Application of Contemporary Education Strategies to the Teaching of Operations Research

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Abstract

Based on higher education goals and the particular characteristics of operations research, we consider in this paper how to enhance operations research teaching by utilising contemporary teaching methodologies. Three possible approaches, concept mapping, group work and 'inverse' PBL (Problem Based Learning) are proposed, and corresponding new assessment schemes for ensuring these new methods' maximal efficiency are suggested. Also discussed are possible problems about their combination with traditional teaching methods. We believe that, as long as these reforms are implemented properly, the best possible teaching/learning results can then be achieved.

Introduction

The pace of technological change and the growing access to new technology means that young people are part of a society in which knowledge is rapidly changing. They face a world in which much of the work they will do has not yet been imagined, and they will constantly need to reinvent themselves. In order to be successful, they must have the ability to access and generate new knowledge in a purposeful fashion, and to move beyond simple content knowledge to critical analysis and an understanding of emerging trends and issues. That is why almost all main universities around the world nowadays demand that their graduates should have certain generic attributes as well as a body of factual knowledge in the field(s) studied. These generic attributes include rigorous and independent thinking, good communication skills, flexibility and adaptability to continue learning in their disciplines throughout life, practical skills, personal skills and attributes.

It is hardly possible for us to help students develop the above generic skills under the conventional teacher-focused, information transmission teaching approach, from which students would only get some factual knowledge and could only answer those simple 'what questions'. Information to answer the 'what questions' is very readily and easily available nowadays through various resources. Even worse, a lot of empirical research has shown that under the traditional teaching approach, students, as passive learners, usually adopt a surface learning approach (focusing on rote memory and reproduction), instead of a deep learning approach (focusing on meaning and understanding). A wealth of evidence has been reported to support the deep learning approach, which is thought to lead to greater academic success. For this reason, many contemporary teaching strategies have been developed from the so-called constructivism learning theory. The main point of these strategies is that effective teaching should be student-centred, so that students are active learners. If students are to become independent, lifelong learners, our program of teaching strategies needs to include methods and tasks which are interesting, motivating and require both team and individual learning tasks, so that they have every encouragement to react with the level of cognitive engagement that our objectives require. There are different ways to achieve these goals, such as interactive teaching, peer interaction, group work, case study, problem based learning (PBL), etc.

On the other hand, learning and assessment are inextricably linked. The importance of assessment in influencing students' approaches to their learning has been well documented (see the review in Scouller and Prosser 1994). Results suggest distinct patterns according to assessment method. Students were more likely to employ surface learning approaches in the multiple choice question examination or the usual closed book examination (where it is impossible to ask students to do rather difficult problems) and to perceive these conventional examinations as assessing knowledge-based (lower levels of) intellectual processing. In contrast, students were more likely to employ deep learning approaches when preparing their assignment essays, oral presentations, or group project report, which they perceived as assessing higher levels of cognitive processing (Scouller 1998). Consequently, non-conventional assessment methods are increasingly being used in higher education in an attempt to introduce more realistic and meaningful tasks and provide broader and more reliable indicators of students' achievements. A number of positive effects on learning have been identified and students strongly support new methods of assessment (McDowell 1995).

We have seen a huge body of theoretical, empirical research results and successful applications of contemporary teaching, learning and assessment approaches in science education in high schools, as well as in the teaching of medicine, chemistry, physics and some engineering subjects in universities. However, there is not much research about the application of these current education strategies in the teaching of mathematics courses for undergraduate students majoring in pure or applied mathematics. One reason suggested for this is that the aim of many mathematics courses is to help students develop rigorously abstract thinking ability or active manipulation of meanings, and another is that it is very difficult to connect contents of high level mathematics courses with reality. Therefore, the traditional teacher-focused lectures are still widely used in mathematics departments of various universities or colleges. As a result, graduates did possess sufficient knowledge of the various subjects, but could neither apply nor integrate this knowledge without support. They were never prepared for solving practical problems, which is especially serious for Chinese students. Employers often complain about graduates' poor applicative and collaborative abilities (Perrenet and Adan 2002). But as the (applied) mathematicians of the future, tertiary graduates should possess those generic skills given at the beginning of this section. In particular, mathematics students should learn how to efficiently apply complex, abstract mathematical methods to solve various difficult practical problems, and should be able to deal equally comfortably with the symbolic language of mathematics and the natural language of English used in its service, so that they can communicate mathematical knowledge and information to different audiences in their future work environment (Wood and Perrett 1997).

It is difficult to apply contemporary teaching approaches in those fundamental mathematics courses, such as mathematical analysis, algebra and functional analysis, which students take in the first one or two years of their study. We should try, however, to use these modern teaching strategies when we teach those application-oriented courses, such as numerical solution of differential equations, applied statistics and operations research, which students take in their third or fourth year. For these courses, we have to do our best to utilise these modern teaching strategies, because it is the only way to develop our students' generic skills. Considering these reasons, in this paper we investigate how to apply contemporary teaching/learning theories to teaching operations research. Based on the characteristics of operations research, three possible ways to enhance its teaching are discussed. Relevant new assessment schemes are proposed, and problems, which may arise by combining these with traditional teaching methods, are considered. We briefly illustrate the characteristics of operations research and the current approach used to teaching it. Three possible ways, concept mapping, group work and 'inverse' PBL, to improve the teaching of operations research are investigated by utilising available research results about these modern teaching strategies. How to efficiently combine these new ideas with the traditional teaching approach so that we can obtain the best possible teaching/learning results from these reforms is discussed.

Operations research and its current teaching method

Operations research (OR) is the systematic application of scientific methods, especially quantitative methods, techniques, and tools to the modelling, analysis and solution of various problems involving the operation of systems. The aim is the evaluation of probable consequences of decision choices, usually under conditions requiring the allocation of scarce resources – funds, manpower, time or raw materials. The objective is to improve the effectiveness of the system as a whole, with emphasis on the last three words (Daellenbach and George 1978). Therefore, most OR projects involve the optimisation of some operation of a system, such as minimising production costs or maximising profits. OR is essentially a collection of mathematical techniques and tools, which, in conjunction with a systems approach, are applied to solve practical decision problems of an economic or engineering nature. OR techniques have been used in such diverse fields as finance, medicine, ecology, urban planning, architecture, electrical and chemical engineering, space exploration, and logistics.

OR is usually taught as a one-semester optional course in the third or fourth year for students majoring in applied mathematics, engineering or business management. This paper will mainly concern the teaching of OR to applied mathematics students. Nowadays, most lecturers in mathematics departments are still using the traditional information transmission/teacher-focused approach in teaching OR, via lectures and tutorials. This is especially so in China. As well as those problems given in the previous section about the traditional teaching method, this goose-feeding method is even more problematic for OR teaching due to the following facts.

After two years' study, students already know a lot about mathematical analysis, algebra and probability and statistics. Because they feel they understand those mathematical tools used in OR, they think it is simple to learn OR. The problem is that different sorts of problems in OR require different mathematical tools, and so students get confused about which mathematical tool to apply in different situations. It is therefore important for us to use a teaching approach, which will encourage students to think creatively about each problem.

In OR, various different solution algorithms have been devised, aimed at various types of real problems. In order to rigorously describe and analyse these algorithms, many concepts have been introduced. Students often find it hard to remember the definitions of these concepts and to understand the underlying reason for introducing them. Meanwhile, for each kind of decision problem, there usually exist several different solution algorithms. Students always have trouble deciding which algorithm to use when they are asked to solve a specific practical problem. It is undoubtedly vitally important to help students grasp the theoretical structure of different OR methods and get a clear, overall picture about various OR techniques. However, this is difficult to do under a traditional teaching approach.

As a rather application-oriented subject, the final purpose for students in learning OR is being able to solve various management or engineering problems in their future career. This objective can hardly be attained under the traditional teaching strategy. Apart from the doubt about whether students have really mastered sufficient theoretical knowledge about OR under the traditional teaching approach, there is no attention paid to generic skills such as real problem solving skills, collaboration and communication ability. In order to efficiently solve practical management problems, some background knowledge about the operation being studied, other than the mathematical tools, is necessary. OR draws upon many areas of knowledge and OR projects require a team approach. Students must be able to work in a group and cooperate with people from other fields. At the same time, they must be able to understand non-mathematically defined practical problems and convert them to some OR models and, conversely, to explain their solutions or decisions to different audiences. So communication ability is essential for students.

Lecturers often ask students to solve very trivial problems as an OR exercise. Students can therefore easily solve them by just following examples in the textbook or repeating the relevant algorithm step by step. In China, this kind of exercise is the only assignment we ask students to do before the final closed book examination. It is not feasible to put very hard or complex questions in such a final examination. Therefore, it is easy for students to get rather good marks by just remembering some factual knowledge or reproducing what is in their books. As a consequence of this simple assessment scheme, the students are very likely to be adopting surface learning approaches, because they do not have appropriate stress and thus lose their learning motivation.

Considering the above problems, it is imperative for us to reform the OR teaching method, especially in China. According to contemporary education theory, what we essentially need to do is to convert the traditional teacher-focused method to the student-centred approach, along with suitable assessment schemes. In the next section several possible ways to accomplish this goal are examined.

Some new teaching strategies and the corresponding assessment methods

Based on extensive research results about different student-centred teaching strategies and typical characteristics of OR, we believe that at least three approaches can be adopted at the present. These are concept maps, group work and 'inverse' PBL. In the following three subsections, after a brief illustration about each of these approaches and the corresponding characteristic of OR, we will explain how each strategy can be used in OR teaching and how to measure students' achievement by devising proper assessment schemes.

Concept maps

A concept map is a diagram in which various types of knowledge, typically concepts, are classified and their linkages are shown. The concepts are sorted into a hierarchy, or circles, from most general to most specific. They are arranged so that similar terms are near each other. Links, either non-, uni- or bi-directional, are then drawn between the concept words, and statements written to describe or explain the links. Developed by Joseph D. Novak, the concept map can encourage students to think for themselves about relations between concepts and can help students clarify their understanding of a topic and promote deep learning (Novak and Gowin 1984). On the other hand, concept maps can help lecturers to quickly establish what the students' preconceptions are, to identify misunderstanding, and to find out what it is students have learned and what it is they still do not understand. All these can be very useful for lecturers in deciding or modifying their lecture content, and can also be used in designing an assessment tool (Stuart 1985; Roberts 1999). While concept maps have been used extensively in high school science classes in the United States and other countries, their use in tertiary education, and particularly in OR classes is a relatively new phenomenon.

For each topic in OR, many concepts are introduced in order to explain the main idea or underlying methodology. Different mathematical tools and the relevant concepts are used, depending on the algorithm to be developed and the specific type of problems to be solved. It is very important for students to remember the definitions of these concepts and to see the underlying reason for their introduction and the relationships between them. We thus believe that concept maps should be a very useful adjunct to other classroom methods in the teaching of OR. One possible way to use it might be as follows. Students are asked to draw one concept map just before we formally begin teaching a new topic in OR and another one at the end of that topic. From the first map, the lecturer can find out what the students' preconceptions are and what might be their misunderstanding and weakness. This can lead the instructor to work out the best way to teach that topic, and thus to modify his/her lecturing content and teaching strategies correspondingly. One natural method would be displaying (without identification) both good examples and those that demonstrated some misconceptions in the class as a basis for group discussion. From the second map, the lecturer would know what students have already learned and what they still do not understand. The lecturer could then not only provide timely feedback to students, but also assess students' learning based on the improvement between the two consecutive maps. On the other hand, drawing these concept maps could help students to test their understanding and force them to actively and critically think about what they have learnt and what the relationships between all those relevant concepts are. This will aid students' learning by explicitly integrating new and old knowledge and assimilating new concepts and propositions into existing cognitive structures. In addition to the two concept maps mentioned above, we would ask students to draw maps at regular intervals throughout the course (monthly, say). These maps should link together all those concepts that students had learnt so far in the course. With all these activities, we hope that students would get a logically clear picture about what they have learnt, both locally and globally, thus enhancing their active learning, understanding and other skills.

To enforce students' energetic participation and get the most benefit from this teaching strategy, we need to find some suitable assessment method for scoring the concept maps they have drawn. Scoring schemes used in the literature can be divided into two basic types. The first method counts the occurrence of features such as words explaining the connections between terms (known as propositional links), branching points or levels of hierarchy, then allocates a point score to each, and adds them up (Novak and Gowin 1984; Wallace and Minizes 1990; Roberts 1999). An alternative approach is to rate the maps against specific criteria (Mason 1992) or combine aspects of both counting and rating (Stuart 1985). Since none of these methods seems ideal for the OR concept maps, a new scheme is necessary.

Apart from utilising usual counting methods based on the number of concepts included, the levels of hierarchy, etc. and typical rating criteria described in the literature, our new scoring scheme will pay special attention to the following aspects. As there is no uniquely correct hierarchy for concepts in many OR branches, hierarchical levels are seen as less important than the right logical flow from general to specific. Considerable weight will be placed on the correct direction in linking lines and the correct, concise propositional statements (verbal explanation of links). Some credit for links which seem logical although unlabelled will be allowed, and extra points will be awarded if students can correctly point out the connections between OR terms and those relevant concepts in mathematics, or give possible application areas/examples of specific OR methods. Additional scores will also be given for those maps with a clearly professional standard of layout. We can use the detailed scoring scheme proposed by Roberts (1999) for statistics as a good reference.

Group work

A lot of surveys tell us that whenever students have problems with their study, the first person they ask for help is their classmates. To make students become active learners, the natural choice would be letting them work in groups. The development of skills in questioning, cooperation and communication, student interaction and participation is deemed desirable. As we all know, it is often easier to negotiate meaning and to manipulate ideas with others than it is to do so alone. More importantly, peer interaction can be used to allow students to introduce different points of view, to facilitate higher order elaborations and justifications and to pool problem solving skills. Encouraging students in verbalisation of their concepts and in explaining the conflicts they see between different misconceptions could help them gain a higher level of achievement. The use of cooperative learning strategies can also result in improvements in the quality of students' interpersonal relationships. For all these reasons, many forms of cooperative or collaborative learning methods, such as discussion-questioning, group work, and community activities, have been proposed in contemporary education theory (Damon and Phelps 1989; Slavin 1991; Webb and Palincsar 1996). The effectiveness of these methods is well supported by many results.

Webb (1989) has shown that the level of elaboration that a student gives to others in a group directly affects the level of student achievement. In order for the group learning to be truly cooperative, the following elements must be present: positive interdependence; individual accountability; face-to-face interaction; and interpersonal skills (Johnson et al. 1991); as well as team rewards and equal opportunities for success (Slavin 1991). Therefore, as early as possible, students must feel linked together by their common learning goals. Group members should work together on their activity until they all understand and complete the assignment in each learning cycle.

Because of the multi-disciplinary nature of OR, most OR projects, in practice, are not the sole effort of a single analyst, but the fruit of a team effort where team members complement each other with specialised knowledge. The composition of the team may change as the project progresses. Consequently, it is vital for OR students to develop collaborative, questioning and communication abilities.

For these reasons, small group work and discussion-questioning strategies should be introduced in OR teaching. Research results show that groups are more effective when the ability distribution within the group does not cover the full spectrum of ability in the classroom (Williams 2000). While Cnop and Grandsard (1998) argue that groups of three are ideal in higher mathematics education, at some places mathematics projects with groups of six are successful (Kjersdam and Enemark 1994). Our group size would be between three and six, depending on the total number of students, their abilities and the specific content students need to discuss. The concrete implementation process could be as follows.

After we have taught an OR method, such as mathematical programming, or after students have learnt several algorithms which can be used to solve a particular kind of management problem students will be divided into groups of three to six according to group composition criteria given by Johnson et al. (1991), Webb and Palincsar (1996). They will be asked to discuss those OR techniques and answer questions such as: What are the assumptions and new concepts under each model or algorithm? What are the basic ideas underlying its design? What kind of mathematical tools are used and how? What is the strength and weakness of each algorithm? What are the differences between these algorithms and what do they have in common? What kinds of real life problems a specific algorithm can solve? How many different algorithms can be used to solve a given practical problem? Is it possible to improve an existing algorithm or to find a new algorithm to solve some real problem? How? The first three questions will help students fully understand different OR methods, while the next two questions would force students to compare different OR methods and thus get a clear picture about those algorithms. The sixth and seventh questions can lead students to think about possible applications of each OR method. The last two questions are the most difficult questions, not only demanding extensive enquiry and discussion, but also encouraging creative thinking. We are pretty sure that students will adopt the deep learning approaches to accomplish these tasks and, hopefully, this will help them to learn how to devise new algorithms or OR techniques. After all these questions are answered, each group should write a report based on their discussion and prepare for presenting it to the whole class.

The stated group work can enforce students to become active learners and lively debaters. More importantly, it can improve their critical thinking and verbal communication skills and develop their ability to work cooperatively. In addition it will give them practice at writing coherent reports with a professional standard of layout, and at giving a formal presentation. To ensure that each student is actively involved in the group discussion, contributes sufficiently and functions properly as a group member, students will be assessed for their performance using the following assessment scheme.

Our assessment method is a three-fold one, consisting of self-assessment, peer assessment and lecturer or tutor assessment. Self-assessment means that each student first measures his/her performance, then each student in a group assesses every other member's contribution in that group, and finally the lecturer or tutor gives his/her judgement of every student's performance during the whole coursework. The three assessments are averaged to get the final assessment for each student. The ability to self-assess properly is helpful if students are to develop life-long evaluation skills. The lecturer should tell them at the beginning of the course how to realistically carry out self-assessment. Peer assessment and lecturer or tutor assessment are introduced to minimise behavioural problems and to get a fair judgement for every student. These two assessments can also be used to provide timely feedbacks and to help improve individual and group performance. Each of these three assessments will be given in an assessment sheet, which should include items such as:

- the student's attendance;
- preparation for class and group project;
- the ability to finish his/her own share of task or responsibility thoroughly;
- contribution of relevant information when solving group problems;
- oral communication ability; and
- the ability to write a professional standard report.

There should be space on the assessment sheet for any additional comments on each individual's performance or the group's performance.

Another subsidiary way to enforce each group member's contribution and his/her understanding of relevant knowledge might be to randomly select one student from the group to present the group's work just half an hour before the oral presentation. This method can force every group member to be actively involved in the group's project as well as the final report writing, since otherwise he or she could not give a clear and correct presentation.

The 'inverse' PBL

Many research results (for example, Jonassen 1991) tell us that the most effective learning contexts are those, which are problem- or case-based, and activity oriented, immersing the learner in the situation and requiring him or her to acquire skills or knowledge in order to solve the problem. PBL is exactly this kind of learning strategy. Briefly, PBL is a strategy for encouraging critical thinking and problem solving skills along with acquiring content knowledge through the use of real world problems. It is a specific approach for engaging students in collaborative learning (Woods 1994). Here learning is driven by a complex, usually ill-structured, open-ended problem. The main reason for introducing this kind of teaching methodology is that it can help us to attain the central goal of higher education, as PBL has the potential to teach students self-directed study techniques for life-long learning, problem solving skills, better communication skills and the art of group dynamics. It is well documented in the literature that PBL is a very good teaching strategy. It has worked very well in several fields, for example medicine (Norman and Schmidt 1992) and engineering (Hessami and Gani 1993). Unfortunately, there also exist some problems with this approach. Typically, it is time consuming, difficult to control and difficult to assess. The selection of appropriate problems or tasks, which is important for collaborative learning (Cohen 1994; Williams 2000), is rather hard for some disciplines. PBL students are sometimes less confident about having acquired as strong a foundation in the fundamentals as have students from a conventional program.

If you read through any textbook about OR, you would become increasingly aware of the fact that the complexities of reality call for great flexibility in how OR projects are tackled. There exists no one absolutely correct approach. The 'best' approach to be followed not only depends on the nature of the problem and the amount of time and funds available, but also on the training and personality of the operations researcher. Another reason for this is, as with any other scientific method, we have to make some simplification or omit some details when the OR model for the related problem is derived, so that the resultant mathematical model can be handled by existing OR algorithms. Depending on how the model is established and how the obtained theoretical solution is adjusted, different decisions can be proposed for one specific management problem. Therefore, most OR projects are very complex, open-ended problems, which demand not only 'objective' decision ability, corresponding to the theoretical part of OR, but also 'subjective' decision ability, corresponding to the decision-maker's practical experience and personality. All these facts make PBL a suitable approach for teaching OR.

Unfortunately, it is difficult to apply standard PBL all through the course. Without knowing basic OR techniques, it is very hard and time consuming for students to figure out by themselves how to solve real decision problems by OR methods right from the beginning. They would not know what kind of modelling, algorithm selecting or designing technique to use, nor what mathematical tools they need to analyse the related theoretical problem. In the end, students would be driven mad and still could not learn enough fundamental OR methodology, because of the time limit and the abundant content in OR. On the other hand, the ultimate aim for teaching students OR is to let them learn how to solve real management or engineering problems, and the best way to test whether they really attain this aim might be to use some form of PBL type teaching approach. As a compromise, we feel that the following variation of PBL, called the 'inverse' PBL, which is closely related with the so-called 'models of reality' teaching approach and the 'case studies' approach, can be adopted.

Near the end of the course, students will watch a video about some large company (or actually visit it) to find out how productions are planned and different departments are organised. Of course, there exist some management problems for this company, which need to be solved. After this, students are formed into groups of size around four, and are asked to do a series of independent investigations, which typically involve the following steps:

- Problem Recognition. What is (are) the management problem(s) for this factory?
- Verbal Model. Describe the problem in the usual non-mathematical way. For these two activities, students can consult with managers from that company, if they need any help.
- Factor Classification. How many factors are there for the problem to be solved and what are their relationships?
- Mathematical Modelling. Establish a proper mathematical model based on previous steps' analysis.
- Algorithm Selection. How can you solve the identified OR problem? Can you directly use some existing algorithm in OR or do you have to modify a specific algorithm?
- Solution Evaluation. Is the solution acceptable? If not, refine it according to the background of that company and the likes and dislikes of the people in that field, so that your solution is a real optimal one both 'objectively' (from the theoretical point of view of OR) and 'subjectively' (according to practical experience and the common sense of people in that kind of industry).
- Final Report. Explain your results verbally to managers using common, non-mathematical terms so that they can fully understand what you mean, and then write a formal report (or an essay, if possible). The standard of the report should be that of an academic paper in mathematics.

During the above process, the lecturer should provide sufficient support and monitor students properly, even though it is a very engaging and self-directed collaborative learning approach. For example, whenever necessary, the lecturer should tell students about the best way to find research materials, whether from journals/books in the library or from a website. He/she should also explain whether there is any suitable software for students to use in the computer laboratory, etc. More importantly, the lecturer should help students if he/she finds that students get a wrong scheme.

The benefits from this kind of teaching and learning are similar to those claimed for PBL. That is, it will be a very rewarding experience for students to practice the whole process relating to the application of OR techniques in solving practical management problems. It will allow them to find their possible weakness in some aspects and rectify that as soon as possible. At the same time, students' generic skills will be improved, since the process involves higher-order thinking, problem solving ability, collaborative ability, and communication ability.

As for the assessment, we can use the three-fold scheme given in the previous subsection, except that additional attention should be paid to students' ability and effort to combine theoretical OR knowledge with practical things like people's common-sense and specific regulations in the field corresponding to the problem to be solved.

Possible problems with the implementation

Firstly, having been used to the traditional lecture-tutorial teaching method, students might be reluctant to change. A good orientation period is thus essential each time we introduce one of those new teaching approaches given in the last section. We should explain in detail the main reason and purpose for doing it, give concrete details about the way it will be done, and how it will be assessed. If we do this, students may become accustomed to the new teaching strategy quickly, thus ensuring the hoped-for effect.

While strongly advocating those three new teaching methods, we should by no means abandon the formal lectures. On the contrary, the usual lecture should still be the main component, not only because we have to teach students many basic OR techniques, but also because the new teaching approaches are only suitable at specific stages. Corresponding to this, the overall marks students finally get would be based on two parts: the scores they obtain from the three assessments described in the last section would account for one half of their total marks, and the other half would be from the final closed book examination.

It has become a commonplace belief that no one strategy is appropriate to all learning contexts and no single method is superior to another in all situations, particularly in terms of student performance. In order to make our lectures more participatory and thus enforce students to become active learners and adopt the deep and strategic (achieving) learning approaches, we, as lecturers, must try to use as many different ways as possible to vary the traditional lecture format. Some useful tips are:

- begin your lecture by asking interesting questions or posing a problem, and eliciting several answers or solutions from the students;
- create an atmosphere that encourages student participation by using a conversational tone and not criticising student questions or comments in front of the class;
- when a student asks a question, instead of answering yourself, ask for an answer from other members of the class;

- always repeat a question or paraphrase a response before going on if you are giving a lecture to a large group;
- always leave the most important thing to the end of the lecture or introduce it just at the beginning of your lecture;
- after making a major point, or near the end of your lecture, give students a one-question 'quiz' (either a yes-no question or a multiple choice question) to test their understanding.

All these strategies can be adopted for teaching operations research.

Last but not least, students should be encouraged to use computers during the whole course. There are two main reasons for this. Firstly, being able to make use of various computer resources flexibly and efficiently for their study and future work is an essential skill for students if they are to succeed in a technology-based age of information. Secondly, without the help of computers, it is hardly possible to solve many complex real decision problems by OR techniques. Therefore, we should provide sufficient facilities and enough time for students to use the computer lab for their OR learning. For example, during the tutorials, the tutor should, whenever possible, show students how to use some popular mathematical software, such as *Matlab* or *Mathematica*, to practice and test algorithms they have just learnt. This will help them to further understand the underlying principle and their usage of various OR methods. Meanwhile, during their group work and the real problem solving period at the end of the course, the lecturer and the tutor should introduce some high-level professional OR software, for instance *CPLEX* or *LONGO*, to students. It is very useful for students to get some preliminary feelings about what properties a good commercial OR software should have, and to learn how to solve practical management problems by utilising suitable software.

As long as we can properly cope with these facts, together with suitable ways to apply those three new teaching approaches given in the last section and the corresponding new assessment, we are confident that the quality of the teaching of operations research will be greatly improved. More importantly, this series of reforms will be very useful for developing students' generic skills.

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