The Mathematics Educator
2007, Vol. 17, No. 1, 32–41

Some Reflections on the Teaching of Mathematical Modeling

Jon Warwick

This paper offers some reflections on the difficulties of teaching mathematical modeling to students taking higher education courses in which modeling plays a significant role. In the author's experience, other aspects of the model development process often cause problems rather than the use of mathematics. Since these other aspects involve students in learning about and understanding complex problem situations the author conjectures that problems arise because insufficient time within mathematical modeling modules is spent reflecting on student work and enabling "learning to learn" about problem situations. Some suggestions for the content and delivery of mathematical modeling modules are given.

Over the last 20 or so years of teaching in higher education, I have had the pleasure of teaching various aspects of the mathematical sciences to students at levels ranging from pre-degree to master levels. Although each module[1] that one teaches presents challenges, the one subject that has been the most challenging to my students and myself has been that of mathematical modeling.

In this article, I reflect on the mathematical modeling process and how it has influenced the way I teach modeling. My own experience of modeling has been acquired within the management science domain. This domain is concerned not only with modeling physical processes but can also include considerations of systems and organizational culture. Although this may give my views a different slant than those of someone working as a modeler in the pure sciences, the issues discussed apply across many modeling domains.

By mathematical modeling I mean the "pencil and paper" type of modeling characterized by written assumptions, equations, and so on, as opposed to computer-based simulation models that can be built using graphical interfaces. Students usually enjoy the latter since the medium is interesting. These situations often divert attention from tough modeling considerations and the need to see the dynamic equations! This, however, is another story and I wish to restrict my discussion to mathematical models derived without the use of software.

Jon Warwick completed his first degree in Mathematics and Computing at South Bank Polytechnic in 1979 and was awarded a PhD in Operations Research in 1984. He has many years of experience in teaching mathematics, mathematical modeling, and operations research in the Higher Education sector and is currently Professor of Educational Development in Mathematical Sciences at London South Bank University. He is also the Faculty Director of Learning and Teaching.

Examples of these pencil-and-paper models are often presented in management science or operational research texts and would include some standard models relating to inventory control, waiting line models, and mathematical programs. These models can be written in terms of equations that give optimal order quantities, average waiting times, and so on for differing sets of conditions. For these standard models the underlying assumptions are well known. Students taking my modules at the undergraduate level are encouraged to develop their own models which may be based on a standard form but must be described using mathematical notation and with pencil and paper.

In practice I have often used academic library management as a contextual area where, over the last forty years, mathematical modeling has been applied to good effect, producing a wealth of accessible literature and different types of models (Kraft and Boyce, 1991). By way of example, I shall describe some experiences from an introductory modeling module given to undergraduate students studying mathematics related to management. Having first spent some time with the students studying examples of a number of the standard model forms found in management science (stochastic, deterministic, simulation, etc.), the students are given a simple situation to start the modeling process. Briefly, this involves the students working in groups to develop a model that can be used for determining the effect of changing the loan period of a single title (multiple copy) text appearing on a class reading list. My students must develop a model (and if possible solve it) using pencil and paper only. A crude measure of

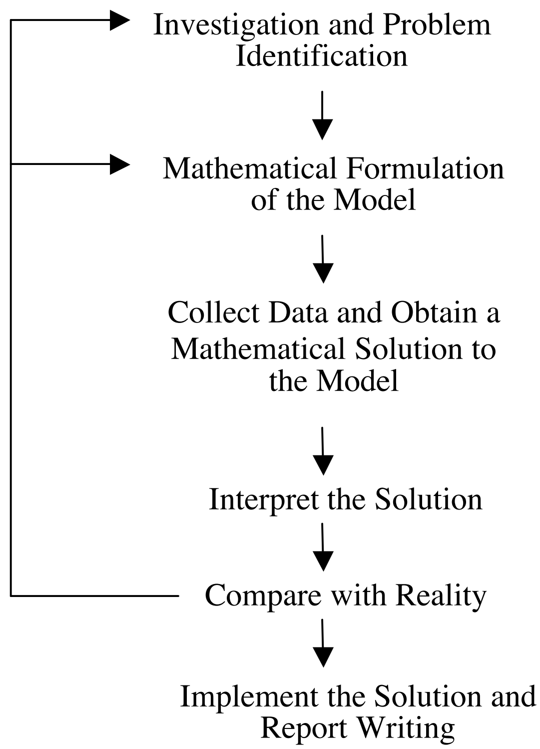

Figure 1. Stages in the modeling process.

library user satisfaction is the likelihood of finding a book on the shelf when desired. Students are asked to find loan periods that provide certain satisfaction levels for differing numbers of copies and class size. The idea is, at this stage, to encourage simplicity in modeling and highlight the importance of assumptions. Working in groups is also important as group discussion facilitates the model development process.

The Modeling Process

Examination of textbooks dealing with undergraduate mathematical modeling (or any of the related fields, such as management science) will normally yield a description of the modeling process in general terms incorporating the stages as outlined in Figure 1. There are many variations on this theme from both specialist texts on mathematical modeling (see Edwards & Hamson, 2001) or texts on more general quantitative analysis (see Lawrence & Pasternack, 2002), but the basic structure of the process is usually similar to that shown. There are two things to notice about the process. First, as described in Figure 1, it is essentially a looping process. Second, it is a process that students generally find difficult to undertake, despite the fact that the process is fairly simple to state, the steps are logical, and the language fairly non-technical.

The Art of Modeling

As a student of mathematical modeling, I was introduced many years ago to an article that dealt with the process of mathematical modeling and attempted to give some hints and tips as to how the novice modeler might proceed (Morris, 1967). It is a paper I often recommend to my students as it recognizes the difficulties that many of them are facing. Morris makes the valid point that, when students read about the development of mathematical models and look at examples of models that have been developed by others, the writing is nearly always in the spirit of *justification* rather than the spirit of *inquiry*. By this we mean the writing justifies the final product and comments on the results obtained, the validity of the model, etc. However, it does not dwell on the frustrations and problems that may have been encountered on the way to the final model, the models that were discarded, or false trails that were followed. Adopting the latter style of writing, describing the ups and downs of the inquiry process that eventually produced the final model, would be far more illuminating to students than just a description of the final model.

In addition, Morris (1967) gives a nice description of the art of modeling and notes that the model development process has a looping structure with two major loops. The first looping process is developing a working model from a set of assumptions and continually testing the model against real data until it may be regarded as acceptable within the limits set by the realism of its assumptions. The second involves changing the assumptions either by relaxing those that seem unrealistic or by imposing new assumptions if the model is becoming too complex. These two looping processes are often in operation at the same time as the modeler strives to balance model tractability with performance. Model tractability here means the ease manipulating and solving the model. Morris refers to the looping process through which model assumptions are relaxed and the model enhanced as enrichment and elaboration.

In addition to these two primary looping processes, Morris (1967) gives a checklist of hints and tips that he suggests will help the novice modeler. These may be summarized as:

- Try to establish the purpose of the model to give clues to model form and perhaps the level of detail necessary.
- Break the problem down into manageable parts so these smaller pieces can be solved before being reincorporated into the larger whole.
- If possible, use past experiences or other similar problems already solved to give clues as to the solution required by the current model. This is the process of seeking analogies and is a powerful weapon in the modeler's armory (see for example Warwick, 1992).
- Consider specific numerical examples. This may give clues as to where assumptions might be needed or how the problem situation is structured.
- Establish some notation as soon as possible and begin building relationships in the form of mathematical equations.
- Write down the obvious!

These hints and tips together with an appreciation of the general looping processes involved in model development are the core activities that students need to master in order to build models. They are easily learned, or perhaps memorized, and yet still students find model building difficult. There are at least two learning processes with which students are required to engage in order to become proficient in modeling. Each makes quite distinct demands of the student.

The first learning process requires the student to become conversant with the tools of the trade such as mathematical symbolism, algebraic manipulation, the stages involved in model building, the looping processes, and archetypical model forms. These elements, often as not, form the core content of mathematical modeling modules. In terms of the type of learning that is being undertaken, we can refer to Bloom's (1956) taxonomy of learning in the cognitive domain that describes different categories of learning arranged sequentially. The learning required to become proficient in the mechanics of model building is primarily within the three lowest categories–knowledge, comprehension, and application–and my students seem to have few problems here. Problems begin to surface when we consider the second learning process, which is not explicit in Figure 1.

In this second process the modeler is coming to terms with the intricacies of the problem being modeled, the subtleties of the situation being studied, and the implications these will have for the model being developed. No model can be developed successfully unless the modeler has a clear understanding of what is to be modeled and this learning will need to take place as the modeling proceeds. Yet there is nothing in the modeling process model that helps the modeler with this. In other words, there is a requirement for the skills of *learning to learn* to be appreciated by students as every modeling situation they meet will be different and often complex.

Learning to Learn

What do we mean by learning to learn? Reference to the literature allows three general observations. First, this idea has been the subject of research for more than 30 years with researchers considering learning-to-learn issues at the K-12 (Greany and Rodd, 2003) and university levels (Wright, 1982), as well as within the work environment (Ortenblad 2004). Learning-to-learn

Table 1

Considerations for learning to learn and comparison with Morris (1967).

Achieving Learning to Learn	Some Key Considerations for the Individual	Considerations from Morris (1967)
Begin with the past;	It is important to look back and consider what was your previous experience about how you learn, how was learning structured before and what worked well in similar circumstances.	If possible, try and use past experiences or other similar problems already solved to give clues as to the solution required.
Proceed to the present;	There needs to be a clear reason for doing what you are doing! Which parts are important? Which should be tackled first? What is controllable and what is not and which bits are already learned to form a basis for further learning?	Try and establish early on the purpose of the model so that this will give clues to model form and perhaps the level of detail necessary for the model.
Consider the process …	What is the structure of the work to be learned? Get a feel for the general theme, the main points, key words. Are they understood?	Write down the obvious! Establish some notation as soon as possible and begin building relationships i.e. writing equations. Break the problem down into manageable parts so that these smaller pieces can be solved before combination back into the larger whole.
… and the subject matter;	How much of this subject is known about already? How much is known about related subjects and what is the link? What resources are available and are they accessible now? Decisions need to be made about how quickly to proceed through material, when to attempt questions, when to seek guidance etc.	Seek analogies and associations with other, related, modeling problems. Consider specific numerical examples—this may give clues as to where assumptions might be needed or how the problem situation is structured.
Build in review;	Decide here what went well and what did not and how this might affect further learning attempted.	This is a key area that Morris describes as lacking in modeling articles and reports. In practice, I have found it useful for students to keep a log or workbook that includes reflections on the various models built during the course of a taught module.

research also spans academic disciplines with examples from such diverse subject areas as history (Knight, 1997), physical education (Howarth, 1997), and science (Hamming, 1997; Elby, 2001). Little has been written in the context of mathematical modeling. Second, the recent interest in learning to learn has coincided with the development of research in cognitive and metacognitive strategies (Waeytens, Lens, and Vandenberghe, 2002) and the expansion of higher education. As a result, many universities now recruit students from a variety of backgrounds and consequently with a range of abilities and previous educational experiences. Third, there is little agreement about the definition of learning to learn or how it should be taught. Some researchers have a narrow view in which learning to learn involves essentially study skills, hints, and tips, whereas others take the broader view that students should be able to apply skills in critical analysis, goal setting, personal planning, and so on (Rawson, 2000).

Regarding how learning to learn should be taught, there has been debate as to whether it is appropriate to approach it as a separate, isolated module or whether it should be embedded into other regular study modules. These days, conventional wisdom suggests it must be taught within regular modules and not as an isolated subject (Waeytens et al., 2002). In my view learning to learn incorporates a broad set of skills including reflective and critical thinking and it should be approached within the context of a module. In fact, it is crucial in developing effective modeling skills.

Because learning to learn is now becoming a key part of many university learning and teaching strategies, one way of approaching it is to consider the key elements as shown in Table 1 (amended from Landsberger, 2005). These considerations apply as much to the learning of mathematical modeling as they do to any other subject. The hints and tips given by Morris (1967) do, in fact, sit quite well within this framework, as seen in Table 1. In other words, Morris seems to be tacitly addressing the learning-to-learn difficulties associated with modeling through his practical advice.

We can further strengthen this idea that modeling is as much about learning as it is about applying mathematics. To accomplish this, we must reconsider the classic process model of mathematical modeling (see Figure 1) and re-formulate it to emphasize the learning processes that are truly going on. True to the spirit of Morris (1967), we can do this by seeking analogies with other models of the learning process. A particularly useful representation has been developed within the field of organizational learning.

Organizational Learning: Single and Double Loop Learning

According to Senge (1990), learning enables us to do things we were never able to do, change our perception of the world and our relationship to it, and extend our capacity to create. In this context, learning organization is an "organization that is continually expanding its capacity to create its future" (Senge, 1990, p.14). In their classic work on organizational learning, Argyris and Schon (1978) define learning as occurring under two conditions: (a) when there is a match between an expected or desired outcome and the actuality or real outcome, and (b) when there is a mismatch between expected or desired outcomes and reality that is identified and corrected so that the mismatch becomes a match.

Argyris and Schon (1978) describe two types of learning response that can occur when a mismatch is detected, single loop learning and double loop learning. Single loop learning is described as focusing on the status quo by narrowing the gap between desired and actual conditions (University of Luton, 2006). It is a simple feedback loop where the learner's actions are changed to accommodate mismatches between expected or desired and observed results in the perceived real world. Single loop learning has also been described as an error-correcting or fine-tuning process. There are, however, a number of limitations to single loop learning (Peschl, 2005):

- It is an essentially conservative process that seeks to retain the existing knowledge structures rather than exploring new alternatives.
- There is very little chance that new insights will be gained or that anything new or innovative will be learned.
- It is a process that lacks any form of reflection.

Double loop learning (or reflective learning), on the other hand, tries to overcome these limitations by first examining and altering the current mental model and then the actions. It is single loop learning with an extension, or second feedback loop, that allows for the possibility of change in assumptions, premises, mental models, etc. As Peschi (2005) states:

> In double loop learning a second feedback loop introduces a completely new dynamic in the whole process of learning: each modification in the set of premises or in the framework of reference causes a radical change in the structure, dimensions, dynamics, etc. of the space of knowledge. By that process, entirely new and different knowledge, theories, interpretation patterns, etc. about reality become possible. (p. 92)

This allows us to adapt our mental models in the light of experience and information. An example of the structure of single and double loop learning is shown in Figure 2.

To illustrate the difference between these models, consider a fall in enrollment numbers on a previously popular course. In single loop learning (i.e. identifying a mismatch between desired and actual outcome), faculty members may respond by increasing efforts to publicize the course in the media, with feeder schools, and with colleges, as well as working more closely with the local community. Fundamental beliefs are unchallenged but actions are amended to address the mismatch. An alternative response characterized by double loop learning would be to re-examine beliefs about the course, such as the suitability of its curriculum, the attractiveness of the subject area to potential students, and whether its current state is "fit for purpose". This double-loop-learning response may result in radical change to the course offering.

Organizations as well as individuals derive and amend their mental models through experience, observing, and interpreting the outcomes of their actions and decisions (Argyris and Schon, 1978; Bartunek, 1984; Levitt and March, 1988). In this sense, double loop learning requires the generation of new knowledge, insights, and intuitions by modifying existing models.

Double Loop Learning and the Modeling Process

We now can see how the mathematical modeling process can be placed within the framework of double loop learning. When we develop a mathematical model, there are two aspects to be considered. First, when we develop a model based on a set of assumptions derived from our current understanding of the problem situation, we effectively engage in single loop learning. The assumptions we have made determine the formulation of the model, the data requirements, and so on. Once the data has been collected, we solve the model and interpret this solution within the context of the problem situation. This leads to model validation and verification considerations. The validation and verification process may indicate problems with the model, a mismatch between our expectations and real situation dynamics. In this case, it may be that the model has not been formulated correctly in terms of the assumptions, that the model contains errors in its formulation, or that the data used is unreliable or inappropriate. In any event, the model needs to be amended. Within the limitations of our current set of active assumptions about the problem situation, we seek to find a model that does not deviate from our expectations. This is a single loop learning process.

When the model is decided to be valid, then we can begin the process of enrichment and elaboration, extending and developing the model by broadening our understanding of the problem situation, in terms of both the breadth and sophistication. This produces an amended set of working assumptions for the model requiring further development. This second looping process is double loop learning. It requires from the student not just the technical mathematical and statistical skills, but also the learning to learn skills that were described above. The mathematical modeling process is outlined in Figure 3.

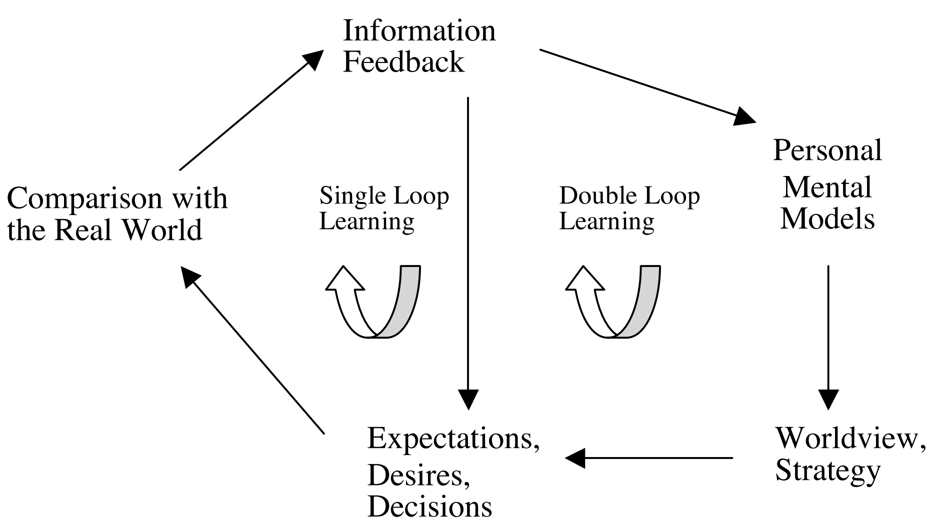

Figure 2. Single and double loop learning – adapted from Sterman (2000).

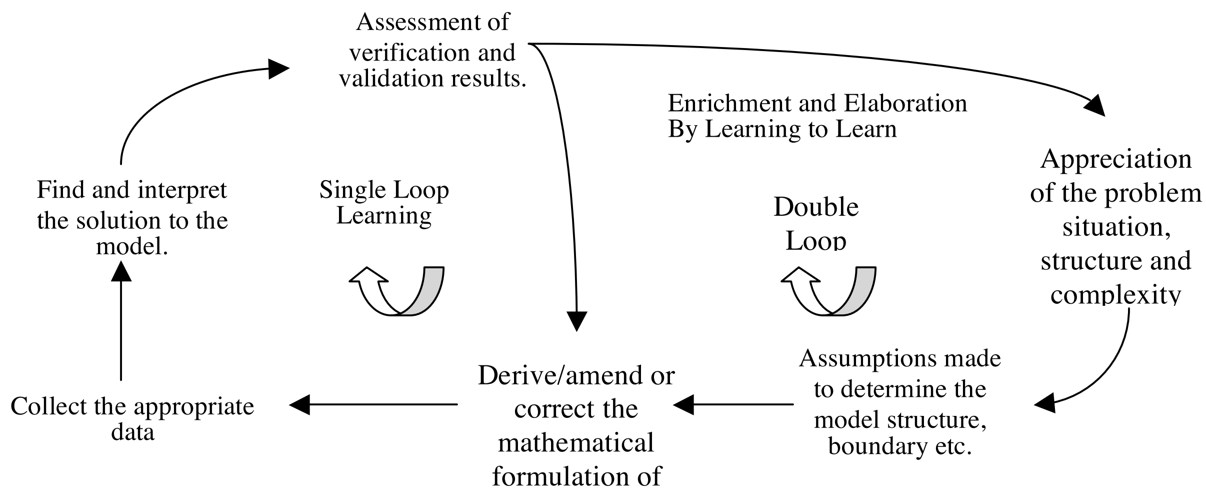

Figure 3. The amended modeling process.

To paraphrase Dooley (1999), the single loop learning phase can be described as "building the model right" whilst the double loop learning phase relates to "building the right model" (p. 13). This mathematical modeling process model (Figure 3) is richer than the conventional process model used with students. It allows the discussion of mathematical modeling to be extended to include elements related to the double loop learning aspect of the process. These are the difficult elements of the modeling process for both teachers and students. Yet these are just the skills that enable effective modeling and engage the students in the higher levels of learning as described by Bloom's taxonomy (i.e. synthesis and evaluation).

Now, returning to our example drawn from library management, my teaching experience suggests that students will initially adopt a variety of model forms often using analogy as recommended by Morris (1967). Common themes here are the conceptualization as either one of an inventory control problem or as a waiting line (queuing) problem. In the case of the inventory model, the copies of the title on the shelf are the stock being demanded (borrowed) by students and then immediately re-ordered. The average inventory level is a measure of the satisfaction level and lead times are assumed fixed initially, corresponding to an assumption that all books are kept for the full loan period and then returned promptly.

For the waiting line model, the service mechanism represents the copies of the title (one server for each copy) and average service time equates to the loan period. Actual borrowing times are assumed to be random in the basic waiting line model. The queue itself might represent reservations having been made for the title if it is not immediately available. In this case, the satisfaction level is related to the probability of finding idle servers. Calculations can also be made of average waiting times to get the book depending on the number of copies, the loan period, and the class size.

Students are provided with some sample data, and then test their models. If necessary, they refine and correct any faults until they are satisfied with the results. This is iteration around the single-loop learning phase. The complexity of the situation is then increased gradually so that students will, at first, try to adopt single loop learning in order to accommodate any new information within their existing models. Eventually, they must consider broader and more complex issues that may require radically changed assumptions, significant new modeling and understanding, and, in the extreme, adopting a completely new model formulation.

For example, I might begin by asking students to relax their assumption about borrowing times by allowing users to return their copy early or late according to some probability distribution. This modification can be built in to both models described above relatively easily but requires the students to research how to do this. As a result, their models become more complex, moving away from standard inventory or waiting line models into more specialized versions.

A higher level of complexity is introduced by allowing feedback into the system. Students are asked to consider that demands for the title will not be regular but depend on the perceived likelihood of obtaining a copy in reasonable time. If many copies are available in the library (high satisfaction levels), then this encourages use of the library, increasing demand and eventually reducing satisfaction levels. Otherwise, if copies are never available, potential borrowers might go elsewhere (or buy it for themselves), lowering demand.

Dealing with these new complexities requires students to engage with aspects of double loop learning. For example, they need to explore their existing model, ask further questions of the system, and revisit their assumptions and their understanding of the situation to incorporate these new factors. At this stage, students often get stuck dealing with the additional complexity and need help moving forward with double loop learning. I have been able to help students with this by using structured discussion.

The Importance of Advocacy, Inquiry, and Reflection

In this paper, I have argued that the skills that are most difficult for students to master are those related to the double loop-learning cycle in the modeling process. We have borrowed the notion of double loop learning from the field of organizational learning and, in completing this analogy, we can shed some light on how this sort of learning can be fostered in students. Senge (1990) argues that, in helping organizations undertake double loop learning, members of the organization should be able to combine advocacy and inquiry. Advocacy refers to the ability to solve problems by taking a particular view, making the appropriate decisions, and then gathering whatever support and resources are necessary to make things happen. Inquiry, on the other hand, is being open to questions, asking questions of others, inquiring into the reasoning of others, and expressing one's own reasoning. Senge states:

> When both advocacy and inquiry are high, we are open to disconfirming data as well as confirming data–because we are genuinely interested in finding flaws in our views. Likewise, we expose our reasoning and look for flaws in it, and we try to understand others reasoning. (p. 200)

Thus, creative outcomes are far more likely as a consequence of using advocacy and inquiry.

When working with a group of students modeling a complex situation, they should be encouraged to use advocacy and inquiry to challenge and explore modeling ideas. There are a number of guidelines proposed by Senge (1990) that, when used as prompts, can encourage students to explore the problem situation. For example, when advocating personal views the guidelines may be summarized as:

- Make your reasoning explicit.
- Encourage others to explore your views.
- Encourage others to provide different views.
- Actively inquire into others' views that differ from yours.

Or, when inquiring into others' views, try to:

- State any assumptions you are making about the views of others.
- State the data on which your assumptions are based.
- Ask what data or logic might change their view.
- If there are disagreements, design an experiment or collect data that might provide new information.

Discussion among the groups of students can be structured using these types of prompts, resulting in creative thinking about the way modeling should proceed (I have rarely seen aspects of creative thinking mentioned as part of mathematical modeling module descriptions!).

In practice, students find this sort of debate and discussion difficult. They often need prompting from the teacher when group discussion has reached a dead end. Eventually, a greater understanding of the new problem is achieved. This usually leads to the amendment of the existing model, incorporating new assumptions and factors. As a result, students investigate stock control models with variable demand patterns or waiting line models with non-independent arrival patterns. In this way, students develop further mathematical knowledge and research skills as well as engage in a cycle of learning.

In extreme cases of paradigm shift, students will reject the existing model completely in favor of a new formulation. This was the case with one group who rejected a simple inventory control model as too restrictive in favor of a model built using simple differential equations linking the number of copies available on the shelf with the number of potential borrowers. If the number of copies available on the shelf is low, then frustration will reduce the number of potential borrowers. In time, this causes the number of copies available to increase (reduced demand), leading to an increase in potential borrowers, and so on. These students found stable solutions to their model and investigated its sensitivity to changes in the loan period.

Finally, we turn to reflection. Having looked at one way to encourage double loop learning, we need to then give students the skills to reflect individually on their performance, their learning, and how they can further improve their modeling skills. Thus, it is important to get students into the habit of reflecting on their work and the work of others. As King (2002) states, when undertaking reflection, "a variety of outcomes can be expected, for example, development of a theory, the formulation of a plan of action, or a decision or resolution of some uncertainty" (p. 2). Furthermore, "reflection might well provide material for further reflection, and most importantly, lead to learning and, perhaps, reflection on the process of learning." (King, 2002, p. 2)

Morris (1967) pointed out that reflective writing is sadly lacking in the professional literature. However, recent educational research has addressed reflective writing (see for example Moon, 2000) and how skills in reflection and reflective writing can be developed. King (2002), for example, suggests a model of the reflective process as having seven stages: Purpose, Basic Observation, Additional Information, Revisiting, Standing Back, Moving On, and either Resolution or More Reflection. Although UK Higher Education courses are expected to promote reflective thinking in many aspects of student's work (Southern England Consortium for Credit Accumulation and Transfer, 2003), I would argue that it is a particularly crucial aspect of the mathematical modeler's toolkit.

Some General Conclusions

Reflecting on my own teaching of mathematical modeling over the years has led to a number of changes to the way modules are designed, delivered, and assessed. When working with students (whether undergraduate or graduate) the following has been useful in meeting some of the issues referred to in this article:

- Ensure that the content of the module includes some mathematical and statistical theory (as required by the particular program) but also sessions on creative thinking, learning to learn, and reflective writing.
- Although some smaller models are used for the purposes of example, students are encouraged to work on a progressively more complex problem during the course of the module. This gives the opportunity for the development of successive models through enrichment and elaboration. Furthermore, it is helpful if the problem at hand can be modeled using a variety of approaches. This enables students to identify alternatives and to reflect upon the criteria for selection.
- For longer projects, allow students to work in groups. Group meetings are held during class time so that the instructor can observe the discussion and try to move the students towards double loop learning as they seek to enrich their models. Questioning each other using the prompts discussed earlier can help here. Students take minutes of their meetings so that there is a record of the inquiry process.
- Assessment is based upon the models students produce as a group as well as students' individual reflection, both on the model development process and on their own learning. Each student each keeps a reflective log of his or her work during the module, commenting on the skills and lessons learned and identifying the skills needing further development.

It is difficult to say whether students who complete a mathematical modeling unit with this type of structure are better modelers at the end. What I can say, from my experience, is that this structure engages students more readily than modeling taught as a more technically-oriented and solitary experience. The basic skills required of a mathematical modeler are probably little different now from when Morris (1967) originally wrote his guide. Technology, of course, has advanced enormously, but the individual's ability to learn about, understand, and unpack a complex problem remains at the heart of modeling.

References

Argyris, C., & Schon, D. A. (1978). *Organisational learning: a theory of action perspective*. Reading, MA: Addison-Wesley.

Bartunek, J. M. (1984). Changing interpretive schemes and organisational restructuring. *Administrative Science Quarterly*, *29*, 355–372.

Bloom, B. S. (1956). *Taxonomy of educational objectives, Handbook I: The cognitive domain*. New York: David McKay.

Dooley, J. (1999). *Problem solving as a double loop learning system*. Retrieved on January 12, 2006, from http://www.well.com/user/dooley/Problem-solving.pdf

Edwards, D., & Hamson, M. (2001). *Guide to mathematical modelling*. Basingstoke, United Kingdom: Palgrave Macmillan.

Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics, 69*(7), 54–64.

Greany, T., & Rodd, J. (2003). *Creating a learning to learn school*. London: Network Educational Press.

Hamming, R. W. (1997). *The art of doing science and engineering: Learning to learn*. Amsterdam: Gordon and Breach Science.

Howarth, K. (1997, March). *The teaching of thinking skills in physical education: Perceptions of three middle school teachers*. Paper presented at the annual meeting of the American Educational Research Association, Chicago.

King, T. (2002). Development of student skills in reflective writing. In A. Goody & D. Ingram (Eds.), *Spheres of Influence: Ventures and Visions in Educational Development. Proceedings of the 4th World Conference of the International Consortium for Educational Development*. Perth: The University of Western Australia.

Knight, P. T. (1997, May). *Learning How to Learn in High School History*. Paper presented at ORD-Congress (Onderwijsresearchdagen), Leuven, Belgium.

Kraft, D. H., & Boyce, B. R. (1991). *Operations research for libraries and information agencies: Techniques for the evaluation of management decision alternatives*. San Diego: Academic Press.

Landsberger, J. (2005). *Learning to learn*. Retrieved on January 12, 2006, from http://www.studygs.net/metacognition.htm

Lawrence, J. A., & Pasternack, B. A. (2002). *Applied management science*. New York: John Wiley and Sons.

Levitt, B., & March, J. G. (1988). Organisational learning. *Annual Review of Sociology*, *14*, 319–340.

Moon, J. A. (2000). *Reflection in learning and professional development*. Abingdon, United Kingdom: Routledge Falmer.

Morris, W. (1967). On the art of modelling. *Management Science*, *13*(12), 707–717.

Ortenblad, A. (2004). The learning organisation: Towards an integrated model. *The Learning Organisation*, *11*(2), 129–144.

Peschl, M. F. (2005). Acquiring basic cognitive and intellectual skills for informatics: Facilitating understanding and abstraction in a virtual cooperative learning environment. In P. Micheuz, P. Antonitsch, & R. Mittermeir (Eds.), *Innovative concepts for teaching informatics* (pp. 86–101). Vienna: Carl Ueberreuter.

Rawson, M. (2000). Learning to learn: More than a skill set. *Studies in Higher Education*, *25*(2), 225–238.

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organisation*. New York: Doubleday.

Southern England Consortium for Credit Accumulation and Transfer. (2003). *Credit level descriptors for further and higher education*. Retrieved on January 17, 2006, from http://www.seec-office.org.uk/SEEC%20FE-HECLDs-mar03def-1.doc

Sterman, J. (2000). *Business dynamics: systems thinking and modelling for a complex world*. Boston: McGraw-Hill Irwin.

University of Luton. (2006). *Effecting change in higher education*. Retrieved on January 13, 2006, from http://www.effectingchange.luton.ac.uk/approaches_to_cha nge/ index.php?content=ol

Waeytens, K., Lens, W., & Vandenberghe, R. (2002). Learning to learn: Teachers' conceptions of their supporting role. *Learning and Instruction*, *12*, 305–322.

Warwick, J. (1992). Modelling by analogy: An example from library management. *Teaching Mathematics and its Applications*, *11*(3), 128–133.

Wright, J. (1982). *Learning to learn in higher education*. London: Croom Helm.

---

[1] My intention is to use 'module' to mean part of a course of study so that a student studies several modules per year.