# MODELLING STUDENTS' LEARNING OF INTRODUCTORY STATISTICS ®

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*In this exploratory study, we followed approximately 1000 students (Economics and Business) in their freshman year at the University of Maastricht (Netherlands). Those students attended three compulsory courses in Quantitative Methods, each having an important component of statistics. Our population of students exhibits a strong heterogeneity with respect to several aspects: attitude towards and prior knowledge of mathematics and statistics, nationality, type of prior education and the mastery of languages. To study the impact of this heterogeneity on learning introductory statistics, the development of a model of students' learning of introductory statistics was chosen as the goal of the project. In order to develop a relational model, several surveys were taken and data sources were used with regard to the students' characteristics, learning context, students' perceptions and the approaches students took. The major contribution of this study is the broad range of different determinants of learning that is considered, which allows investigation of the interrelation between several factors influencing learning besides studying the direct impact of each factor on learning.*

## MODELLING STUDENT LEARNING

The aim of the study is to develop a model that explains student learning and its outcomes. Given the context of the study, the model will be of the type of 'presage-process-product model of classroom learning' (Biggs, 1993, 1999; Prosser & Trigwell, 1999). According to this 3P modelling approach, learning is seen as a progression from presage (teaching context) through process (teaching acts) to products (class achievement). The approach distinguishes several building blocks in explaining learning outcomes. The student-based building block contains factors that explain learning from individual differences psychology. These factors include abilities, prior knowledge, motivation, personality facts, learning styles, stabilised learning approaches, and so on. The second building block builds on traditional staff-developmental models, and focuses on teacher behaviour. The third building block, strategies for handling the task, derives from information processing psychology, focussing on the process, on the efficiency with which basic cognitive strategies are developed. The complete model integrates teaching-based, student-based and process-based approaches to learning, and in addition to that, allows for feedback from process to presage, and from product to process and presage. Crawford et al (1994, 1998a, b) constitute examples of the application of the 3P modelling approach to learning mathematics.

## THE FACULTY AND ITS STUDENTS

In 1984 the Faculty of Economics was established as part of the University of Maastricht, founded in 1976. The faculty offers an English-language International Business and Dutch and English-language Economics programmes. All programmes are characterised by a student-centred educational approach known as problem-based learning. Students develop their knowledge and skills while working on problems in small groups. This is the dominant instructional tool, with a limited number of exceptions, the first year service courses in Quantitative Methods 1 (QM1) being the most important one. The three QM1 courses cover subjects from mathematics, statistics and computer skills. The material is often regarded as being difficult and unattractive by most of our students. In order to let the subject matter sink in, courses are spread over most of the academic year. The total study load of the 3 first year QM courses is 10 weeks (of fulltime study). The QM1 statistics programme covers the following subjects: in QM1.1, data processing and descriptive statistics, and probability theory; in QM1.2, inferential or inductive statistics; and in QM1.3, regression analysis, including the multiple model and inference for regression models.

Of the approximately 1000 students participating in QM courses (the number fluctuating over the years, so we will focus on the '99/'00 data) a great majority are freshmen (900 students).

The remaining students are 'repeat' students that did not manage to pass that specific course the year before. As a long term average, about one third of the total number of participating students fail to pass either the first or the second attempt of any QM1 examination. Many of them not only fail one or more QM1 courses, but also fail other courses. If that happens too often, students get a so-called 'negative binding study advice', that prevents them from continuing their studies at the faculty. About one quarter of the faculty's students will find themselves in this position at the end of their freshman year. Those who fail a QM1 course, but have their other study results good enough not to receive such an advice, will enrol the course a second time; in '99/00'this was approximately 100 students.

The 900 freshmen inflow can be decomposed according nationality: 600 Dutch students, 240 German students and 60 students of other nationalities. That decomposition is important since huge differences exist between secondary school systems in Europe. All Dutch freshmen entering our faculty participated in a final, national exam in at least seven subjects, including either basic mathematics (calculus oriented), or advanced mathematics (algebra and geometry oriented), or both. In contrast, German pupils have four subjects in their final exam, two at advanced level, two at basic level. Having chosen mathematics in their final exam ('Abitur'), either at advanced level ('Leistungskurs') or at basic level ('Grundkurs'), their mathematical schooling is somewhat comparable to that of Dutch students in the two different groups. However, a sizeable proportion of German freshmen did not select mathematics at any level for their final exam, and their level of mathematical schooling is really incomparable to that of Dutch students. Besides that, the share of statistics and probability theory in mathematical courses will differ from state to state in Germany, whilst in the Netherlands those two topics are incorporated in basic mathematics, but not in advanced mathematics.As a first step in the modelling process, the following data was collected.

All students:

- Mother language: Dutch, English, German, or Other.
- Gender
- Country of secondary education.

Dutch students:

- Indicator variables for all secondary school subjects, indicating if the subject was included in the exam
- Final exam grades for the subjects included in that exam
- Number of subjects chosen in the final exam (minimum of seven is required, but more subjects are allowed).

Foreign students:

- Indicator variable identifying mathematics at advanced level, basic level or not taken in the final exam.

## PRIOR KNOWLEDGE IN LEARNING STATISTICS

In educational research for factors influencing academic performance, prior knowledge appears to be amongst the most influential variables, and often the single factor with largest contribution in explaining the variation in performance. From a theoretical point of view, this should not be very surprising: modern theories on learning, like the cognitive view, regard learning as a stepwise increase through elaboration and restructuring of the students' knowledge-base. Given the impact of prior knowledge, some institutions have used it as the key variable in designing curricula. Distance learning institutions, like Open Universities, are characteristic examples of such schools, attracting students with strongly differing backgrounds and depending on computer-based learning as their main instructional tool. This part of the study is strongly based upon the empirical research of Filip Dochy into the role of prior knowledge of different types of students participating in the Dutch Open University courses (Dochy 1992, Dochy, Segers & Buehl 1999). In his research, Dochy distinguishes two types of prior knowledge indicators: 'prior knowledge state tests', being tests specifically developed to measure prior knowledge states, and so-called 'cheap indicators': data available from other sources, e.g. the central administration, regarding previous education, work experience and so on. In our context, secondary education data, as described in the last section, can serve that role. With regard to exogeneity, one can distinguish between the variables describing the portfolio of subjects chosen in the final exam (decided upon three years before the final exam takes place) versus the grades achieved in the final exam.

In addition to these ‘cheap indicators’, two prior knowledge state tests were administered in the very first week students entered faculty. The first test comprised of two short tests in calculus and algebra that were adapted from the Dutch Open University. These tests are subsets from a more extensive test developed as an ‘optimal requisite knowledge test’ for economics students. The level of this test is however rather low: to be described more as ‘minimal requisite’ than ‘optimal requisite’. From this test, several items regarded as more difficult were selected in the topics calculus and algebra. As a second prior knowledge state test, focussing on statistics, the Statistical Reasoning Assessment (SRA), was used Garfield (1991). That test will be described in the next section.

In determining the success of students’ learning of statistics (and as an additional interest: mathematics, being the second major component of Quantitative Methods), it was decided to regard the students’ achievement on the final exam as the knowledge test. Final exams consist of 4-choice items, both on mathematics and statistics. Dochy (1992) distinguishes a third category of tests, situated in between prior knowledge tests and knowledge test: so-called progress tests. These tests are assessments of knowledge states observed at different times within the learning process. In our project, weekly quizzes served the role of progress tests. Taken together, the following portfolio of knowledge tests and indicators of (prior) knowledge, all of them ordered according exogeneity, arises:

❶ Personal factors of students:

❷ Secondary education data, students with Dutch education:
- Number of subjects in national exam
- Indicator variable for each subject in national exam

Secondary education data, students with foreign education:
- Mathematics and / or statistics as major in final exam

❸ Secondary education achievements, students with Dutch education:
- Grade of each subject in national exam
- Average grade of subject in national exam

❹ Mastery of prior knowledge mathematics, all students:
- Calculus prior knowledge
- Algebra prior knowledge

❺ Mastery of prior knowledge statistics, all students:
- Statistics: correct conceptions
- Statistics: misconceptions.

❻ Prior knowledge states measured by progress tests, all students:
- Weekly progress test scores statistics

## STATISTICAL REASONING ASSESSMENT

All incoming students are, to some extent, introduced to the principles of statistical reasoning, defined as the way people reason with statistical ideas and make sense of statistical information. This involves making interpretations based on sets of data, representations of data, or statistical summaries of data. Much of statistical reasoning combines ideas about data and chance, which leads to making inferences and interpreting statistical results. Underlying this reasoning is a conceptual understanding of important ideas, such as distribution, centre, spread, association, uncertainty, randomness, and sampling. Students’ acquaintance with statistical reasoning will be based both on formal schooling and, more often, on informal conceptions. It is expected that both can have a strong impact on the learning of statistics.

Realising that statistical reasoning may best be assessed through one-to-one communication with students (e.g., interviews or observations) or by examining a sample of detailed, in-depth student work (e.g., a statistical project), researchers of the NSF-funded ChancePlus Project felt the need for an objective instrument and developed the SRA (Garfield, 1991; Konold, 1990), to use in evaluating the effectiveness of a new statistics curriculum for high school students in achieving its learning goals. The SRA is a multiple-choice test consisting of 20 items. Each item describes a statistics or probability problem and offers several choices of responses, both correct and incorrect. Most responses include a statement of reasoning, explaining the rationale for a particular choice. The following types of reasoning are included in the SRA: reasoning about data, about representations of data, about statistical measures, about uncertainty of samples, and about association. In addition to determining types of reasoning skills, the SRA also identifies types of incorrect reasoning students should not use when analysing statistical information. The SRA therefore includes items measuring the following misconceptions or errors in reasoning: misconceptions involving averages, Outcome orientation, Good samples have to represent a high percentage of the population, the Law of small numbers, the Representativeness misconception, and the Equiprobability bias (Garfield, 1998a).

KNOWLEDGE STATES RELATED

Relating both knowledge and prior knowledge states to demographic/personal factors and secondary education data gives rise to remarkable differences between several subgroups of students. Figure 1 contains 95% Confidence Intervals for the proportion of correct answers on tests measuring the two knowledge states: statistics and mathematics (the two parts of our final exam) and the four prior knowledge states: calculus, algebra, total correct conceptions from SRA and total misconceptions from SRA.

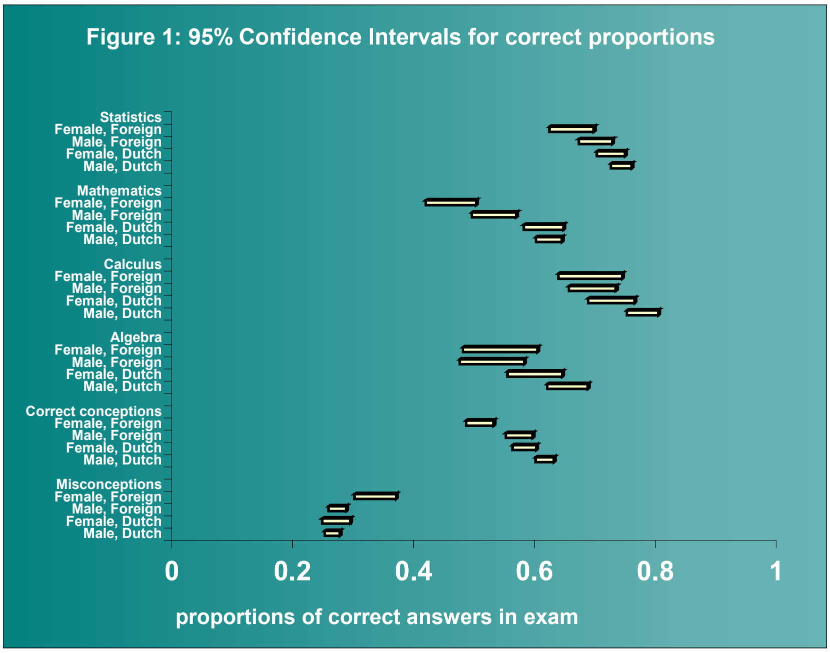

Figure 1: 95% Confidence Intervals for correct proportions

The differences between students with a foreign secondary school diploma and those with a Dutch one are as expected: Dutch students in general outperform foreign ones. The differences between female and male students do not have an easy interpretation: whilst foreign males had more mathematical schooling than foreign female students, the reverse is true for Dutch students. A striking outcome is the gender dependency of the SRA outcomes: female students have fewer correct conceptions and more misconceptions than male students. That outcome is in agreement with studies of Garfield (1998b) and Liu (1998), but it is not that easy to interpret.

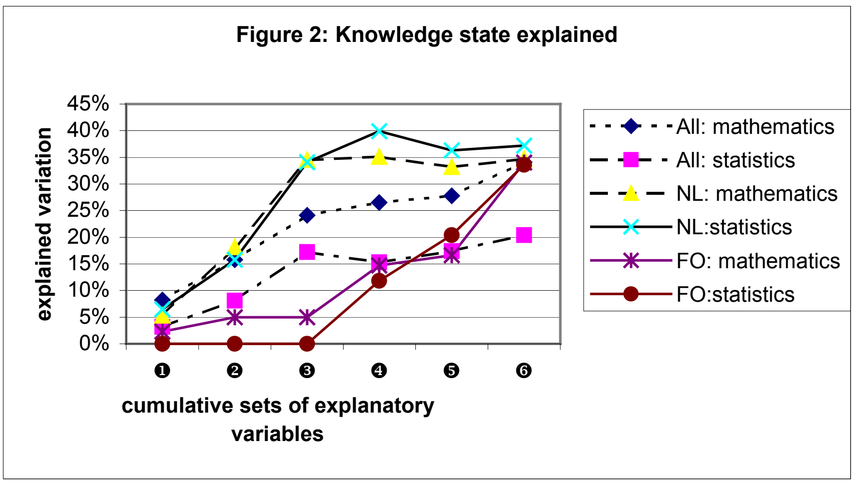

Figure 2: Knowledge state explained

the several sets of prior
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the Dutch students (NL),
›et on secondary school
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The size of this contribution severely restricts a profound description of all our research outcomes; some of the instruments included in the research, as e.g. student's learning styles and personality characteristics, are even undiscussed. At the same time, the results described are quite representative for all other partial outcomes left out, in the sense that all outcomes demonstrate:

- Strong relationships between several of the factors that are viewed as potential determinants of the learning process, such as e.g. between attitudes and gender;
- The absence of a strong and significant relationship between any of these potential determinants and knowledge states (exam grades), except one category: prior knowledge states are a powerful predictor of knowledge states, and explain variation in knowledge up to 40%.

As a proof of this very last outcome: the best predictive model of knowledge state statistics, excluding all prior knowledge states as causal factors, only explains 1.5% of the variation, and contains one single significant regressor: the personality trait Conscientiousness.

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