Computer-Based Education in a Student-Centered Curriculum

The "Modeling for Learning" Metaphor

Dirk T. Tempelaar
Faculty of Economics and Business Administration, University of Maastricht, Maastricht, the Netherlands

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1. PROBLEM-BASED, STUDENT-CENTERED LEARNING VERSUS TEACHER-CENTERED LEARNING

The two questions 1) which subjects should be incorporated in the quantitative methods courses? and 2) what educational approach should be used to teach them?, have been major issues in the development of the problem-based curriculum for the Maastricht Business School. Mathematics, statistics and computer science invariably take the position of subsidiary yet essential courses in business studies. When designing the problem-based curriculum of our faculty, we posed ourselves the following functional and substantial question:

- Is problem-based learning as an educational system suited to teach mathematics and statistics; if not, can it be modified into an educational system that 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

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with additional techniques for problem solving, which the students in turn can use in their other courses?

Problem-based learning is an instructional principle that uses problems as a vehicle to start off the learning process, and to supply students with additional motivation to become engaged in that learning process. Together with other forms of student-centered learning, problem-based learning places the student at the position to trigger the learning process, and not the teacher, which brings about the crucial difference with traditional, teacher-centered instructional methods. To guarantee the successfulness of this transfer of initiative, a number of requirements should be fulfilled. E.g., to give up the use of instructional means intended to raise the extrinsic motivation of the students, a sufficient level of intrinsic motivation should be ensured. Stimulating and provoking problems that relate to important issues in the daily life of the student are needed to reach that goal. And for an effective brainstorm and discussion in the tutorial group, the group cannot be too heterogeneous with regard to pre-knowledge and abilities. In particular for quantitative methods in a business curriculum, it seems to be rather difficult to fulfill all these requirements to problem-based learning.

2. SYSTEM THINKING AND SYSTEM DYNAMICS

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 recognizes that learning fundamentally is a construction rather than an assimilation process. It follows that, since constructions take on many different forms, learning cannot be standardized. 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.

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 effect 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.

Learning processes differ to the extend they are effective, 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. The persistence of such cycles is an evident proof that the learning process of the (majority of) investors is rather ineffective.

What factors can account for this difference? In both situations we can recognize 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.

In some situations, we come off even far worse. When our natural environment provides no feedback at all with regard to a specific learning process, any form of learning by “real” practice is excluded. Abstract learning, as opposed to concrete learning, is the extensively described example of such a situation. In both cases of restricted or lacking feedback in the natural environment, the obvious solution is to extend that natural environment with an artificial one, which looks after the provision of adequate feedback to the learner. Computerized tools based on the system dynamics method have a long-standing reputation as such “artificial learning environments.”

3. MODELING FOR LEARNING VERSUS LEARNING THROUGH MODELS

Outside education, system dynamics plays an eminent role in the field of corporate strategic planning, not in the last place thanks to the impact of Peter Senge’s “fifth discipline.” As a result, its concepts and tools are widely used in corporate consultancy. In this context one can remark a third and analog paradigm shift: from the traditional method of consultancy towards the “modeling for learning“ approach (Lane, 1994). In the
traditional model of consultancy, experts play a crucial role: they extract the relevant company information from the clients, and then retreat to the backroom to conceptualize, build, test, and analyze a system dynamics model. Running this model yields the wanted simulation outcomes. Implicit in this approach is the assumption that clients will learn through the confrontation with this model and its simulations, both being the outcome of a black box process when seen through the eyes of the client. Therefore, expert consultancy is sensitive to a number of objections, such as the analysis and its results not being client-owned or a rejection of the expert role.

In contrast, the objective of the modeling for learning framework is to improve the mental model of the client her or himself. By opening the black box and conceiving the modeling process as a shared undertaking of consultant and client, the perspective emerges of learning through modeling.

4. COMPUTER-BASED LEARNING ENVIRONMENTS VERSUS MANAGEMENT FLIGHT SIMULATORS

To facilitate the participation of the client in the modeling process, we need easy to use modeling tools as a form of artificial learning environment as described before. Such modeling tools should support several phases in the modeling process, both qualitative and quantitative, from causal loop diagramming to simulations, and that allow for prototyping and experimentation. Tools that go by names of "learning laboratory," "computer-based learning environment" or microworld, the last name referring to the strong analogy with Papert's LOGO as a virtual environment for learning abstract concepts. System dynamics' tools as STELLA are often mentioned as characteristic examples of such a computer-based learning environment, modern spreadsheet applications being a good second.

At first sight, there seems to exist important similarities between computer-based learning environments and computerized management games or "management flight simulators," educational tools popular in cased-based business studies. However, although both allow for experimentation and simulation, there is an important difference: in business games, the underlying model is developed by someone other than the student, and thus a black box, whereas computer-based learning
environments force the student to be an active model creator. Several studies conclude that this difference appears to be a crucial determinant of educational effectiveness; e.g., Graham, Morecroft, Senge and Sterman (1994) state:

> What emerges from ... model-supported cases is that the learning comes from the full model-building experience, not primarily from simulation or game play. Model-building experience here means the full range of conceptualization, formulation, and testing...

5. **QUANTITATIVE METHODS IN THE BUSINESS CURRICULUM**

Linking the three antitheses elaborated above provides the educational foundations of the computer-based education of quantitative methods (which includes statistics, mathematics and computer science) in a student-centered curriculum. Such courses satisfy two different educational requirements:

- the educational system used in the teaching of quantitative methods is congruent with the student-centered (problem-based) aspect of the curriculum as a whole, and

- the courses supply students with knowledge and skills, such as the mastering of relevant computer-based learning environments, that empower the students in their self-directed learning capacities.

These two principles served as a guideline in the design of the quantitative methods' courses taught at our school. The statistics, mathematics and computer science courses, as given to all our freshmen (economics, management sciences and business studies), are based upon project work (see Roberts, 1987). 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. However, not every detail of our project work 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 are carried out in small groups: the tutorial groups. This is not only the result of the number of freshmen that follow the course: about 600, 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 of the project. When students were free to choose 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.

6. STUDENT ASSIGNMENTS IN THE PROJECT WORK

The quantitative methods course, treating mathematics, statistics, and computer science in parallel, extends to the whole freshman program, allowing the projects to tune in to the subjects and problems treated in the business courses. E.g., in the very first block of the first year program, our freshmen have an introductory course on organization and marketing. The problems of this course revolve around Macintosh, a Dutch firm in the international non-food retail sector. As part of a problem, students receive time series of important quantities from twenty consecutive annual reports, and are asked to analyze 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. Exploratory data analysis of this data, using different descriptive statistics, supports the study of the corporate strategy of Macintosh performed by the students.
7. THE MONTY HALL PROBLEM

Although we find ourselves in a permanent quest for business related topics to be used in project work, we do take the freedom to use assignments not related to the content of our study. To be honest, our most successful project assignment appeared to be the "Monty Hall problem," stimulating and irritating our students much more than any of the other, really practice oriented, problems. And not only our students. The Monty Hall problem, or the three doors puzzle, as it is also called, was debated in prestigious newspapers as The New York Times, Parade and the Dutch NRC-Handelsblad. Well-known scientists threw away their reputation defending the wrong answer at first, and refusing to accept the correct one afterwards. In the "Dutch debate" (by the way: it took place several years after its international counterpart, so much for the swift diffusion of scientific knowledge) a leading professor in econometrics participated. In the first round, he gave a thoroughly constructed mathematical foundation of the incorrect answer (saying that you should be indifferent between sticking or switching: in both cases, your chance to get the prize is 50%). In the second round, he admitted to have studied the problem over and over again, and have solved it "in the dirty way": by simulation. And found the other answer to be correct (you double your chance on winning by following the switching strategy). But even then added a postscript to his confession, expressing the hope that someone would find a bug in his simulation program. As a last remark, this debate lasted for several weeks, in some cases filling several full pages with readers' letters.
We use the Monty Hall problem for two successive projects. In the first one, we ask the students to solve the problem analytically. Our students not being so much more gifted than the mean professor in econometrics, choose by large majority the intuitive but incorrect answer.
In the tutorial groups, they discuss their answers and the underpinning of it, including the acclaimed correct answer. In the project assignment of next week, we ask the students to solve the problem numerically, using any of the simulation tools they are acquainted with. What makes the Monty Hall problem such an attractive project assignment? There are several factors:

- Students are highly intrinsically motivated to solve the problem: the fact that such a simple problem has such a counter intuitive answer forms the best stimulus one can think of.
- The motivation doesn’t fade away when the acclaimed correct answer is brought up. In fact, the converse is true: the ambition to refute the “correct answer” and to restore the intuitive answer provides a significant amount of additional motivation.
- It is a problem that indeed can be solved along different lines: analytic and by simulation. Even more important, the simulated solution renders important insights to solve the problem analytically.
- Being informed about the acclaimed correct answer, there is an important beacon in the modeling process students undertake. Having the opportunity to confront the simulated outcome with this norm at each step, students are self-reliant with regard to the “check on the error.” Which is of overriding importance for the learning process to be really self-directed.
- In modeling the Monty Hall problem, students have the disposal of several tools appropriate for this type of simulation, and thus have some