

# Effective Strategies to Teach Operations Research to Non-Mathematics Majors

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## Abstract

Operations Research (OR) is the discipline of applying advanced analytical methods to help make better decisions (Horner (2003)). OR is characterized by its broad applicability and its interdisciplinary nature. Currently, in addition to mathematics, many other undergraduate programs such as management sciences, business, economics, electrical engineering, civil engineering, chemical engineering, and related fields, have incorporated some topics in OR in their curricula (Ramirez et al. (2004)). Therefore the course content and teaching strategies used to teach an OR course should be effectively aligned with the students' objectives and course goals in the host department. Based on the existing literature, in this paper we discuss five strategies to enhance the teaching of OR skills that are essential for students in practical disciplines. Instructors should use an optimal dosage of each of these teaching strategies depending on the background of the students and their expectations from the course.

## 1 Introduction

Blumenfeld et al. (2004) defines Operations Research (OR) as the science of decision making, which provides a systematic and scientific approach to various government, military,

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and manufacturing operations. It is an exciting area of applied mathematics that combines mathematics, statistics, computer science, physics, engineering, economics, and social sciences to solve real-world problems. Due to the wide applicability of OR in different industries (e.g., see Hovey and Wagner (1958), Sodhi (2001), Sodhi and Son (2008)), and in order to provide their students with appropriate educational training and reasonable mathematical background in OR, many academic departments host OR courses. These courses tend to be taken by third and fourth year undergraduate students. For example, at the University of Waterloo, several departments in faculties other than the Faculty of Mathematics such as Faculties of Art, Engineering, and Science, offer some undergraduate courses that cover some topics in OR (see Table 1 <sup>1</sup>).

Department	Course Number	Course Title
Electrical and Computer Engineering	ECE 204	Numerical Methods
Civil Engineering	CIVE 596	Construction Engineering
Management Sciences	MSCI 331	Introduction to Optimization
	MSCI 332	Deterministic Optimization Models and Methods
	MSCI 435	Advanced Optimization Techniques
	MSCI 436	Decision Support Systems
	MSCI 452	Decision Making Under Uncertainty
Systems Design Engineering	SYDE 311	Engineering Optimization
	SYDE 361	Introduction to Design
	SYDE 362	Systems Design Workshop 1
	SYDE 411	Optimization and Numerical Methods
	SYDE 511	Optimization Methods for Stochastic Systems
	SYDE 554	Systems Models
Economics	ECON 211	Introduction to Mathematical Economics
	ECON 311	Mathematical Economics
	ECON 411	Advanced Mathematical Economics
Physics	PHYS 339	Scientific Computation 2

Table 1: Undergraduate Courses with an OR component at the University of Waterloo.

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<sup>1</sup>Table 1 was generated based on the course in the undergraduate calendar 2009-2010 at <http://ugradcalendar.uwaterloo.ca/?groupID=23>. Only those courses whose descriptions include at least one of the words *optimization* or *operations research* are listed in Table 1.

The content of an OR course is typically a blend of key steps in OR. Blumenfeld et al. (2004) counts these key steps as problem formulation, mathematical modeling, data collection, theoretical solution methods and proofs, validation and analysis, interpretation, and implementation using computer programs, OR software, and simulations. Academic departments generally attempt to align the content of their OR courses with the goals of their students, and choose engaging materials (Mingers (1991)). However, as is reported in the literature, they do not align their teaching strategies with these goals. For example, the case study by Eiselt and Eiselt (1994) indicates that while the topics covered in the curricula of OR courses in business schools are usually identical to the topics that students use in their future careers, the ranking of topics according to their use differs substantially from the ranking of topics according to the amount of time used to teach them. Trick (2006) believes that, this is explained chiefly by the fact that many instructors mimic their previous education rather than teaching students what they should really know. This is particularly problematic in OR, since most instructors of OR courses in non-Mathematics departments have been studied and graduated from mathematics programs. Therefore, the education most of them received and the teaching methods they experienced as students are far different from their teaching goals and their students' objectives.

These instructors usually choose lecturing as the main teaching strategy, mainly because lecturing is the most typical teaching strategy in mathematics programs, and it enables instructors to cover many topics (Liebman (1994)). However, to ensure that students receive the OR training they require, the use of lectures alone is inadequate. Inefficient teaching strategies might discourage students and turn them against the useful topics in OR. In contrast, aligning the course content and teaching strategies with the primary goals of teaching OR in the host program, where the course is taught, helps students to approach mathematical programming and other OR techniques eagerly and positively. It helps students

to appreciate OR as a discipline or profession rather than simply as a body of definitions, theorems, proofs, and techniques.

In recent years, innovative alternative teaching strategies for conventional lectures to be adopted in teaching OR undergraduate courses to students with practical disciplines have been received much attention; indeed, the institute for operations research and the management sciences (NFORMS) has started a Teaching Management Science Conference. Several constructive instructional methods to teach OR have been proposed in the literature. In this paper, we discuss five of these teaching strategies that haven been suggested for programs for non-Mathematics majors. These strategies are to promote opportunities for active learning, to provide real-life examples during lectures, to integrate technology and multimedia, to use puzzles and games and to invite for guest speakers. We then discuss appropriate percentages of these strategies to be used depending on the department in which the course is taught.

This paper is organized as follows. In Section 2, the incorporate of active learning in the teaching of OR is discussed. Sections 3 and 4 present some suggestions from the literature to provide real-life examples during lectures and to integrate technology in the teaching process. The use of puzzles and games is discussed in Section 5. Section 6 addresses advantages of inviting guest speakers to the classroom when teaching OR. Section 7 provides a discussion about the use of these strategies in teaching OR to non-Mathematics major students. Concluding remarks and some recommendations are presented in Section 8.

## 2 Promoting Opportunities for Active Learning

Active learning environments to teach undergraduate OR courses have frequently been recommended in the literature to enhance students' understanding and mastery of materials (e.g., see Liebman (1994), Liebman (1996), Liebman (1998), Lasdon and Liebman (1998), Corner and Corner (2003)). Previously, active learning had been suggested for other fields of mathematics (e.g., see Paas (1992)).

Based on cognitive psychology, Liebman (1998) argues that instructors should identify types and difficulty of knowledge to be learned, and to accordingly create opportunities for active learning. The adoption of active learning methods can range from pausing periodically in lectures, so that students can undertake short discussions or do a short exercise, to replacing some parts or all of a lecture with carefully structured student group discussions.

Ten activities to promote active learning when teaching undergraduate OR courses are suggested by Liebman (1998): (1) *Taxonomies*, e.g., develop a taxonomy for optimization models. (2) *Similarities and differences*, e.g., list the similarities between simple gradient search and Newton search. (3) *Forms and functions*, e.g., explain the role of constraints in an optimization model. (4) *Advantages and disadvantages*, e.g., explain advantages of developing a deterministic rather than a stochastic model. (5) *Type 1 frames*, e.g., fill in the cells of a table whose rows represent different nonlinear optimization algorithms and columns are labeled initialization, determining direction of movement, and termination criteria. (6) *Type 2 frames*, e.g., fill in the missing steps of a proof. (7) *Concept mapping*, e.g., develop a hierarchy map representing the categorical relationship of optimization models. (8) *Metaphor and analogy*, e.g., extend gradient search in two dimensions. (9) *Rehearsal*, e.g., use the simplex method on an assigned problem. (10) *Advance organizer (instructor activity)*, e.g., take advantage of the similarity of the simplex method in algebraic form and in matrix form

when teaching the later topic.

These ten activities can be applied for both individual student activities in the classroom or group activities, in which case it is called *cooperative active learning*. It has been highly recommended by Lasdon and Liebman (1998), specifically to teach nonlinear programming, which typically involves the teaching of different OR algorithms.

In moderate size classes, cooperative active learning can be implemented by the use of *learning groups*. Johnson et al. (1990) recommend that formal cooperative learning groups to be composed of two to four students and to be heterogeneous with respect to gender, nationality and major field of study. As learning groups undertake the assigned activities, the instructor should move around groups listening to the discussions taking place. Occasionally the instructor joins a discussion if no one in the group has a good answer to the question under discussion. Lasdon and Liebman (1998) describe in detail the cooperative activities practiced in their undergraduate OR courses. In particular, Liebman (1996) suggests questions on making counter examples or joint quizzes for cooperative active learning.

In large classes, cooperative active learning can be used by asking students to turn to the student next to them, discuss the question, and develop a joint response. This approach is called *turn-to-your-neighbor* discussion. Liebman (1996) recommends using such discussions every 10 minutes or so throughout each lecture. Depending upon the difficulty of the question, the resulting discussions can last from 30 seconds to 15 or 20 minutes. Then one or two student groups will be randomly called on to provide the answer. To use turn-to-your-neighbor discussions, Liebman (1996) suggests the instructor begin the first lecture or two in which the approach is used, by describing the process and asking the students to identify their discussion partner, and after that, only the instructor begins the activity by saying "now turn to your neighbor and discuss ...".

Learning activities in the classroom increase the students' understanding and retention of knowledge. Cooperative active learning involves all of the students in developing the answer to the question. It provides students with opportunities to teach each other and to improve their interpersonal and collaborative skills. Moreover, differing student perspectives emerge and enrich the quality of the resulting discussions. Furthermore, the element of panic (the professor is going to call on me for the answer and I'm not sure I know it!) is eliminated, and the energy level in the class increases perceptibly. Such group discussions stimulate a deeper level of mental processing than passive listening.

Active learning approaches will definitely reduce the amount of time available to the instructor, and less material will likely be covered in the course. However, the amount of material actually learned by the students will significantly increase. Indeed, cognitive psychologists predict a better long term learning result!

Liebman (1996) states that most students appreciate the opportunity to participate in discussions. On the end-of-semester course evaluations of an undergraduate OR course taught by Liebman (1996), the cooperative active learning approach was singled out for praise by the students. Students in learning groups recognized that they had assumed the responsibility for learning and believed that their own learning skills had improved. Based on the experience of incorporating the independent learning style in an undergraduate OR course, Belton and Scott (1998) argues that independent learners are likely to turn into reflective and effective practitioners of OR.

### **3 Providing Real Life Examples During Lectures**

Cochran (2004) believes that one very effective way to recapture and hold the attention of

students is to provide examples that are relevant and meaningful to them. Due to the nature of OR and its wide applicability, preparing real life examples to mention in the classroom is not challenging. I believe society-dependent examples related to the everyday life of students are appropriate, e.g., applications of OR in transportation in Middle Eastern countries, or managing water storage behind dams in Canada.

Motivating real-life examples can be used at appropriate times during the lectures specially at the beginning of each topic. Alternatively, they might be used in assignment questions. Instructors may also ask students to give related examples and present them to other students in the classroom.

One area of application that many OR professors have used successfully in this manner is *sports*. The use of examples from sports has previously been practiced in teaching courses in similar fields, such as undergraduate statistics (Reiter (2001), Albert (2003)). Several OR instructors, who have successfully integrated **sports examples**, into their courses are named in Cochran (2004). In particular, examples from baseball have been used to teach Markov chains to undergraduate engineering students, to prove the potential existence of Simpson's paradox with integer programming to undergraduate business students, and to describe fundamentals of Markov decision processes and decision analysis. Cochran (2004) also reports teaching integer and constraint programming in MBA classes using sports scheduling, teaching Monte Carlo simulation to business students using the National Hockey League, and to teach optimization and modeling under uncertainty by optimizing travel considerations for the National Collegiate Athletic Association (NCAA) basketball tournament.

Cochran (2004) argues that students who see such examples of OR concepts are generally better equipped to understand and to independently envision other applications. Using real-life examples improves retention and leads the students to place greater value on OR concepts.

According to the literature (e.g., see Cochran (2004)), instructors who have used sports examples in OR courses for many years have found them extremely effective, provided proper care is taken to give necessary background information to those students who are not familiar with sports.

## 4 Integrating Computer Technology and Multimedia

The use of computer technology in the teaching process has developed over the last two decades and has created a highly flexible learning environment for students (Laurillard (1993)). Educational software packages, the World Wide Web, course web pages, email, discussion groups, bulletin boards, and applications of audio, video, or computer-based multimedia, have changed teaching in all disciplines and at all levels.

In the field of OR, perhaps the first attempt to integrate technology in teaching OR courses has been through spreadsheets, first suggested by Bodily (1986). James (1988) discusses some advantages and challenges of using spreadsheets and textbook floppy disks. Spreadsheets help instructors to involve students actively in modeling OR problems (Powell (1995)). Some OR courses and textbooks, such as the book by Winston and Albright (1997), are now totally based on the use of a spreadsheet software.

Since 1990, various educational software packages to enhance teaching OR courses have been designed. Climaco et al. (1993) describes one of the first software packages to teach OR. Belton et al. (1997) developed a computer-based multimedia teaching tool for OR, called *MENTOR*, that has been used by educators with varying degrees of success (e.g., see Daellenbach and Petty (2000), Simpson and Edwards (2000)). They note that instructors must effectively adjust their teaching styles to use *MENTOR* constructively. In particular,

Ramirez et al. (2004) recommend the use of educational software in the classroom to teach OR in electrical engineering. They proposed a computational optimization environment tool, called *Optimise*, in order to carry out sensitivity analysis and illustrate the performance of the algorithms studied. *Optimise* has a user-friendly interface and a set of implemented visualization functions, and is capable of displaying graphics, thereby enabling students to easily investigate various features of OR methods.

Bhargava and Krishnan (1998) describe several examples of the impact of Web technologies on OR education and professional interaction. The widespread use of course websites and electronic mail are the most immediate results of web technology. The course webpage is the means by which an instructor may disseminate information. Students get all exercises, readings, problem sets, study guides, and lecture notes from the course website. Its functionality can be further extended to include links to other websites, answers to frequently asked questions, student feedback, and group discussions. Course websites must be maintained for them to be of value to students. Delayed updates discourage and frustrate students. This service is especially appreciated by students who live off campus because it allows easy access to class-related materials. Email, as the most common tool for supporting students' learning, may be used to promote student-student or faculty-student communication between class meetings. Email also allows students and instructors to exchange files for problem detection and discussions.

While software packages, email and course websites are generally used for the teaching of most OR courses, some techniques for integrating technology, such as the use of animations or virtual office hours, are not commonly practiced. A detailed discussion of the use of multimedia and other computer technology are provided by Seal and Przasnyski (2003).

Seal and Przasnyski (2003) describe in detail their methods to use technology in undergraduate OR courses that they teach. The focus of those OR courses is on applications

and the use of OR as a decision making tool. They use many hands-on examples in the class, and assign complex projects based on case studies and real-life problems as homework. Using a teaching grant of \$6000 from the university, they initiated using technology in their OR courses in several ways. The methods used by Seal and Przasnyski (2003) and their advantages and challenges are briefly addressed below:

1. *Videos Explaining Concepts and Solutions to Problems*: They created short videos of instructors explaining difficult concepts or solving homework problems as an extension of the classroom. Students can watch these videos multiple times to suit their own schedules and paces of learning. Although, they report very positive student feedback to the videos, they found this technique unattractive mainly due to the challenges in shooting, digitizing, and editing the videos, and difficulties in producing CDs or DVDs.
2. *Screen-Capture Movies for Software Demonstrations and Tutorials*: In order to avoid wasting class time explaining how software tools work, they used screen-capture software to record all the screen activities in a movie format. Students can then review the produced movies to learn the commands and mechanics of the software.
3. *Animations Explaining Course Concepts*: They used animations (made by the Flash software) to show the inner mechanics of difficult concepts. For example, they created animations showing the internal calculations of some Excel functions, the working of the various Crystal Ball toolbar buttons, and the mechanics of a queuing system.
4. *Group Web Sites*: They used community or group websites such as eircles.com and eproject.com to facilitate students' collaborative learning through virtual discussions, exchange of files, and mutual mentoring. However, these services might not be stable.
5. *Electronic Forums*: Electronic forums allow good students to help and teach others. They designed Internet forums to extend the learning beyond the classroom. They are

also excellent sources for obtaining frequently asked questions on the course website.

6. *Web-Based Feedback*: They used forms via the web to obtain instant feedback on each topic taught during the course. Obtaining immediate feedback allows instructors to adjust the course to address students' concerns. Web-based form service performs the administrative aspects of the process and so it takes less time.
7. *Virtual Office Hours*: They used virtual office hours to extend their availability to the students. During each virtual office hour, several question-and-answer sessions are run in which each student's concern is addressed individually while other students being present in the session. Seal and Przasnyski (2003) address some difficulties of virtual office hours. First, the students must be taught how to access and use the technology, which takes around one hour. Second, the technology used for virtual office hours presents some difficulties with connectivity, speed, and reliability. Furthermore, it does not support reviewing some files. Nevertheless, they believe that virtual office hour sessions are very useful for discussing ideas.
8. *Real-Time Collaborative Computing*: Collaborative computing is particularly recommended for OR courses, in which instructors create, manipulate, and demonstrate models. With this method, students can access and manipulate files on the instructor's computer and on each other's computers in real time. This service can be a powerful tool for remote teaching. However, security is a concern in collaborative computing.

These methods, proposed and used by Seal and Przasnyski (2003), can improve pedagogy for introductory OR courses, and help students to visualize difficult and abstract concepts. Integrating technology into a course curriculum when appropriate is proving to be valuable for enhancing and extending the learning experience for instructors and students. Indeed,

Smith (1997) argues that multimedia creates a favorable environment for active learning and supports interactive and independent learning. The structured nature of OR plays a key role in achieving success through integration of technology. For example, in OR courses, students typically must use various software packages, and thus screen-capture movies will be very valuable.

Seal and Przasnyski (2003) comment that among these methods, the course website, web-based feedback, virtual classrooms, and some collaborative learning methods, are easy to develop and implement, and provide immediate returns. However, others such as digital video instruction, animations, and real-time collaborative computing need more time but may provide better pedagogical benefits in the long run. The benefits from all of these efforts accumulate over time.

Overall, Seal and Przasnyski (2003) report positive results about their experiment with integrating technology. In formal feedback, students also mentioned the effectiveness of the virtual sessions as they learned from the questions of others. Moreover, when using virtual sessions, instructors do not have to answer the same question over and over again via email or traditional office hours. Moreover, remote tutors, guests, and other faculty members can join the sessions and share the office-hours load as long as they have access to the Internet.

## **5 Using Puzzles, Games, and Paradoxes**

Recent research supports the idea that students are happier and more motivated when they enjoy their studies. For example, Rogers and Williams (1993) use experiences of teachers and supervisors to suggest that fun enhances both learning and productivity.

Many students see OR courses as overly theoretical and boring. One way of making

OR courses more fun and fascinating is by using games as pedagogical tools to support complicated OR steps such as modeling (Depuy and Taylor (2007)).

The use of games and puzzles for educational purposes has been previously suggested in the literature. The majority of literature, related to teaching engineering modeling through games, comes from the field of computer science, e.g., see Jones (2000), Hill et al. (2003), Levitin and Papalaskari (2002). The use of simulation games to assist in teaching statistics and experimental design has also been documented (Schwarz (2003)).

Sniedovich (2002a) address several benefits of using games to teach OR, especially to teach problem formulation techniques, which is one of the most difficult OR topics for students. Sniedovich (2002a) briefly describes six games. Other puzzles and games addressed in the literature to reinforce the teaching of OR include the riddle of the pilgrims (Chlond (2002a)), towers of Hanoi (Sniedovich (2002b)), the traveling space telescope problem (Chlond (2002b)), egg drop (Sniedovich (2003b)), flip (Trick (2001)), fiveleapers a-leaping (Chlond et al. (2003)), nimatron (Chlond and Akyol (2003)), logical puzzles (Chlond and Toase (2003)), the counterfeit coin problem (Sniedovich (2003a)), and chesspiece placement puzzles (Chlond and Toase (2002), Letavec and Ruggiero (2002), and Foulds and Johnson (1984)). Depuy and Taylor (2007) consider four chessboard games whose mathematical formulations serves as an excellent introduction to linear or integer programming.

Sniedovich (2002a) argues that due to the important role of mathematics in OR, games, puzzles, and paradoxes, are valuable sources for developing educationally rich material for OR courses. This is so because the area of combinatorial optimization is at the heart of OR, and many problems in games can be formulated as combinatorial optimization problems (Sniedovich (2002a)). Games are excellent supplementary tools that encourage students to tackle highly structured problems creatively, using OR concepts, while working on interesting and enjoyable tasks (Depuy and Taylor (2007)). The goal of teaching the craft of OR

modeling cannot be achieved by merely teaching well-structured industrially relevant problems, because the basic configurations of many such problems have already been formulated and solved in many textbooks. Thus such problems are inappropriate for use in problem sets and projects. Furthermore, more complicated related problems are often too large to be formulated or solved using basic OR techniques taught in introductory undergraduate OR courses. In contrast, games provide a platform for teaching creativity and the art of modeling, because employing OR for them is fairly new. Most of these games can be tractably solved via mathematical programming and teach skills that are immediately transferable to realistic problem settings and other applications. Games — especially familiar games — are very useful in assisting students to visualize problems, breaking them down into manageable subsections, developing solution strategies, and seeking known and well-established goals. Simple board puzzles can help students learn creative formulation and solution techniques, and therefore, can enhance their understanding of the foundations of solution techniques in more realistic settings.

Games can be incorporated effectively into the teaching of most topics in undergraduate OR courses. Specifically, Sniedovich (2002a) suggests games to teach the following topics in an introductory OR course: (1) *Mathematical Modeling*: games can be used in a variety of ways to train students in the art of mathematical modeling. (2) *Simulation*: simulation techniques are important tools in the analysis of the behaviour of complex systems. (3) *Algorithms*: games can be employed to explain and test students' understanding of the working of OR algorithms. (4) *Heuristics*: games enable students to experiment with and test the performance of heuristics. In particular, they are useful in explaining why greedy heuristics sometimes yield optimal policies. (5) *Pattern Recognition and Analysis*: analyzing the behaviour of a simulation model of a game helps students to recognize patterns and constructively use them in the analysis of the game. (6) *OR Software*: games provide a rich

source for problems in which students can test and discover the capabilities and limitations of standard OR software packages.

Games can be used in lectures, assignments, tutorials, lab sessions, projects, quizzes and exams (Sniedovich (2002a)). They are particularly suitable for self-study and supplementary readings.

Below, we describe two of the games recommended and used by Depuy and Taylor (2007) to teach modeling integer programming.

1. *The Cracker Barrel peg Problem*: This game involves jumping pegs over other pegs into empty holes on a board containing holes. The jumped peg is then removed from the board. The objective is to be left as the only remaining peg at the end of the game.
2. *Peg Solitaire Problem*: In this game, pegs are arranged in an initial configuration on a holed board. Then a series of peg moves are made, where the jumped peg is removed, in order to arrive at a desired final board configuration. The variations of peg solitaire come from the shape of the board, the initial peg configuration, and the final peg configuration.

These puzzles can be assigned as a two or three-week group project to junior undergraduate students. In the project assignment of each case, Depuy and Taylor (2007) briefly described the problem, directed the students to the interactive Internet site, and included a hint on the definition of decision variables. Students were required to hand in a written report showing both their formulation and solutions for the assigned initial scenarios. This assignment can be served as a good introduction to large-scale optimization problems and can fuel discussions of both the size of, and solution techniques for the formulations

of real-world problems. Moreover, since these puzzles require students to link the values of decision variables from one time period (i.e., move) to the next, they can be used as a good introduction to a variety of other classic problems with similar timing traits in areas such as inventory control and scheduling.

After engaging in such projects, the vast majority of students responded positively and favorably to the puzzles. Students found the projects useful to improve both their formulation skills and knowledge of the solution software.

## 6 Inviting Guest Speakers

Inviting a guest speaker or a panel of speakers from the field into the classroom is an opportunity for students to connect course content to the practices that occur in the real world (Tice et al. (2005)). Giving students an opportunity to meet and interact with a person possessing special expertise creates a classroom experience. Hearing how OR techniques have allowed companies to compete effectively with other companies or achieve other successes can highly motivate students and may be worth more than many hours of lectures on the details of OR algorithms. Guest speakers can increase student involvement by adding interest, bringing in new perspectives, experiences, and communication styles, and providing expertise in specific content areas. Professionals can share their early and current career experiences with the students.

Due to the nature of OR and its wide applicability in real world, inviting guest speakers to the classroom seems both effective and possible. It is indeed highly recommended by Phillips (2003) for teaching revenue optimization. Phillips (2003) suggests two guest speakers from different industries per course.

The instructor should, however, be careful in selecting guest speakers and should explain to students the rationale for having a guest speaker. After the guest speaker leaves, the instructor should debrief the students to put the visit into a framework consistent with the goals and visions for that class session.

Virtual guest speakers (Hemphill and Hemphill (2007)) to facilitate asynchronous discussions is another way to enhance students' critical thinking skills. By this means, students can question an expert at specified points of an activity, or read a guest facilitator's articles and ask questions and participate in a discussion with the guest.

A variation on the guest speaker is to assign students research on a topic related to the course, interview experts in that field, or gain actual experience with the subject matter if possible, and present the results in class. Such experimental learning lets students customize their assignment to gain exposure in a field they are considering.

According to student feedback, professionals in the classroom provide a very effective and enjoyable real-life learning experience for students.

## **7 Teaching Strategies and Non-Mathematics Majors**

Whether or not the teaching strategies discussed in the previous sections should be incorporated in an OR course, and how optimally these strategies should be combined, depend on the teaching goals of the host department and the students' objectives. It may vary significantly depending on the background of the students, their expectations of the course and the topic under consideration. For example, Sniedovich (2002a) argues that if the stated goal of the course is to teach students how to deal with practical OR problems then surely the OR content of the concrete examples in lectures should not be entirely replaced by games and

puzzles. Sniedovich (2002a) recommends larger dosages of mathematical games and puzzles for engineering students and those with a solid mathematical background. However, games and puzzles should be used in moderation and be integrated in a suitable manner with other ingredients of the OR courses; excessive use of games may dilute the perceived OR content of the exposition below a critical level.

Some views on the objectives of an OR course for business students is presented by Ólafsson (1998). Ólafsson (1998) believes that an OR course should enable business students to use models as a tool in making better decisions, and to tackle problems in a systematic way. So he considers three goals for teaching OR to business students: (1) to give students an overview of the potential of OR. (2) to increase students' ability to make and use mathematical models for decision making. (3) to give students a good understanding of the OR process.

To align the course content with these goals, Ólafsson (1998) omits the teaching of the dual linear programming problem or solution methods such as Simplex method from OR courses for business students. Instead, he replaces them with the use of software and spreadsheet models. He argues that business students always have access to computers that are able to solve mathematical models, and it is more important for them to learn how to use these tools. Therefore, screen-capture movies for software demonstrations are very beneficial for business students. Bringing guest speakers and professionals into the classroom, virtual guest speakers, and including relevant business examples, that students might experience right after they reach the professional world, can provide students with an appropriate overview of the potential of OR. Some projects involving games and puzzles can teach business students about mathematical modeling and the OR process.

Corner and Corner (2003) particularly recommend active learning and discussions appropriate for the teaching of OR to MBA, Management Sciences, and executive students.

Discussions and cooperative active learning help students develop managerial skills, including strategic thinking, communication, conflict resolution, logic, and visualization of links between technical solutions and competitive advantage. Cooperative active learning can simulate team decision making, which is prevalent in organizations, and thus builds important managerial skills of oral communication, listening, influencing, and conflict resolution. Moreover, during discussions experienced students are likely to identify links between OR techniques and problems that arise in other areas in management sciences. Using appropriate examples by the instructor during lectures can also help students develop managerial insight into OR problems that arise in their future career.

## 8 Concluding Remarks

Efficiency of a strategy in teaching an OR course depends on the course goals and students' objectives. To ensure adopted teaching strategies are efficiently aligned by the course goals, instructors should incorporate different teaching techniques in addition to lecturing. Based on the existing literature, in this paper we addressed five teaching strategies and discussed their applicability in some of the non-Mathematics major programs such as engineering, business, and management sciences.

During my research, I realized that case studies on the alignment of strategies in teaching OR courses and students' major are scarce and relatively old. It would be interesting to conduct such case studies to realize the degree to which this teaching strategy alignment is practiced in universities today.

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