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PAPER

Statistics in Forest Engineering Degree Programs: What Should be Taught and Who Should Teach It

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ABSTRACT

Planning the subject of statistics in Forest Engineering degree programs initially requires asking why it should be taught, who should teach it, and what should be taught. This article aims to answer these questions. To achieve these objectives, the method of natural discussion groups and the SMART preference method were used to rank the main contents of the statistics course by importance. The members of these discussion groups were professors from UPM and the National University of Santiago del Estero in Argentina. The results reached the experts' consensus on the subject: statistics are needed in the training of forestry engineers, and that the main contents should be descriptive statistics, sampling techniques, estimation, hypothesis testing, and linear models. It was also determined that the course should be taught by forestry engineers to demonstrate and involve students in real, practical cases that solve engineering problems, which facilitates student learning. In conclusion, knowledge of statistics is vital for forest engineers to make decisions in natural resources and industry management. Most Forest Engineering degree programs include statistics courses, although some of the content of the courses may vary. Future research to determine the opinions of students, alumni, and teachers through surveys would help improve the design of these courses.

KEYWORDS

discussion groups, Forest Engineering, higher education, statistics subject, teaching

1 INTRODUCTION

Planning the subjects in a specific academic degree requires a solid foundation. For this reason, institutions of higher education should consider establishing the relationships between the subjects in the degree program, the profession to which it provides access, and the job market for graduates [1].

For these reasons, three main questions must be asked, even before considering the methods and materials of a subject:

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- Why should this subject be taught in the degree program?
- Who should teach the subject?
- What content should be taught?

To answer these questions, it is necessary to first understand the main characteristics of the degrees and their subjects. In the case of Engineering, the degree comprises multiple branches with different origins and objectives. However, they all essentially share the applied (practical) spirit, the types of tasks involved, the complexity of the problems, the systematic approach to problem solving, the reliability and rigor of the models used, and the high quality expected of the results [2]. Engineering also has a strong interdisciplinary component, requiring engineers to integrate knowledge from various disciplines in order to explain events, solve problems, or design products [3]. But, working across disciplines can pose challenges for students [4].

The definitions of statistics emphasize its capacity to solve problems and make decisions. Peña's [5] definition of highlights the integration of two disciplines: the calculus of probabilities and statistics (or the science of states, from the Latin, *status*), which study how to draw conclusions from empirical research using mathematical models. Mood [6] and Barnett [7] define statistics in relation to its applicability. Mood stated: "Statistics is the technology of the experimental scientific method. Statistics provides tools for decision-making when conditions of uncertainty prevail." Barnett defines statistics as "the science of how information should be used and how to guide action in practical situations involving uncertainty."

Based on these definitions, one of the fundamental ideas is the application of mathematical models to quantify uncertainty and make a decision.

Knowledge of statistics is crucial for engineers in designing and innovating products, systems, and processes [8, 9]. Since actual data forms the basis of engineering decisions, risk and uncertainty are inherent in these decisions [10, 11]. Experienced engineers place significant importance on understanding the sources of data variability and how to eliminate it due to its impact on the profession and its ability to increase employability [10, 11].

In the case of Forest Engineering, applied statistics can provide a range of criteria and tools to enhance the management of forestry and forest industry activity, develop new competitive technologies in global markets, and protect natural resources [12]. Furthermore, applied statistics is instrumental in addressing the social demands related to environmental protection and conservation, land planning, landscaping, gardening, urban woodland management, environmental impact assessment, biodiversity enhancement, risk and natural disaster management, rural development, environmental quality control, innovative use of wood products, and ecosystem services [13, 14].

The training of forestry engineers aims to prepare professionals who are capable of generating social, ecological, and economic progress, and thus respond to the aforementioned social demands through the appropriate use of science and technology. In this context, statistical techniques play a central role in decision-making process since excessive data collection, recording, and measurement are required to effectively monitor and implement natural resource management plans [15].

The FAO (Food and Agriculture Organization of the United Nations) and UNECE (United Nations Economic Commission for Europe) have projected an increase in the demand for forest products and wood energy in the forthcoming decades. Also, the implementation of new sustainable management systems to mitigate climate change and increase the biodiversity of European forests will necessitate increased utilization of data monitoring and modelling [16], which means that statistics will play an important role in the future of forest management.

Given the apparent decline in the fundamental mathematics knowledge among engineering students, recent surveys by the Universidad Politécnica de Madrid reveal that over 30% of the students entering engineering programs reinforcement in mathematics [17, 18, 19]. This deficiency in mathematical proficiency poses challenges in teaching mathematics and statistics, necessitating the implementation of innovative learning methods to address these areas of weakness among students [20].

This means that not only are the characteristics of the statistics course important, but also the level of preparation and performance of teachers, whose impact on the quality of engineering education is related to the quality and competitiveness of Engineering [21, 22].

This study aims to identify the primary content that should be incorporated into the statistics course within the Bachelor's degree in Forest Engineering. It aims to determine the appropriate orientation and characteristics of the teaching staff through the utilization of the expert judgment decision-making method.

2 METHODOLOGY

In this study, a decision-making methodology based on expert judgments was used. This method relies on a group-dynamic technique that is widely used today [23]. According to Escobar-Pérez and Martínez [24], the expert judgment is defined as an informed opinion provided by an individual with a proven track record in the subject matter. These individuals are recognized by others as qualified experts in the field and possess the ability to provide information, evidence, judgments, and assessments. Skjong and Wentworth [25] have proposed the following selection criteria: (a) Experience in making judgments and decisions based on evidence or experience (teaching, research, publications, position, experience and awards, among others), (b) Reputation in the community, (c) Availability and motivation to participate, and (d) Impartiality and inherent qualities such as self-confidence and adaptability.

Some of the group techniques used in qualitative research include the so-called "natural focus group," where members belong to areas close to the target of the study, are acquainted with each other, or correspond to previously established focus groups [1].

The following methodology was applied in this study:

1. Identification of the members of the natural focus groups according to the characteristics proposed by Skjong and Wentworth [25]. In this case, statistics professors teaching Bachelor's degrees in Forestry Engineering, who knew in depth of the profession and the degree, were identified.
2. Determining the objectives of the meetings to be discussed by the focus groups:
   a. Importance of statistics for engineers as an introductory topic.
   b. Importance of statistics for forestry engineers and technical forestry engineers and identification of the degree and master's degree subjects to which it is related.
   c. Identification of the main content of the statistics course in the Bachelor's degree in Forest Engineering, from a list of blocks of topics proposed to the focus group.
   d. Characteristics of the teaching staff.

3. Methodology applied in the focus group meetings.
   a. Objectives 2.a, 2.b, and 2.d were discussed in three meetings. The secretary of the meeting recorded the main ideas and conclusions on the different topics that were discussed. The participants approved the final report.
   b. Objective 2.c: Application of the SMART preference ordering method to rank the statistics blocks. A value function was formulated that integrated each expert's opinion for each block of topics [1y, 26]. Each member of the panel assigned a value from 1 to 9 to every block. The value of a block was the sum of the values of the members of the panel for that block.

      The formulation of this function is as follows:

$$x_i = \sum_{j=1}^{n} w_j a_j \tag{1}$$

      Where x_i is the integrated value of the preference of the experts for block i, w_j is the weight, 1 in this case for every expert, a_j is the preference value assigned by expert j to block i. a_j varies between 1 and 9.

      The lower the value of the function for a block, the higher its importance.

In this study, two natural groups were established. Group 1 consisted of six members of the Educational Innovation Group in Quantitative Techniques for Environmental Engineering (all PhDs in Forest Engineering) of the School of Forestry, Forestry and Natural Environment Engineering of the Polytechnic University of Madrid, together with two professors from the former University School of Forest Engineering of the UPM, from the area of Applied Mathematics. Group 2 consisted of three professors with PhDs in Statistics from the National University of Santiago del Estero in Argentina and two professors from the Polytechnic University of Madrid. All of the participants in this study met the characteristics proposed by Skjong and Wentworth [25]. They are research professors with over 25 years of teaching and research experience, all holding PhDs. They have a well-established reputation within their respective universities and demonstrated interest and motivation to participate in this study as members of the educational innovation group.

The blocks that were proposed for them to evaluate were topics related to the forestry profession and research [27]:

- Descriptive Statistics
- Probability Calculation
- Sampling and Estimation
- Statistical Inference
- General Linear Model
- Experimental Design
- Stochastic Processes and Geostatistics
- Multivariate Analysis
- Survey Analysis

3 RESULTS AND DISCUSSION

This section presents the results in the order discussed during the group meetings.

Regarding the importance of statistics for engineers, the discussion groups emphasized that training in this discipline should equip all engineers with the ability to apply the scientific method and develop practical thinking skills to solve complex problems under conditions of uncertainty. Ayuga et al. [28] and Schefer-Wenzl and Miladovic [29] highlight these skills, as well as the need to encourage the communication skills among future forest engineers.

In terms of the curriculum, the focus groups concluded that engineers need to acquire statistical scientific methods to effectively collect data from different sources, such as field data from study areas, geographic information systems, environmental databases, data analysis, model building and validation, and model interpretation.

The focus group also indicated that while basic knowledge is fundamental, it is even more important to create a positive attitude towards statistical methods among students. Teachers should effectively communicate to students their conviction of the value of these methods as tools for analyzing data and making informed decisions in real-time scenarios that the students will encounter in their future professional work. To achieve this, Chick [30] proposed that teachers should identify the inherent opportunities within the tasks, lessons, or examples to establish statistical methods, data, and professional issues.

Regarding, the second point of discussion on the importance of statistics in Forest Engineering and the identification of the subjects in the Bachelor's and Master's programs to which it is related, the main finding was that the natural resources require a wide range of knowledge that is strongly related to statistics, such as Forest Inventory, Forest Exploitation, Hydraulics, Hydrology, Geographic Information Systems, Forest Planning, and Business Administration.

The panel therefore highlighted that to be successful, teachers should formulate and solve real-world forest management cases that are of great interest to students and encourage active participation of students in the data analysis. To do this, students should perform practical tasks based on data from the aforementioned related subjects with the help of statistical case-solving software. This conclusion is in line with the findings of Ginovart et al. [31], who concluded in their study on the impact of the use of real-world data on learning by Agricultural Engineering students that "by dealing with their data, students have felt very involved in the whole process of analysis, which has allowed them to combine their concerns with statistical analysis, increasing their interest in the subject". In short, incorporating real practical cases that address engineering problems is helpful for students learning [11] and generates greater student satisfaction [32]. This means that achieving student engagement is essential for enhancing motivation and promoting learning [33].

The panel also felt that statistics should be compulsory for engineering students, in semesters after the mathematics courses (differential and integral calculus,and matrix algebra) and before forest inventory, hydrology, hunting and fishing, forest fire management, forest exploitation, and business administration.

The panel also indicated that the number of credits, 6 ECTS, the number of ECTS most commonly allocated to this subject (1 ECTS equals 27 hours of student work), is insufficient to achieve the objectives laid for this subject. Twelve universities were selected based on their reputation and the availability of information about their degree curriculum and course content. Table 1 shows that with the exception of Boku and North Carolina State University, which have assigned seven and 12 ECTS, respectively, the rest of the degrees allocated six ECTS or even less (University of Freiburg). In addition, in some of the courses, the discipline of statistics is shared with computing or biometrics. Also, some degree programs scheduled statistics courses in the same semester as mathematics (Boku and University of Santiago de Compostela), which can result in students lacking the required level to understanding to grasp the subject (see Table 1). The panel also concluded that it would be more beneficial from an educational standpoint to spread the subject across multiple courses so that students could develop a deeper understanding of the practical application of statistics in relation to other subjects closely aligned with their professional occupation.

Table 1. Characteristics of statistics courses in Forest Engineering B.Sc. programs in 12 selected universities

University	Bachelor's Forestry Degree Name	Statistics Course Name and Credits	Year Semester
Technical University of Madrid [34]	Forest Engineering	Statistics 6 ECTS	2 Fall semester
Technical University of Valencia [35]	Forest Engineering and Natural Environment	Statistics Methods 6 ECTS	2 Fall semester
University of Santiago de Compostela [36]	Forest Engineering and Natural Environment	Statistics 6 ECTS	1 Fall semester
University of Córdoba [37]	Forest Engineering	Statistics Methods and Software 6 ECTS	1 Spring semester
University of Lleida [38]	Forest Engineering	Statistics and Computing 6 ECTS	2 Spring semester
University of Vigo [39]	Forest Engineering	Statistics 6 ECTS	2 Fall semester
University of Oviedo [40]	Forest Engineering and Natural Environment Degree	Statistics 6 ECTS	1 Spring semester
Oregon State University [41]	Forest Engineering	Introduction to Statistics for Engineers 3 credits ≈6 ECTS s	2 Fall or spring semesters
University of Canterbury, New Zealand [42]	Bachelor in Forest Engineering	Forest Measurement 15 points ≈6 ECTS	2 Fall semester
University of Natural Resources and Life Sciences, Vienna (BOKU) [43]	Forestry	Forest Biometrics I 4 ECTS Forest Biometrics II 3 ECTS	Fall semester
University of Freiburg [44]	Forestry and Environment	Statistics 5 ECTS	2 Fall semester
North Carolina State University [45]	Forestry management	Introduction to Statistics 3 credits ≈6 ECTS Introduction to Statistics II 3 credits ≈6 ECTS	1 Spring semester 2 Fall semester

Regarding the ranking of the topics proposed by focus group 2, this rank was: 1 Descriptive Statistics (DS), 2 Statistical Inference (SI), 3 The General Linear Model (GLM), 4 Sampling and Estimation (SE), 5 Design of Experiments (DE), 6 Multivariate Analysis (MA), 7 Probability Calculation (PC) and Stochastic Processes and Geostatistics (SPG), and 8 Survey Analysis (SA). Table 2 shows the topics taught by the universities listed in Table 1.

Table 2. SMART method results. Topics taught in statistics courses in 12 selected universities

University	Topics Taught in Different Forest Engineering Bachelor's Degree Programs by University							
	1 DS	2 SI	3 GLM	4 SE	5 DE	6 MA	7 PC	7 SPG	8 SA
Technical University of Madrid [34]	X	X	X	X			X		
Technical University of Valencia [35]	X	X	X				X		
University of Santiago de Compostela [36]	X	X	X				X		
University of Cordoba [37]	X	X			X		X		
University of Lleida [38]		X	X						
University of Vigo [39]	X	X					X		
University of Oviedo [40]	X	X					X		
Oregon State University [41]		X	X	X	X		X		
University of Canterbury, New Zealand [42]	X	X		X			X		
University of Natural Resources and Life Sciences, Vienna (BOKU) [43]			X	X					
University of Freiburg [44]	X	X	X				X		
North Carolina State University [45]	X	X	X	X	X		X		

According to the discussion groups, the primary contents that should be taught are data collection (sampling and design of experiments), descriptive analysis of data, and basic statistical inference methods (confidence intervals and hypothesis testing for quality control).

Linear models, which allow variables to be related (regression) and models used in the analysis of experimental design (variance analysis) were also considered very important.

The discussion group were also of the opinion that only the theoretical content of calculus of probabilities is required to establish the foundation for the remaining subjects. This includes probability theory, random variables and vectors, and probability models. They emphasized that this block of content should be kept as concise as possible, explaining only the necessary basis for understanding the theory of statistical inference or estimation.

The focus groups did not consider the design and analysis of questionnaires as a necessary component of the statistics syllabus but suggested it as a potential elective subject. On the other hand, they deemed treatment of time series, geostatistical data and multivariate analysis were considered more appropriate as required coursework for Master's degrees. For an Environmental Engineering degree, Piegorsch and Edwards [46] propose an introductory statistics course that covers random sampling, basic summary statistics, basic probability, and statistical distributions, point estimation, confidence intervals, significance testing, correlation, and regression. For Master's degrees, they propose nonlinear models, generalized linear models, time series, geostatistics, and quantitative risk analysis [46].

The panel unanimously agreed that the transmission of this knowledge should be in person, since this establishes the best student-teacher relationship and is the best way to transmit information. This finding aligns with a study by Tawil et al. [47], which surveyed engineering students' preference for learning mathematics and statistics through lectures rather than e-learning. However, there is a unanimous opinion that multimedia and data analysis software are key in statistics learning [48, 49, 50]. Blended learning could also solve the problem of low student motivation and commitment [51].

Regarding the characteristics of the teaching staff, the focus groups discussed the nature of the teaching profession and the engineering profession. The professional engineer must be capable of developing and applying science, technology, technique, etc.

The groups discussed on two different approaches to teacher characteristics:

The first approach suggested of an engineer-teacher teaching along with other engineers. The main conclusions of this approach were: (1) The teacher learns statistics quickly through textbooks based on application problems and acquires teaching skills over a period through self-teaching and practice. (2) There should be more opportunities to contact and share information among colleagues. (3) The result of following the first two steps mentioned above is that after some time, the teaching skills of the teachers keep improving year after year and they succeed in teaching statistics from an applied point of view and thereby improving the student's performance [52, 53, 54, 55, 56].

The second approach is an engineer-teacher who teaches with mathematical peers The main conclusions of this approach were: (1) Statistics is harder to learn through textbooks based on mathematical developments that take longer to understand. (2) Teaching skills also take longer and are acquired through practice, (3) The applied aspect is less important than the theoretical concepts. (4) There is more peer rivalry. (5) The result, over time, is teachers who do not make much effort to improve their teaching skills and approach the teaching of statistics from a point of view that is less applied than what the students require. The focus groups concluded that the main characteristics of an engineer-teacher include, a love for the profession, recognition of the high degree of social responsibility among forest engineers, commitment to ethics and the defense of natural resources and their sustainability, and the understanding that forestry should be related to social use. The development of a tool for managing faculty knowledge in Forest Engineering schools and departments could be a supportive tool to develop courses with an interdisciplinary approach.

This means that universities face challenges in selecting faculty who possess not only subject knowledge, pedagogical knowledge, and teaching experience, but also practical applications and understanding of forest engineering or engineering in general [57]. Teacher training programs should consider focused teaching skills. Albéniz et al. [22] propose the use of teacher evaluation instruments to promote and retain faculty in the universities who can encourage good teaching practices [22]. Moreover, universities may seek for new applicants to university positions, based on their education, experience, and skills, have a course in engineering work, which professional associations could offer.

4 CONCLUSIONS

Statistics is a fundamental subject for most engineers, and it is applicable especially for the forestry engineers. It should therefore be present in all syllabi aimed at training professionals in the forestry sector.

Why is statistics so important? Because forestry engineers and forestry outside Spain require the evaluation of large forest masses, both from the point of view of stocks (wood volume, biodiversity, etc.) and to assess fire damage, so decisions must be made regarding actions related to the management of the natural resources that make up the forest, and in forest industries, that require the evaluation and control of the quality of products and management of manufacturing inventories.

Who should teach this subject? The panels felt that it is essential for teachers to know the applications of statistics to forestry, both in the management of natural resources and in forest industries. These teachers will preferably be from the Agroforestry Engineering Department.

What content should be taught? Foresters must know and expertly apply sampling techniques, descriptive statistics, and linear models to manage the natural resources of the forest. They must also have a good knowledge of estimation or statistical inference to estimate stock and work adequately in the quality control of manufacturing products. All forestry degrees analyzed included a statistics course, although the content varied in some.

The limitations of this study are those associated with the use of focus groups [58]. In this case, although the group was quite homogeneous, did not feel coerced, the moderators were experienced, and a great deal of information was obtained from each participant. The unavoidable limitations were the impossibility of quantifying the information and the characteristic lack of statistical representation of the data.

Future research on the questions posed in the objective of the study could be carried out with surveys involving students, alumni, and professors of these degree programs, transforming the questions into attitude questions with scale answers (Lickert type), which would make it possible to quantify the opinions and obtain more statistically representative conclusions. It would also be interesting to have information from other universities to see these trends in the teaching of statistics in forest engineering at the global level.

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