehensions of the relevance of the course and compare it with other courses at our department. We also report from a minor study of the quality of some students answers on an exam.

Table 1: Facts about the two courses

	<i>Basic course for Environmental engineering</i>	<i>Stationary stochastic processes</i>
Teaching format	7 weeks, 2h lecture per week, 8h exercises per week, co-operative learning, project	7 weeks, 4h lectures/week, 4h exercises/week, 6h computer lab
Examination	Written individual examination with computer, peer reviewed project report	Written individual exam, lab participation
Students	60 students in 3 rd year, all from Environmental engineering. Percent who pass the course: 85%.	100 students in (2 nd and) 3 rd year, from Computer and Electrical engineering, Engineering mathematics, Engineering physics, Industrial management and engineering. Percent who pass the course: 80%.
Course content	2/7 probability, 2/7 statistics, 3/7 regression with time series analysis	Auto- and cross-covariance, spectrum and cross-spectrum, linear filters, AR, MA, ARMA, identification, FFT
Special conditions	Students have their individual laptop computer with <i>MATLAB</i>	After completed course student can do an extra project of choice; examples: heart rate and EEG analysis, stock exchange models, Manchester United's stock price, music as 1/f noise
Economy	Paid 17% more per student than other basic statistics courses	Paid 10% less per student than other elective statistics courses

CONDITIONS FOR SUCCESS

We shall discuss four conditions for success, on four different levels: Collaboration and interaction between statistics and other faculty, Student's experience of and preparedness for variation, Student-focus in course design and content, Teachers experience and support.

Collaboration and Interaction

- Joint view of the role of statistics in the course, suitable for the specific students: The Faculty of Engineering has experienced large changes during the last decade. Many new programmes have started, often with substantial contents of science, economy, and management; old programmes, with a more traditional design, have been redesigned. In all programmes collaboration and interaction between subjects are emphasized. Intentions of collaboration from the Faculty board and from other engineering subjects lead however not automatically to success for the statistics courses. Analysis of the success stories in newer programmes such as Bioengineering, Risk management, Environmental engineering, and Chemical engineering, demonstrates the importance of other factors. In the most successful courses, the importance of statistics is recognised by the engineering partners either from the beginning or in the programme redesign, and integrated within the programme. The new programme boards demanded that Mathematical statistics developed courses according to the programmes' specific needs, and they often provided better financial support than the traditional engineering programmes, allowing the Statistics division to give their students special treatment.

The programme in *Environmental engineering* was initiated in 1998 in response to societal and student demand. From the very beginning it was regarded as a joint project between the engineering faculty and the science faculty at Lund University, and teachers with experience from non-engineering students were invited to the planning. The statistics course was partly developed together with the faculty board and teachers from other subjects.

For a majority of Environmental engineering students the basic course is the only course in the programme in which they learn about statistical methods. The basic course is therefore designed around the essentials in environmental analysis, including basics methods for time series analysis. The emphasis in statistics is not on traditional engineering views on statistics. Instead, influenced by the environmental issues in the programme, the statistical course has a focus on understanding and description of environmental data: What questions can we ask and have an answer for? What models are suitable? Open-ended questions are common.

The Faculty of Engineering in Lund has a very strong tradition in systems engineering, Automatic Control, Signal processing, and Information technology. Since the 1980's a course in *Stationary stochastic processes* has been part of a tripod together with a mathematics course in *Linear systems* and a course in *Automatic control theory*. Until the year 2002 the course in Stationary processes was compulsory for Electrical and Computer engineers, and the course was also designed basically around signal processing problems.

In the early 2000's student interest in financial statistics increased, the programme in Industrial management and engineering expanded its curriculum in Mathematical modelling, and a completely new programme in Engineering Mathematics was started. As a consequence the course in Stationary stochastic processes was redesigned to satisfy the needs from a broader range of students' interests, without losing its basis in signal processing.

The elective course in Stationary stochastic processes lives in an environment where statistical methods penetrate almost all other courses as well as advanced research, for example in Information technology and Systems engineering. The statistical competence at the neighbouring departments is high and applications are abundant. The role of the statistics course is therefore to provide deeper insight into the language and mathematics of stochastic processes, and at the same time give a broad view of their wide range of applications. Many students take a subsequent course in Time series analysis or Financial statistics. The course is a recommended prerequisite for courses in Control Theory and Signal processing or Communication theory.

- Common research interests or common experience with data or issues: Common research interests between statistics teachers and teachers/researchers from the engineering side give personal connections and facilitate the discussions. Examples, important issues and data sets from other courses or researchers are used.

Stationary processes and their engineering applications in control, electrical, marine, and safety engineering are dominating research interests in the department. The course in stationary processes started in 1973, in response to demands from electrical and computer engineering. Lately the course has been broadened towards other application areas. Teachers, senior and PhD students, all have their research in the area. Guest lecturers from other departments also participate in the course. Teachers in the course for Environmental engineers have their background in environmental statistics and environmental time series.

- Clear strategies on pedagogical issues from the Educational board: A declared interest in pedagogical issues and variation in teaching styles are encouraged by the programme boards. The Environmental engineering programme is interdisciplinary with science and technology, and it is not burdened by old traditions at an engineering school. Instead it is often inspired by other forms of teaching in subjects like ecology or environmental subjects. It is noticeable that students have their own laptop computers.

Students

All students at the Engineering faculty have about one semester of mathematics at university level when they start their statistics course and many have more. The statistics courses use to be the first courses in their education where the students meet genuine uncertainty. This change in focus, from right-or-wrong courses to a course which poses open-ended questions can be frustrating for some students, but is in the core of the idea with the courses.

We have seen a significant difference in attitude towards statistics between students from engineering programmes such as Chemistry, Bioengineering, and Environmental engineering, where variability is part of daily life from the very beginning of the education, and students from "deterministic programmes," such as Engineering physics and Mechanical engineering. In the same vein, students in year three seem to be more motivated to discuss variability.

The students come to the courses with very different expectations and motivations. Only a few take the course because it is required in the final Masters examination. Many feel that it may be a relevant course for future jobs or for other courses, but surprisingly many claim that the courses have a reputation to be interesting. As a whole the student contingents are rather homogeneous in that they have a positive attitude towards cooperative work. It is our impression that the students who take any of the two courses, mostly in their 3rd year, are mature, and that they also have realised the usefulness of statistics in other parts of their education.

Student-focused Courses

In light of the factors discussed – moral and financial support from the boards, collaboration with teachers/researchers in engineering subjects and a fairly good understanding of the capability, interests and needs of the students – how is then the actual courses designed?

- Capability-driven curriculum design in the basic course for Environmental engineering: Based on previous experience from courses for Chemical engineers and Biologists, and from cooperation with environmental researchers, the curriculum in the course for Environmental engineers has changed from content-focused to a more capability-focused design, that tries to give the students capability to act, especially in a real-life professional setting (Bowden, 2004).

The following “can do” settings hold for the Environmental engineering course. In the basic statistics course we try to give students capability to: read and interpret reports; structure open questions and problems which involve variability and uncertainty; identify situations and important general questions where a statistical argument can give an answer and where it can not; interpret and evaluate time series; validate assumptions for statistical reasoning and conclusions; handle the computer for statistical illustration, modelling and estimation, prediction, etc.

- Content-driven curriculum design in the advanced course in Stationary stochastic processes: The course in Stationary stochastic processes has grown gradually from being designed to meet very specific demands from the Electrical engineering programme and from Signal processing/Control theory courses, to appeal to a broader group of students, with more emphasis on problem identification and interpretation and potential of the stochastic language and method.

After the advanced course in Stationary stochastic processes students can: identify situations with spatial and temporal dependence; formulate linear models for time dependence; identify situations where frequency domain models are relevant and where they are not; appreciate the limitations of common methods for prediction in time series; handle computational software for simulation and estimation in time and frequency domain; formulate and interpret stochastic versions of deterministic methods in digital signal processing.

- Course content: Needless to say, there are a number of factors that should determine the content of a successful statistics course. First of all, when facing students who have experienced the annoying impacts of variability, one should meet the demands for tools to handle it. Expressed or unexpressed demands from the education programme or from other courses are obvious factors. However, it is not always easy to know what these demands are, and it can take time to find out. But it is a long term profitable investment to do a serious inventory of what’s going on in neighbour departments and courses, because it can help us to keep our subject alive!

End-users and the labour market expectations are even harder to account for. If the previous paragraph was optimistic, this point can be equally conservative, or even destructive. Not until we know what others are doing can we expect qualified expectations from end-users.

The course content in the basic course for Environmental engineering is roughly the same as in an “ordinary” basic statistic course – the only exception is the introduction of autoregressive processes, Piegorsch and Edwards (2002). More important is *how* we teach the content. In fact, with the emphasis on modelling and interpretation of data we have deliberately pruned the tree of statistical methods in the course for Environmental engineering. This has also turned out to be necessary with the chosen form for lectures and exercises.

For the elective course in Stationary stochastic processes the content has been selected to form a part of a “Systems theory” approach in engineering education. But we have also realised that many students take the elective course because they want to understand more of the basic statistics course they followed a year before – simply, they want to understand “randomness” means! In the course schedule we have made ample room for this part of the course mission.

- Use of computers in the courses: Based on the idea of a capability-driven course, the course for Environmental engineers uses the computer extensively. All students have their own laptop computer, similar to a realistic future working situation, and they use it in all lessons for exercises, as well as at the examination. Of the exercises, approximately one third are traditional ‘pen-and paper-exercises, one third are computer based and one third are a mixture with computer and theoretical calculations. There is also a project, answering open-ended questions using environmental data set. In Zetterqvist and Werner (2004) different types of computer-supported exercises in the course are described.

- Choosing the form of lessons and lectures in order to activate the students: With the new programme in Environmental engineering, ecology and other topics from the science faculty were introduced in an engineering curriculum. The mixture of teachers with different background, and the interdisciplinary character of the programme, made it natural to design also the teaching so as to increase student activity. The co-operative learning not only increased this activity but was also judged suitable to train the student to co-operative work in the future. The Stationary process course has focus on individual knowledge and understanding.
- Material in the course especially designed for the specific students: Almost all the material used in the two courses has been developed in Lund, and it has been continuously revised. Most of the examples and course data originate from common projects and experiences. This has strengthened connections with other courses and increased flexibility with regard to teachers' engagement in common projects and changing student interests, particularly for the Stationary process course. To overcome remaining heterogeneities in preparation or experience of mathematics and statistics, we have also taken care to link with other courses, upwards, downwards, and sideways. Also the project in the basic course, and the subsequent process projects, has helped to overcome boundaries between courses and topics.

Teachers, Department and Faculty boards

It has already been mentioned that the two courses depend heavily on common interests between statistics teachers and engineering programmes. But it is also important that the teaching style is cultivated, and that new teachers are trained in and accept the ideas behind the courses. In particular, the emphasis on student activities must be supported. The teaching practice in the Environmental engineering course is quite demanding and it is necessary that department leaders and faculty boards encourage and support the teachers and the continuing education of teachers.

What consequences does this have for the training and recruitment of statistics teachers? Development from skill or know-how to professional competence, according to the scholarship of teaching (Trigwell and Shale, 2004) has to be more widely encouraged by department and faculty boards, developing the teaching model from a transfer model to a participatory model where the teacher actually participates in the students' learning (Ramsden, 2003).

OUTCOMES

Students' View

In student evaluations, both courses are rated as relevant or very relevant for their education. The Environmental students particularly appreciate the extensive use of computers and the co-operative learning approach; they see and agree with the goals for the course. After the courses, most students feel safer to tackle unknown problems and have less fear of statistical nomenclature. They handle data, graphics, models, and simulation with great confidence. The students particularly appreciate seeing the wide range of applications for statistical models and methods. It is our experience that almost all students have gained a positive attitude towards statistics in their future career.

For relevance in future education and career, measured on a five degree scale (-100, -50, 0, 50, 100), compulsory courses of very general type use to score between -15 and +20 on the average, with higher values for courses in the third year than in the second year. For courses which have been designed to meet special demands, (besides Environmental engineering, also Chemistry and Bioengineering) the scores are between +50 and +75 on the average. The course in Stationary stochastic processes scores +50 for relevance in the future education and career.

Teachers' View

Teachers are very satisfied with the work and the courses, and they appreciate the energy that the students exercise in taking the courses. In the basic course the teachers have deliberately put less stress on formal capability and more on better understanding and interpretation. This has to be repeatedly explained and sometimes also defended. The easy access of computers has facilitated the change of focus in the basic course. However, great concern has to be taken when choosing the computer-supported exercises and the use of computers has to be a natural part in the learning environment of the course, Zetterqvist and Werner (2004).

Qualitative and Quantitative Outcomes

- The quality of answers to two questions on an exam in the basic course where studied, using the SOLO-taxonomy, described by Biggs and Collins (1982). The questions concerned trend analysis and dependence in a time series – two important concepts for an Environmental engineer. The study, Zetterqvist and Werner (2004), indicates that the students are able to relate the concepts of the course to real world situations but that they have shortcomings in relating formal models in detail to data. Briefly, the students are good at what they have trained on exercises!
- Besides the positive qualitative outcomes we also comment on the economy in relation to student reactions and student performance. The percentages of students who pass the course among those who have registered is 85% for the compulsory for Environmental engineers, as compared to 41, 52, 56, 60, 67, 70% for six other basic compulsory courses. (The low figures in some statistics courses are consistent with low total examination figures for the particular programmes.) Only the Chemistry/Bioengineering course has better figures than the Environmental course, namely 88%. It is noteworthy that the development of the Environmental course drew very much on experiences from the Chemistry course. The elective course in Stationary processes has 80% pass, which is a good figure compared to courses on similar levels.
- The two best courses are also the ones that are best paid: the department gets for Environment and Chemistry 17% and 13%, respectively, more money per student than for the other courses. These courses also show highest figures for student relevance appreciation. It is not clear from our study that the positive observed relation between economy and student performance and appreciation is causal. What is clear is that courses with the highest figures are those which are best footed in the study programme as a whole. Our thesis is therefore that a positive intellectual relation between department/teachers and study program boards/program contents is a (the?) most important factor, leading to better courses, better economy and better student/teacher satisfaction!

CAN IT CONTINUE? THREATS!

Is it really necessary to have eight different basic courses (five groupings) in statistics in the engineering programmes? Our answer is, yes! The answer from the budget office is, No!

REFERENCES

- Acosta, F. M. A. (2000). Hints for the improvement of quality teaching in introductory engineering statistics courses. *European Journal of Engineering Education*, 25(3), 263-280.
- Biggs, J. B. and Collins, K. F. (1982). *Evaluating the Quality of Learning. The SOLO Taxonomy (structure of the observed learning outcome)*. New York: Academic Press.
- Bowden, J. (2004). Capability-driven curriculum design. 4079P ELT ENGINEER-A/rev1/jr 18/5/04, 36-47.
- Lambert, D. (2000). Statistics in the physical sciences and engineering. *Journal of the American Statistical Association*, 95, 971.
- Piegorsch, W. and Edwards, D. (2002). What shall we teach in environmental statistics? *Environmental and ecological Statistics*, 9, 125-150.
- Ramsden, P. (2003). *Learning to Teach in Higher Education*. London: RoutledgeFalmer.
- Romero, R., Ferrer, A., Capilla, C. Zunica, L., Balasch, S. Serra, V., and Alcover, R. (1995). Teaching statistics to engineers: An innovative pedagogical experience. *Journal of Statistics Education*, 3(1).
- Trigwell, K and Shale, S. (2004). Student learning and the scholarship of university teaching. *Studies in Higher Education*, 29(4).
- Zetterqvist, L. and Werner, L. (2004). How can we use computers to enhance learning? A report from an applied computer-supported course for environmental engineers. Lund, Preprint in Mathematical Sciences, 2004:14.

Statistics texts used in the courses:

- Barnett, V. (2004). *Environmental Statistics, Methods and Applications*. Wiley, the chapter on time series analysis.
- Lindgren, G. and Rootzén, H. (2004). *Stationary Stochastic Processes*. Lund, (in Swedish).
- Olbjer, L. (2000). *Experimental and Industrial Statistics*. Lund, (in Swedish).