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Teaching real-life OR to MSc students

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The nature of the 'messiness' of the real projects in which we are involved determines how our OR practice proceeds. In order to train the future generation of Operational Researchers, we need to prepare them with the skills to deal with this messiness. The teachers themselves firstly must have these skills and have fresh experience of using them. This paper discusses the synergies to be experienced between teaching, consulting, research and in-company training. These abilities then need to be passed on to the students. Technique training provides an important tool-kit but the key skills have to be learned through guided experiential learning, with the learning loop closed by guided reflection (fostered and aided by mentors).

Keyword: OR education; experiential learning; Masters course

Introduction

The question 'What makes for good OR education?' is ultimately linked with the questions of 'what is a good Operational Researcher?' and 'what is OR?'. This paper explores the issue 'What makes for good OR education?' with specific reference to the thinking behind and teaching of one particular MSc course. It shows that in exploring this issue, the whole portfolio of what is offered to the student must be addressed, as it is taught, *as an integral whole*. None of the individual parts of this paper, therefore, says anything radically new: but the message it is trying to give is that this whole portfolio is needed to give an effective OR education.

This paper will examine, in particular:

- The nature of the OR world for which we are preparing our students
- the role of academic members of the department, and what is often termed the 'academic/practitioner interface'
- the underlying research culture of a department to support a practitioner—facing MSc
- experiential learning, reflection, and the opportunity for 'mentoring' and preparation for OR 'real life', by both internal and external mentors
- the teaching of techniques.

This paper draws heavily from the MSc in OR at the University of Strathclyde. This has been running for some decades, but underwent a complete revision in the late 1980s under Peter Bennett and Colin Eden. While one of the authors of this paper is the current course Director, the initiatives within the course are due to these pioneers.

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What is an OR MSc for?

The overall aim of a typical MSc course is to convert high quality graduates in numerate disciplines into good OR practitioners appropriate to the needs of the practising profession. The aim is to produce someone who is particularly attractive to professional OR groups, and management consultancy companies who specialise in the application of OR-type techniques to enhancing decision-making. To achieve this, the course in which the authors are involved has three overall aims:

- to realise the potential of graduates who have already demonstrated their ability, so that they can immediately play an effective role in providing decision support to managers;
- to develop a rigorous academic understanding of a range of theories, concepts and methods, and to develop students' ability to apply them to the real world in a creative and practical way;
- to equip them with the intellectual and personal skills needed to work on complex issues within organisations, often as part of a team.

One of the keys in the above set of aims is the use of the word 'immediately'. This distinguishes an MSc from typical undergraduate courses, which aim to produce someone with the basis to be trained up as an operational research. The postgraduate should be in the position that, on the first day of his/her first job in industry, they could be presented with an Invitation To Tender, produce a costed proposal, win and then execute the job (that's not all on the first day, of course!)—as indeed did one of the authors.

The nature of OR consulting problems

What is this 'real-life' for which we are preparing students? It is well-known, and needs little elaboration, that OR has moved in recent decades from solving well-structured 'problems' to attacking 'messes'. A clear illustration of this is given by Pidd,[1] whose figure is replicated in Figure 1; this leans heavily on Ackoff's[2,3] pioneering work. This figure offers a definition of three situations: a 'puzzle', where the formulation of the situation to be solved is straightforward and can be agreed, as is also the solution to the formulation, through to a 'mess', where neither the formulation nor its solution can be taken as read but must be argued as a matter of opinion; these three situations are to be taken as three points on a spectrum. The situations we are preparing our graduates for are nearly always, in the real world, 'messes'. This has significant ramifications for how we approach our consulting practice, and therefore the skills and abilities we need to instil into our graduates—as noted by Scott.[4]

The nature of consulting practice is a subject that has been developed over the past 20 years by a number of authors, but particularly by Eden, who said in 1982 that he was trying to persuade Operational Researchers 'to spend more time developing a body of theoretical knowledge about consulting practice and this can only come about by devoting more time to understanding the reality of decision making in organisations and also reflecting on our theories of practice'.[5] In that paper, he suggested that the OR research might be more appreciated and relevant if it tried to discover ways of helping the decision maker think and decide more intelligently within the real social and political world of which they are a part; he suggests an increased emphasis on developing decision support systems, making the style of analysis more apparent to the client with less 'back-room wizardry' and finding ways of combining the techniques of the behavioral science interventionist with the analytical skills entrenched in OR. He also suggests that publicly broadening the role of OR people to that of helping manage debate seems to be the most obvious strategy for enabling OR to be powerfully involved in the debate where decisions are made. He suggested that we need to find ways of using our analytical ability to work on the content and structure of debate, upon the combination of traditional quantitative modelling skills with new methods of modelling ideas, arguments, beliefs—qualitative statements about an issue.

	Puzzles	Problems	Messes
Formulation	Agreed	Agreed	Arguable
Solution	Agreed	Arguable	Arguable

Figure 1 Problems and messes, taken from Pidd.[1]

Simply teaching of OR 'techniques' to solve problems implies closure to the problem-solving process, which always feels good to a student. In OR consulting practice however, 'messes' are rarely solved in a closed process. Eden[6] stated that 'several consultants and academics, including myself, disown the concept of problem solving in organisations. Instead they insist on referring to the problem finishing/alleviation/closure/disposal as the appropriate description of the outcome of their practice. Problem finishing is a better description of the outcome of the problem solving process. The nature of finishing is such that it is related not to an analysis of the situation but to the owners of the problem. I have therefore emphasised the importance of understanding and empathising with the client or client group. The general sense of my writing and the implications of the content of this chapter are to place emphasis on the role of the OR consultant as an agent of change—an interventionist as well as analyst. 'There is a substantial group of analysts for whom the word 'intervention' correctly suggests that the world will go on without them unless they negotiate a contributory analytical role with the intention of changing the content and/or process of deliberation'.[7] Problem finishing as a description of working on a problem has directed the attention to the 'management of meaning' and therefore the role of the consultant intervening in the act of deliberation.'

Furthermore, as well as the abilities to deal with these types of situations, students need to learn the underlying issues so that they can make conscious choices about their style of consulting. As one example, Eden and Sims[8] describe three paradigms that a consultant may adhere to in order to affect the actions of his client: (s)he may attempt to coerce the client into using models and solutions devised by the consultant; (s)he may attempt to develop empathy with the client, discover the definition of the problem and help the client to devise a satisfactory course of action; or (s)he may attempt to negotiate with the client to redefine the problem and subsequently try to help the client solve it. The student needs to think through this type of issue to decide where to position his/her consulting practice.

This is the type of consulting practice for which OR teachers have long had to prepare their students. Even back in 1986, the Commission on OR said 'the commission would like to see all courses giving sufficient prominence to the true nature of OR in practice. It would also like to see more courses which placed more emphasis on the social, political and business dimension of OR in practice'.[9]

The teachers: the false dichotomy of academics and practitioners

If this is the type of consulting for which we need to prepare students, what sort of teachers do we need? Fundamentally, we can only prepare our students for the world if we ourselves are familiar with the world, if in

some sense we are do-ers as well as teachers (otherwise we can't fulfil the aims and objectives of a practitioner—facing MSc). The phrase often used to taunt teachers or lecturers, 'those who can't do, teach', must be untrue of OR more than perhaps any other profession. This questions the division that has dogged the OR profession for decades, the division between those called 'practitioners' and those called 'academics'.

- Practitioners have to be researchers too: 'The 'R' in 'OR' is Research, and true OR-ers are involved in research all the time.'[10] In general, once a method is systemised, or original modelling work is no longer needed, the work can be handed over to a client organiser and the 'Operational Researchers' moves on. As the Commission[9] found in its study of 1986, the practice of OR is ever-changing. The main reasons given for this continual state of transformation are the 'migration of subject matter and methods to other activities and the dissemination of OR methods to other disciplines', while the envisaged future for OR is summed up by 'A future of continuing change.... The main argument for this view is that the role of OR workers and OR groups has remained stable for 15 or more years. A mixture of adaptability, opportunism, innovation and responsiveness to client needs is both part of the role and the means of maintaining it', in other words, practitioners must research and develop new methods as part of the on-going development of the field. Indeed, the need for the subject to develop and grow in response to client needs was one of the arguments forcibly put against professional membership in the debate within the UK OR Society in 1996.[11]

  Having said that, practitioners don't have to be *academic* researchers—academic research, looking for generic results and general applicability, implies standards of methodology and reporting which are different from—in general arguably significantly more rigorous than, those of practitioners doing research for the immediate needs of their practice.

- On the other hand, academics must be practitioners also. 'Academics who do not go outside to practice their craft are not OR academics, even if they come under that title. OR is only OR when motivated either to solve real problems, or to develop tools known to be needed to solve real problems (hence papers on, say, the better LP)' was the opinion expressed by one of the authors.[10] This means that academics should have under their belt experience of what it is they are preparing their students for, preferably having been full-time 'practitioners' at some point, but certainly keeping a lively involvement in solving real problems for real clients, or at the very least, have fresh experience that they can draw upon. (Although this raises a whole set of issues of time-management—the academic is then not available on-tap to the student, indeed, he might be away from the office for whole periods, satisfying the requirements of a project-based discipline, which can have significant implications for the training of students back in the University).

This integration of academe and practice springs particularly from:

The research culture: the false dichotomy of research and practice

The 'fuzziness' of the boundary between academics and practitioners depends upon the research culture within a University department. There is a traditional view that academic research produces new ideas, and these eventually, hopefully, feed through into practice. A quite different view is expressed by one of the authors,[10] who claims that historically and currently, much of the best research has come about from the reverse process: where the requirements of real studies of real problems require development of theory and thus generic results of general applicability. In these studies, often the generalised theory and insights come serendipitously (that is, the workers didn't set out to discover something general, but it arose from the study).

This process can occur when full-time practitioners or academics carry out consultancy, and it is this latter which is particularly of interest in this paper. Academics, of course, also have the added advantage of time to reflect upon their practice to consider its wider applicability. As one illustration, Reference 10 quotes the work done by a team including one of the authors on the Channel Tunnel *Shuttle*,[12] a piece of professional consultancy that also provided much research out put, concerning aspects such as the nature of large projects and how to model them, hard and soft methods and their synergy, manufacturing learning curves, the use of cognitive mapping as a knowledge repository *inter al.*

This example and subsequent work within the organisation to change its project-management culture[13] might be seen as a type of *action research*, a research methodology described by Eden and Huxham,[14] in particular, they describe fifteen characteristics of action research, of which the primary ones for our purposes here can be summarised as follows. Action research generally includes:

- a researcher integrally involved in an intent to change the organisation;
- implications beyond those required for action or knowledge-generation in the project domain;
- valuing theory, with theory elaboration/development as an explicit concern;
- an explicit basis, related to the theories, for the design of any tools or techniques produced;

- emergent theory: theory developing from a synthesis of that which emerges from the data and that which emerges from the use in practice;
- incremental theory-building, through a theory — action — reflection — developing theory cycle.

It is in this type of research culture, where research aims are embedded in solving real problems for real clients with the long-term aims of developing generic theory that the department operates, whether as part of a planned research programme or as a secondary, but equally important, outcome to consultancy. And this contributes strongly to the phenomenological development of OR. (The contrast between phenomenological and positive research is discussed well by Easterby-Smith *et al*:[15] while all scientific research does progress through positivist processes of formulating hypotheses and factual experimentation, OR and other social science can also develop through phenomenological approaches, studying a small number of phenomena in depth, looking at the totality of the situations and focusing on meanings.). This, of course, is not the sole domain of academics, any practising consultant seeking to develop distinctive competencies and capitalise upon original work done ought to be working in a way with similarities to this research paradigm.

What to teach?

It is in this type of research culture that the teachers who should be instructing the class reside, because the course aims to produce students who are capable themselves of immediately playing an effective role in an organisation. In order to ensure that this aim is met, an MSc must provide a well rounded and integrated package that will balance the need to give students the necessary toolkit of skills relevant for practising OR, with the other learning experiences that are needed that can only be generated by working on realistic problems.

Working with decision makers on real issues in this 'messy' world presents a variety of challenges: data may be inadequate, it may not be obvious what sort of model to use and the most rational proposal can fall foul of organisational politics. While traditional teaching can alert students to such issues, understanding needs to be reinforced by experience. In tandem with this need to provide experience is the desire to make it a worthwhile learning experience. Not only should students learn how to use their technical skills on a real problem but they should also be able to develop the skills needed to work in the real world, and to be able to deal with the social and political dimensions of the working environment within which OR works.

To prepare students for this messy world requires a mix of different teaching techniques. These techniques are not new. Weal,[16] for example, describes some of the ideas in teaching OR to undergraduates back in 1991, and this reference and the later Bailey and Weal give a number of references of research into OR courses and the techniques used within them.[17] But the techniques need to fit together in a unified structure aiming to produce the consultant for the messy world.

Teaching experientially

With these types of messes and situations, many of the skills needed cannot be only taught but must also be learned through experience of similar problems. This spirit imbues the particular MSc with which the authors are associated, but is particularly important for the 'Experiential Learning Stream'. This forms a vital part of the course and aims to provide some of this learning. The stream consists of exercises designed gradually to develop the necessary learning, and to combat the problems caused by a lack of experience. On the whole the workshops are guided by senior OR practitioners who are invited as guests of the department to present a recent problem that has been tackled by their department. Students are presented with this problem, with all the ambiguities of problem definition, data difficulties, lack of information, that will have bedevilled the original problem, and as groups are given a week or two to tackle the issue and present their findings. In order to give a good learning experience, the OR practitioner who presented the problem is asked to report back on the approaches taken and give an account of their own experiences in tackling the problem. Finally, a discussion session is held with the students who are asked to reflect on their work and to focus on anything they have learned from their experience. While this is one of the most valuable parts of this course, such teaching is not without its problems, in particular:

- Students do not immediately appreciate the value of dealing with such messy problems. One student who recently completed his MSc said the first author and his colleagues were 'obsessed with vagueness', and that caused him difficulties in appreciating the usefulness of this stream of training. It was, however, nice to read in his reflections after his summer project that he now saw that the world was indeed vague and messy, and he now saw why we had been teaching him in the way we did! OR workers know that the world is messy and that this has implications for the practice of OR. Students, especially those straight from a first degree in a hard discipline, are used to clear-cut well-defined 'puzzles'. Somehow, academics have to get over to their students the importance of this type of training.
- While a series of 'experiential' problems can be set up to give experience in a range of areas and type of issue, the actual learning achieved is less straightforward to predict; and while a particular exercise can be assessed, the overall learning from the stream of teaching is more problematic

to assess than for training in a simple set of techniques. Many MSc's (including this one) require students to investigate a messy problem under examination or semi-examination conditions, to give a snap-shot of how they would perform under pressure in practice, but that of course only gives an indication of their learning.

But the students need real experience of life as an OR practitioner outside the University, to appreciate fully the issues that arise in the course. The summer project is obviously too late for this experience to influence their learning on the course, so this particular MSc course, uniquely, provides the students with an Apprenticeship period. This pioneering scheme was devised and implemented by Bennett[18] in 1988 (see also Bennett and MacFarlane[19]), and has been a vital feature of the course ever since. The students spend a short period (3 weeks) half-way through the course, working within established OR groups. As well as gaining experience of life within the host organisation and observing this, they also participate in this work, providing benefits both to the organisation and also to their own experience. They do not complete whole projects, rather they act as 'plumbers' mates', helping out with parts of problems as required. On their return they report back to the rest of the class, so that the class as a whole has a good feel for life within 25 or so organisations, which we take care to ensure are a mixture of old and new groups, internal and external consultancies, big groups, smaller groups and one or two one-man bands. The students' abilities to comprehend and analyse realistic 'messy' problems are seen to make a significant step-change over the course of these three weeks.

On most MSc courses the summer project is a standard feature. The aim of this is to give the students direct experience of applying the concepts and theories studied on the course as well as the opportunity to work within an organisation and all its associated learning experiences. The student spends three months from July to September working on a project which is of some importance to the client. The student must demonstrate their ability to plan, carry out, and report on their chosen piece of work. Importantly, in this particular MSc, a significant proportion of the marks is set aside for reflection upon the work, as discussed in the following section.

Reflection

Unlike straightforward teaching, the inculcation of OR by experiential methods requires the student to act and reflect on what (s)he has done, to ensure his gradual improvement as an analyst, otherwise the exercise is pointless. People learn through their experience, the rules and principles that will guide their behaviour in certain situations. This ability to learn through experience and reflection has been described by Kolb[20,21] as a learning cycle with four stages (Figure 2).

In the first stage of the cycle, concrete experiences, the student will use their previous experience as a starting point, trying out various ideas that they already have knowledge about. As they move on to the second stage, reflective observations, they will reflect on their actions noting their implications, they should 'become an observer of their own thinking and acting'.[22] In the third stage the student would conceptualise these observations into general abstract concepts for future use, and perhaps also research a wider knowledge base that could inform their understanding, which may allow growth in their area of expertise perhaps bringing new methods and skills to light that would influence their approach. Finally in the last stage the student would use these new insights and skills to test their approach, allowing experimentation. They will continue round this learning cycle until a clear understanding is reached, reflecting as they go on the knowledge they may have gained and its use in different situations.

The Kolb learning cycle is well-known and used widely in management teaching.[23,24] In particular, it has been used to demonstrate the usefulness of experiential learning techniques when learning about OR by Scott,[4] who also describes different types of technique of learning for different points in the cycle: using his terms,

- *divergent* techniques in moving from concrete experiences to reflecting upon them (which promote creative, divergent thought: brain-storming is an example);
- *assimilation* structuring techniques (influence-diagrams, mind-mapping, hypothesis-forming etc);
- *convergence* techniques as the student moves on those areas in which to experiment; and
- *accommodation* techniques to make use of the gained knowledge.

In order to strengthen this process of moving from Concrete Experiences to Abstract Conceptualization in this particular

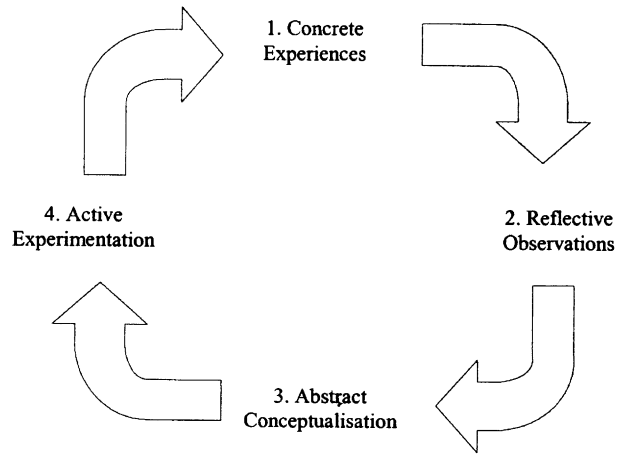

Figure 2 The Kolb learning cycle, taken from Kolb.[20]

MSc course, as part of the summer project the student is expected to write a 'Reflections' section in their dissertation. This document is not normally given to the client but is used more as an aid to allow the student to express their thoughts and experiences of working on the project to help to force them round steps 2 and 3 of the learning cycle. Students are asked to consider such issues as:

- the process of problem definition and whether this changed during the project;
- why the issues were defined as they were;
- how the relationship with the client or end user was managed;
- the role of OR in the project and the lessons learnt about OR methodology;
- difficulties in the execution of the project;
- things that could have been done or done differently;
- observations about the client organisation.

A significant proportion of the mark for the project (30%) is allocated to the degree to which the examiners assess the student has learned from the experience of the project and is a better analyst for having done it, and this 'Reflections' section forms a major input to this part of the marking.

Similarly, after every experiential learning activity, the students get together to reflect on what they have experienced, and discuss learning points.

This idea of learning through doing is not the same, nor does it imply 'Independent Learning'. This term is used by Belton and Scott[25] in their work pioneering courses which include a significant proportion of active participation, but Independent Learning can be distinguished by 'the emphasis given to student involvement in course design decisions'. This successful philosophy has not to date been taken up by the Strathclyde MSc course because of the time-intensive nature of the course, the specific nature of the vocational skills which it aims to imbue, and partly some concern about the accreditation of the course by funders. However, the authors have the idea under review.

Teaching the skills

Of course, the students also need within their tool-kit a set of skills. Some of these are OR techniques: statistics, simulation, system dynamics and so on; others are 'process skills', necessary for the process of carrying out OR. Which techniques and skills need to be taught? Key of course is to make the topics those that industry wants. On most MSc's, course development draws on the experience of an Advisory Board of senior OR managers and practitioners. As part of a review of Warwick's MSc, Mingers[26] presents the results of a survey of practising OR groups in UK organisations. The aim was to determine what OR groups thought would be desirable in such a course. The questionnaire sought to determine which topics or skills were important and which were unimportant, the kind of computing knowledge that would be useful and any subjects that hadn't previously been considered. The questionnaire had a response rate of 68%.

- Topics scoring highly in the questionnaire included, report writing, presentation skills, group work, live project work, basic statistics, basic computing, traditional OR methods and simulation.
- Topics with a low score include game theory, renewal processes, Markov chains and aspects of mathematical programming.
- Computing topics that stood out as being important were spreadsheets, microcomputers, programming and databases. Fortran was the most preferred programming language though Pascal and C were also popular.

But of course, as has been made clear in the previous discussion, the techniques themselves are only part, and by far the simplest part of the OR education. Even back in 1986 the Commission[9] stated that 'comparatively little direct use is made of so-called OR techniques in the practice of OR'. Beasley and Whitchurch[27] give the results of a survey back in 1984 with the help of those attending the Young OR Conference held in Nottingham University in March 1982. The survey had a response rate 64% with the average age of respondents being $25\frac{1}{2}$, the oldest was 37 and the youngest 22. 56% of respondents were in their first job and 31% in their second. From the results it is clear that the classical OR mathematical programming techniques are least used and computing, simulation, forecasting, regression and statistical tests are most frequently used; mathematical programming and dynamic programming were rated as having been covered too much in their education, with simulation, surveys, heuristics and decision analysis as inadequate. But more importantly, they highlight areas of failure in the education, some of the main areas being, too little about computers and computing, report writing and presentations, manager/client relationships, management of an OR project, too much emphasis on techniques applied to well defined problems not enough on sparse data or poorly defined problems. And they highlight problems facing OR education, including the teaching of methodology to deal with ill-defined problems, preparing students for the political and working environment of organisations and the fostering of desirable personal characteristics in individuals. Even when asked about areas of success in their education, they point to areas other than OR techniques, problem solving methodology, ability to work to deadlines or under pressure, ability to write reports and do presentations, as well as 'being aware of the techniques available'.

The process skills are taught in an MSc by a variety of methods, many discussed above—mentoring, experiential learning and so on. But the key element for effective teaching is always the grounding in current (or at least

fresh) process experience on the part of the mentor. Such process skills include:

- consulting practice skills: the role of the consultant; stakeholders; interviewing skills; client/consultant relationships and 'buy-in'; implementation issues and reward systems;
- the context of business management;
- proposal preparation and proposal 'selling'; costing; project planning;
- problem structuring methods;
- methodological issues;
- ethical issues;
- how groups of people work;
- the use of decision support systems to help decision makers (both operationally and with the strategic process).

Some of the elements on some of these issues can clearly be taught by some form of conventional teaching (face-to-face or directed reading, say): the standard problem structuring methods, or the strategic decision-making systems. But the teaching on even these becomes dry and sterile if simply taught conventionally and not motivated by real, or apparently problems. And in general the other skills can only be taught by a mentor, with real and fresh experience, guiding the students as they learn through experience.

It is the authors' opinion that for too long we have taught students the OR techniques described in the next section, without teaching them (say) how to write a proposal to gain the work in the first place. And these skills do need specific teaching. In writing a proposal, there are specific skills in (*inter al*): identifying key issues; structuring a project; planning milestones and deliverables; effort-planning, budgeting and costing; putting across a proposal and so on. These require the guidance of a mentor who has him/herself learned from preparing proposals in anger (and winning them!), and must be learned from doing. During the MSc with which we are involved, the students work through a process: throughout the course they carry out different elements as part of their 'Experiential' stream; some way through the course they are formally taught many of these skills then tested in groups in an intensive time-limited proposal-preparation and -presentation exercise on a psuedo-real very 'messy', ill-defined problem; then individually they have to prepare proposals and plans early in the summer project.

Teaching OR techniques

Turning to the OR techniques themselves, as opposed to the process skills, we have considered to some extent the question which topics should be taught? But two other questions raise themselves: to which depth? And how should they be taught?

The phrase 'being aware of the techniques available' in the section above gives an answer to the second question. There are basic areas of knowledge every OR person needs. And some techniques clearly need to be taught in more depth—statistical and probabilistic ideas, for example. But as far as the production of a tool-kit goes, for many techniques the key is to be aware that a technique exists, its nature and when it is applicable, and then to be able to find out about it and pick it up, understand it and apply it very quickly. A student might not learn all of the techniques of data-mining, but (s)he needs to have a flavour of what they are, and be able, when needed, to recognise a data-mining issue, familiarise him(her)self with the techniques and go and apply them, possibly in an environment where no-one about him/her knows anything about datamining.

How should these techniques be taught? Traditionally the taught classes in any University course consist of lectures and tutorials. As part of the ongoing process within the department to improve the effectiveness of UK OR teaching, a new component has been added to the traditional teaching methods. The UFC-funded MENTOR (Multimedia Educational Technology for Operational Research) project has produced multimedia computer based learning materials which aim to improve both the effectiveness and the efficiency of teaching Operational Research in higher education.[28] 'The materials take the form of fourteen modules, each covering a different OR topic. MENTOR is an integrated piece of software that supports all aspects of teaching and learning from the presentation of theory and method through to the application of a technique. Using a hypermedia system incorporating graphics, video, animation, applications software and specially designed interactive teaching materials the system provides a powerful mechanism to combine theory, worked examples, self assessment quizzes and applications software in an effective tool to support student learning'.[28] 'Students learn by their own investigation of the system through exploration and experimentation with interactive models and graphics. The immediate visual feedback provided in this process engages the students actively in the learning process, encouraging active rather than passive learning'.[29] The efficiency gain is clear: 'Efficient use of staff and resources is increasingly important in higher education and there is clearly the potential to incorporate computer-based learning into a traditional teaching regime to reduce staff/student contact time'.[29] The effectiveness gain is also usually (although not universally) agreed, but different institutions use the software in different ways. The authors have found that with an MSc class, all well-motivated, and needing to study topics in some depth, the software provides a very useful adjunct to traditional technique-teaching methods; it is used either directly as a teaching aid or as a stream running parallel to and supporting a pared-down teaching course. Different institutions

teaching different levels of students have developed different modes of using the tools (see for example an analysis by Hill *et al*,[30] on attempting to integrate a MENTOR module into a first-year undergraduate course, then deciding to integrate it into a second-year Management and Cost Accounting course).

Conclusions

The nature of the 'messiness' of the real projects in which we are involved determines how our OR practice proceeds. In order to train the future generation of Operational Researchers, we need to prepare them with the skills to deal with this messiness.

Firstly, of course, the teachers themselves must have these skills, and be continually honing them in practice. Now as OR academics we do many things, in particular, we teach, consult, research and carry out in-company training. One key message of this paper is synergy. The research culture of carrying out real work for real clients leading to the development theory and thus generic results of general applicability, either serendipitously or as a planned outcome, clearly brings synergy between consultancy and research; the work represented by this consultancy/research clearly informs teaching and training, making it fresh and relevant; but in-company training can also spark off interest leading to interesting consultancy and thus research.... Added to this are synergistic opportunities teaching and training in novel situations which will lead to research outcomes.

Then these abilities need to be passed on to the students. Technique training provides an important tool-kit, but there are key process skills that are essential to practice in the real 'messy' world. These skills have to be identified, then they must be learned through guided experiential learning and mentoring, with the learning loop closed by guided reflection (fostered and aided by mentors).

Various implications for the technique-teaching have also been discussed, but, apart from a few vital OR concepts, the essential is to equip the student with a tool-kit of both techniques that (s)he can pull out and use on demand, and also of knowledge of existing techniques so that the student can go and find out more about a technique if required.

We aim to supply graduates able to grapple with complex, messy, real-world problems and provide useful input to decision-making processes. The OR world of tomorrow depends vitally on the MSc graduates we supply today.

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