

Chapter 23

Quantitative Methods In A Problem-Based Curriculum

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Introduction

The quantitative methods mathematics, statistics and computer science invariably take the position of subsidiary yet essential courses in the studies of economics and management sciences. When designing the problem-based curriculum of our faculty, we posed ourselves the following two questions:

- is problem-based learning as an educational system suited to teach mathematics and statistics; if not, can it be modified into an educational system which preserves most of the principles and objectives of problem-based learning, yet which is adequate to teach these subjects?
- how can mathematics, statistics and computer science play a role in the educational system of problem-based learning by supplying the students with additional techniques for problem solving, which the students in turn can use in their other courses?

In this paper, we primarily address the latter of these two questions, i.e. the substantial question (for the first question, the functional one, we refer to the contribution of de Crombrugge & Pauly, this volume). We discuss the possibilities to partly substitute problem solving abilities for the traditional, cognitive objectives of courses in mathematics, statistics and computer science. As an illustration of the design of our curriculum, we will focus on the ability to make use of computer-based problem solving environments as one of the objectives of the course in computer science.

The Educational System Of Teaching Quantitative Methods

The following observations, which all stress the exceptional position of the subject, play a significant role when addressing the first question:

- quantitative methods are subsidiary courses in our curriculum, accounting for about 25% of the credits to be earned by all students in the first year program, and a varying percentage in the other years of the study program (but for most students less than 25);
- its scientific foundation makes the subject itself rather eccentric within our curriculum, being one of the few axiomatic disciplines within a study that is to a large extent composed of empirical disciplines;

- most of our students feel (and even if they don't feel it, they are in fact) less talented for the subjects we teach;
- as a consequence of the facts mentioned above, our students have a low intrinsic motivation to study quantitative methods. Since both on the side of the students and of the lecturers, there is a lack of time and other facilities to substantially increase the level of intrinsic motivation, this shortage has to be compensated by a sufficient level of extrinsic motivation.
- As with other axiomatic disciplines, our students cannot relate to quantitative methods in their daily life, which makes it rather awkward to build on their intrinsic motivation just by giving examples they saw on television, or read in a newspaper (as is the case with the economic subjects). A meaningful context is thus lacking.

All these arguments form the basis for a strong plea to teach quantitative methods using other educational principles than problem-based learning. However, it is common knowledge (and we have experienced it once more) that when one subject is taught using principles based on intrinsic motivation, while at the same time another subject is taught using principles based on extrinsic motivation, it is always an unequal struggle. Extrinsic motivation drives out intrinsic motivation, as does bad money with good money. Since in our first year program the economics subjects and the quantitative methods subjects are taught in parallel, during the whole year they have to compete in terms of time and attention of the students. Thus, it is evident that we could not decide on the instructional principles in teaching quantitative methods by merely comparing the advantages and disadvantages of the several alternatives while setting aside the other parts of the curriculum. We had to find a compromise between the arguments related to the special position of our discipline and the need to limit deviations in instructional principles.

What this compromise looks like, is exposed in the contribution of de Crombrugge and Pauly (this volume). The format we choose indeed bridges the gap between problem-based learning at the one side, and classical, teacher-oriented educational disciplines at the other side. In this paper we won't elaborate on this functional issue, the matter of the educational principles, but focus on the substantial issue: the matter of mathematics, statistics and computer science as the foundation for the problem solving competencies of our students.

Most concepts need long descriptions in order to only grasp their key characteristics; the concept of problem-based learning is one of the few exceptions to that rule. Already its name gives a short, but concise indication of its meaning. Problem-based learning is an instructional principle, so 'problem-based teaching' would be an obvious choice as a name for the method. But another name was preferred, and as we shall see, with good reason. Most importantly, problem-based learning regards teaching as a stimulus to learning, which implies a much broader definition than teaching as the transfer of knowledge (Wijnen, 1990). It is the student who triggers the learning process (the learning process is student-centred), and not the teacher, which brings about another difference between problem-based learning and traditional, teacher-centred instructional methods. In the latter, the optimal structure of the program will be the most uniform one. It is the teacher who optimises the channels through which the transfer of knowledge takes place, within the constraints of the educational setting, and once this optimisation has taken place, it is this same, unique optimum which is valid for all students. This contrasts sharply with student-centred educational principles, in which the students trigger the learning process. Since all students are different, the chance of having even two students

who choose the same learning path is zero. The great variety in learning activities is an immediate consequence of the method.

In the system dynamics literature we find similar opinions on the ideal educational setting (see e.g. Richmond, 1993). It only is phrased in other words: a teacher-directed approach to learning versus a learner-directed approach. The latter approach recognises that learning fundamentally is a construction rather than an assimilation process. It follows that, since constructions take on many different forms, learning cannot be standardised. Furthermore, construction is an active process, in which the students construct or build, and the teacher accepts the role of providing materials for this construction process.

System Dynamics

It only is a small step from this particular view on educational processes to the so-called approach of system dynamics (or systems thinking). Although the exact content of this approach isn't agreed upon, there surely is no disagreement upon the core of the approach: the fundamental role of feedback and circular-causal relations in the analysis of systems. Systems of many different kinds: system schools can be found in a large diversity of scientific disciplines. Including education, an observation that nicely fits in the line of reasoning in this paper: not only the inclusion of concepts from system dynamics into the courses given to students deserves our attention, but also possible benefits for the educational process itself, using insights offered by this approach.

One of the common ancestors of problem-based learning and system dynamics is the work of John Dewey, who described learning as an iterative cycle of invention, observation, reflection, and action (Sterman, 1994). This feedback-loop character of learning is elaborated by Argyris, who classified learning processes into two types: single-loop learning and double-loop learning (Argyris, 1985). In single-loop learning, there is one feedback-loop, which influences the decisions taken, but which does not affect the models and the decision rules used by the decision maker. In double-loop learning, the model is extended with a second feedback-loop. That is, information about the real world not only alters decisions taken within the context of existing frames and decision rules, but also feeds back to alter the mental models. As these mental models change, different decision rules are created.

All learning processes, then, whether designed by an expert on system dynamics or not, belong to one of these two types; in that aspect our background does not matter. However, some learning processes appear to be much more effective than others, and we can use insights from system dynamics to discover why. To find the 'barriers to learn', Sterman compares the learning processes in two different situations: learning how to ride a bicycle and learning how to invest in real estate (Sterman, 1994). The first learning process is, at least for most of us, a rather effective one: after a short period of training, we usually control our vehicle perfectly. This sharply contrasts with the investment situation. Most real estate markets suffer from chronic cycles of busts and booms. Ideally, then, one would be able to identify busts and booms, in which case an easy strategy is of course to invest during a bust, and to sell during a boom. Such a strategy, in turn, can be implemented on a computer without any problem, using a very simple, low-dimensional system dynamics model that replicates the real estate cycle. At the same time, the persistence of the cycle is an evident proof that the (majority of) investors

don't succeed in applying this type of strategy. Or, in other words: their learning process is very ineffective.

What factors can account for this difference? In both situations we can recognise double-loop learning. Yet the feedback in the bicycle-case is immediate, continuously available with very short time delays, salient (sometimes even too salient) and accurate, whereas the feedback in the investment-case is delayed, and confounded with many other events.

One of the characteristics of problem-based learning has been called the phenomenon of 'concentric circles'. The idea is that the construction of knowledge, like any construction process, takes time; that learning isn't an 'once and for all' project, but one with many iterations, gradually building up knowledge. According to this view, the construction of knowledge can be compared with the circles that grow in the water, after you throw a stone in it. An idea that closely resembles the dominant role of feedback in system dynamics. Using ideas of both disciplines, and especially ideas from their common domain, we tried to design a curriculum for quantitative methods: statistics, mathematics and computer science.

Statistics

The statistics course, as given to all our freshmen (economics, management sciences and business studies), is both traditional and not. It is traditional in the sense that we use one of the many undergraduate texts titled as '*elementary / introductory statistics for business and economics*' or some other permutation of these words. That is, a text that, although characterised as innovative by Cobb (1987) because of its concern with the analysis of real data, and its focus on data analysis, is the backbone of many introductory courses in economic faculties nowadays; courses that introduce statistical concepts at a rather intuitive level, without much formal mathematical background, and that stress the importance of applying statistical methods. We would have preferred an even more innovative text, e.g. one written more strongly from an EDA (Exploratory Data Analysis) approach. In fact, some years ago we switched to such an EDA oriented text. However, we found out that a large portion of our students, and especially the more mediocre ones, performed worse than they usually do, which brought us back to a more conventional text as well as the need to look for other ways to express our ideas on educational innovations.

Except for this issue of the text that is used, several other issues make the course quite non-traditional. One such issue is what we will call, after Roberts (1987), the project work. According to Roberts' pleas, these projects supplement the examinations, and even partly substitute for them. The project work is, again according to Roberts, intensively based on statistical computing, which is carried out on personal computers. We even use the same interactive package: Minitab. However, not every detail corresponds with Roberts' suggestion. Whereas his student projects are individual, with the teacher providing individual guidance and supervision (for about 90 minutes per student per course), our guidance and supervision is carried out in small groups: the tutorial groups. This is not only the result of the number of freshmen that follow the course: about 500, a number that largely exceeds the upper limit of 100 students which Roberts regards as the absolute maximum to successfully implement project work. More important, and crucial within problem-based learning, is the idea that students learn by discussing the project work in the tutorial groups, and by explaining their solutions to the

assignments to their fellow students, or, in case they did not succeed in solving the assignments, by discussing the problems they encountered.

Another issue that differs from Roberts' suggestion is the content of the project: we start with an assignment that is the same for all students, in order to allow for converging group discussion on the project. When students were free to chose their own data set, as a basis for their project, there would be severe restrictions on the extent of the learning within the tutorial groups.

It is in these assignments, that we can bring the more innovative elements of the course. The assignments force the students to perform an exploratory data analysis on different data sets. In the first block of the first year program, our freshman follow two courses in parallel: quantitative methods and an introduction in organisation and marketing. This latter course revolves around a case on Macintosh, a Dutch firm in the international non-food retail sector. As a part of the case, students receive time series of important quantities from twenty consecutive annual reports. Students are asked to analyse the evolution of variables such as turnover, net profit, number of employees and ratios constructed from these variables, both for the firm as a whole and for the several industrial groups and geographic markets separately. The students will repeat this analysis several times during the 9 weeks of the first block, using the different instruments of descriptive data analysis which are taught in the statistics course. The results of this exploratory data analysis support the study of the corporate strategy of Macintosh using written sources such as annual reports and press announcements. An example is the tracing down of the causes of a huge negative trend shift in turnover and number of employees in 1993, together with a huge positive outlier in net profits. All of them being facts that can be traced down to a switch in corporate strategy in the direction of further specialisation in retail activities, by selling its production facilities and concentrating on the retail of clothing and furniture. Which can't be as vividly expressed in any report as in a trend break of 15% in the time series of total number of employees.

Another example of the use of exploratory data analysis in the project work is offered by our third block, during which the statistics course on the regression model is given in parallel with the macro economics course. Nowadays, many texts on macro economics are accompanied by simulation and/or gaming kits, with which the students can analyse economic time series, solve simple static models, or simulate with dynamic models. However, from a statistical point of view, there is a missing link in these exercises. The models the students game with, are deterministic, they don't allow for uncertainty. In other words, whereas the models intend to mirror the behaviour of a real economy (the US one), the relations which are represented in the simulation models are just the regression equations using the time series in the economic data base, while omitting the element of uncertainty. This isn't, in our opinion, a very attractive approach, since it shuts the door to learn anything about the uncertainty involved in the behavioural relations that describe a nation's economy. Analysing time series only by simple graphical means as time series plots, followed by simulation experiments using a deterministic regression model, strongly suggests the existence of a completely controllable economic environment, and suggests that we can predict next year's investments as accurately as we can predict next year's consumption.

Our project work in the third block is intended to provide this missing link. Using the same data base the students are already acquainted with, and the computer package Minitab, the students build their own stochastic version of the model of the (US) economy, in order to find

out, for example, that there is a world of difference between the uncertainty involved in an investment prediction and that in a consumption prediction.

Project work isn't just an educational approach. In our opinion, and at least in our curriculum, project work is inextricably connected with the so-called 'wider view of statistics' (Wild, 1994). The capability to recognise general patterns in the description of a problem, to recognise statistical problems where others are not aware of them, to communicate on problems and solutions in a nontechnical language with other people, all these competencies and attitudes that together constitute the concept of 'statistical thinking' (Wild, 1994), are in our curriculum as important as theoretical knowledge on the subject. At the one side, these competencies build up the characteristics of any good applied statistician; at the other side, they add to the general stock of problem solving skills that our students need in their role within the problem-based learning process.

Mathematics

We put some hard effort in the development of a course based on 'mathematical thinking' ideas, along the lines that appeared to be successful in the statistics course. Yet the results are without doubt less convincing and it is not difficult to see why. Except for economic subjects such as microeconomics, macroeconomics and finance, mathematics have a quite modest role in our undergraduate courses. This restricts the domain of relevant project work, and simultaneously leads to an underrating by our students of mathematics as a valuable problem solving skill. Being unable to change these conditions in a drastic way, we decided to solve this dilemma by bringing down our ambitions. We substituted 'modelling', or 'system thinking', for the surely more ambitious goal of 'mathematical thinking'. Specifically, most subjects within mathematics, and especially those belonging to functional analysis, are rather traditional as regards to their content. However, in linear algebra, we extend the treatment of difference and differential equations, and especially systems consisting of those types of equations, with the modelling of dynamic systems. For that purpose, we make use of two different computer packages: the spreadsheet application Excel and the modelling & simulation package Stella.

During the whole 1_{st} semester course of quantitative methods (3 blocks of 9 weeks), the students get weekly assignments, part of which they have to solve using the computer applications Excel, Stella or Minitab. Some of these assignments, and especially those with a statistical background, form part of the project work, others do not. Students solve these assignments, individually or, in most cases, in co-operation with one or two other students, and discuss their solution in the weekly group meeting (see de Crombrugge & Pauly, this volume, for a description of these group meetings). After each of the three 9-weeks blocks, the students have to demonstrate their competencies in solving this type of problems in a kind of 'oral defence'.

The use of spreadsheets in the curriculum of economics or business studies is rather well documented. As for these treatises, see for example the chapters by Chmieliauskas and Miners & Nantz (this volume). We will not elaborate on that subject, and limit our contribution to the single comment that as weekly assignments using Excel, we use much more open and less structured problem descriptions than the authors mentioned above do. Our assignments primarily stress the modelling exercise: the translation of a verbal, inexact and sometimes incomplete problem description into a more formal (as well as accurate and complete) one with

the aid of the modelling toolkits. To achieve this, it isn't expedient to provide the students with a complete Excel model, and ask them to do additional analysis. Instead, they have to design it themselves.

Somewhat less well documented, in addition to being only documented in journals that aren't read on a daily basis by economists, is the use of Stella as modelling environment. In the next section, we will elaborate on this issue.

System Dynamics And Stella

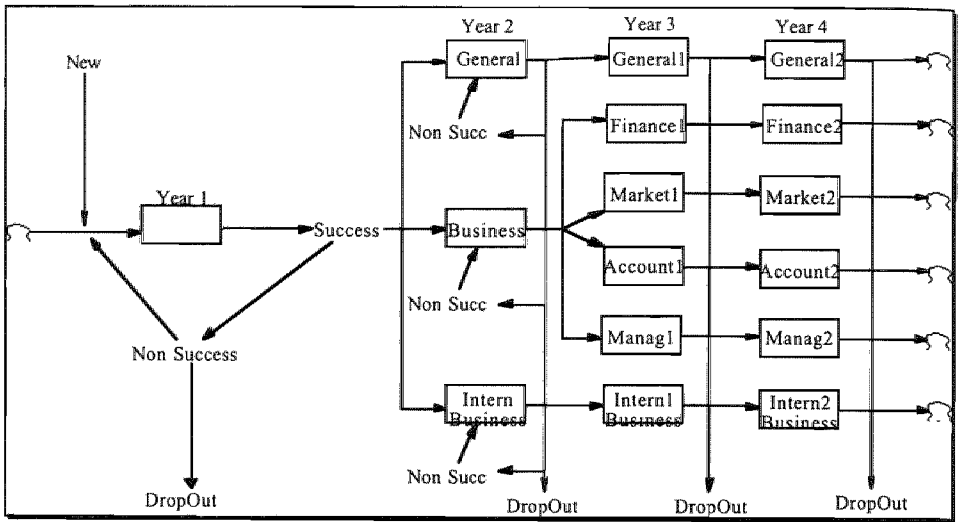
It probably does not raise any surprise, that most of the time we have is spent on getting acquainted with system dynamics and the application based on those ideas: Stella. There were several motivations for choosing this specific content on computer science:

- to provide the students with 'multi-purpose applications' which they can use for other subjects;
- beyond the mere facilities: to give students a 'problem solving environment' in which they can learn and train general problem solving competencies;
- to facilitate the learning process of other subjects by means of 'modelling by learning'.

As for these last two objectives, we consider the application Stella (and system dynamics as the simulation methodology at its background) the main instrument. An instrument that is primarily used as a problem solving & learning environment, and not as a simulation kit. In this respect, our way of using Stella diverges from that described by Sliwa (this volume). These choices are inspired (partly ex ante, partly ex post) by developments as:

- computerised learning environments, like Papert's Logo. In our opinion, Stella is the natural successor of Logo, trying to make abstract concepts concrete by visualising them, being an interactive learning environment, and using an easy to understand graphical language;
- the so-called 'modelling as learning' methodology: *'providing a facilitator that serves as an interactive framework for capturing the students ideas and assumptions in a form that is both straightforward to understand and amenable to the application of suitable analytical tools'*.

The assignments the students have to solve with Stella are rather simple ones, that focus on the modelling part. E.g. to make a model of their own faculty (see the figure below).



Historical Account

Although the composition of this paper may easily give you such an impression, it would be wrong to conclude from this paper that motivation and ideas came first and next the curriculum. Most of the ideas came later, implying that the pedagogical and cognitive foundation of our courses partly are *ex post*. What we did know, however, at the moment we had to design our first curriculum ten years ago, was the situation we wanted to prevent by any means. At that time, all economic faculties in our country shared, for example, a common approach to the introductory course in computer science: some weeks of training in order for their students to master structured programming, mostly in a fourth generation language, mostly using Pascal. After this short but intensive training the students acquired the competence to write a 50 lines program (sometimes using a terminal, connected to a mainframe, in order to try it out, but in other cases just with pencil and paper), only to loose that competence within some months due to a lack of any need to practise that competence. Most students would not engage in computers during their study, and get a cold shower afterwards, when discovering that most young economists spend a large portion of their working time just behind a personal computer. When our faculty was founded, the Apple Macintosh was almost simultaneously introduced in Europe. Being very much convinced of the importance of practical computing experience, especially for students who were neither born nor grown up as whiz kids, we were very impressed by the new graphical interface, and decided to do it 'the Macintosh way': to train our students to use some multi-purpose pc-applications, like Excel and Minitab, as mentioned before, text processing as well as Stella. Stella was, after the Macintosh itself, our second substantial 'discovery'. Very shortly after its introduction, we came to know it and we were impressed (being familiar with Dynamo) by the attractive interfacing. It was, in our opinion, the very first application that made a complete use of the graphical facilities of the Macintosh. We firstly introduced it as a simulation kit and, after realising the parallels with Paperts' microworlds, as a computerised learning environment somewhat later.

The computer lab we started with was quite impressive: 1 computer for every 3 students. This ratio deteriorated strongly, due to a growing number of students and (relatively) declining budgets. Our computer lab now contains a mixed environment, and we evolve, within several years, to an 'all Windows' environment. In this lab, during the first three weeks of their study (so immediately after arrival), our students get a short training in using these applications. After that, the students get a problem set every week, which has to be solved using Excel, Minitab and Stella. Besides that, the students have very regularly writing assignments, for which only a text produced by a word processor is being accepted.

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