SPECIAL INNOVATIVE EDUCATION ISSUE

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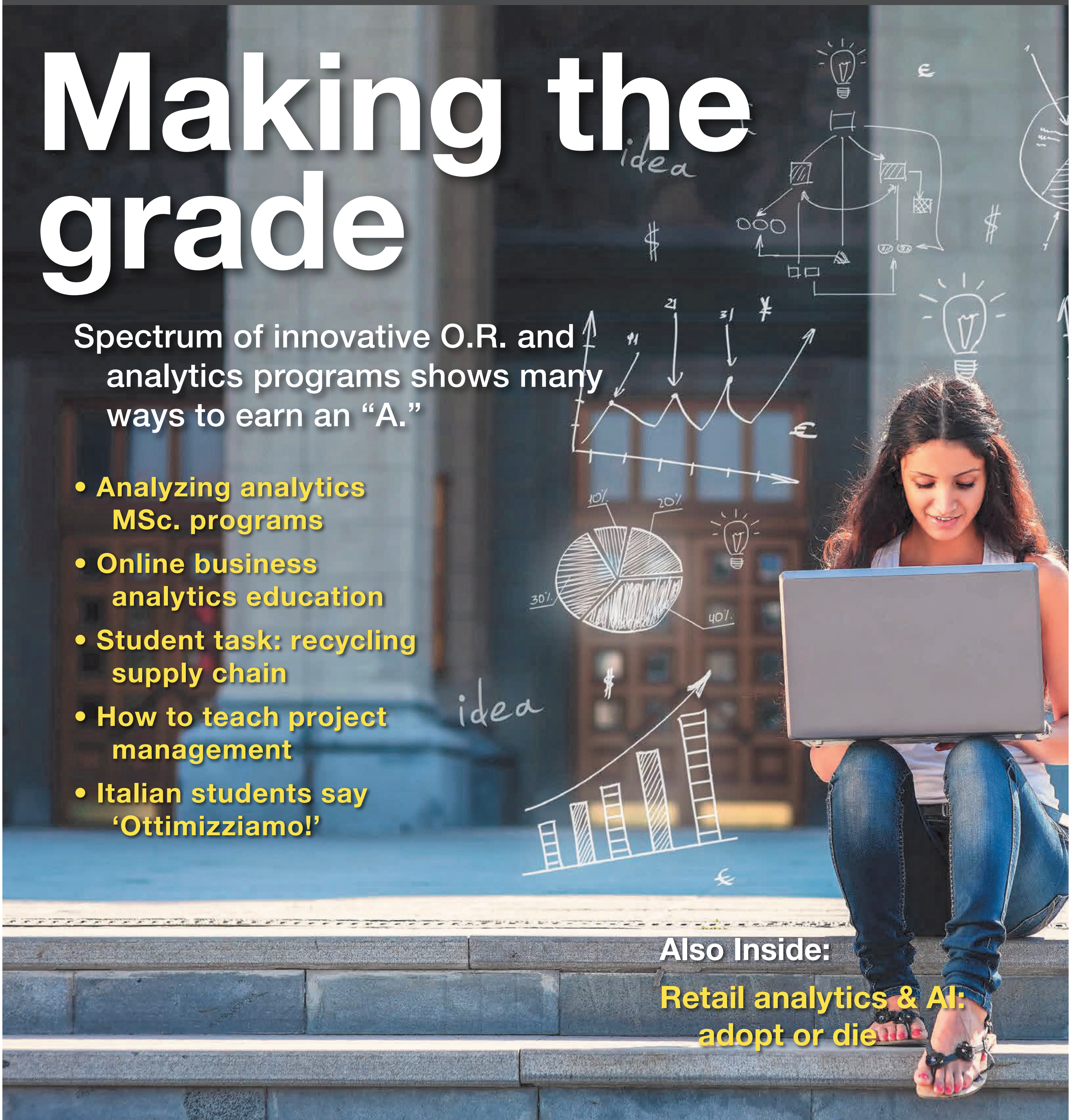
Making the grade

Spectrum of innovative O.R. and analytics programs shows many ways to earn an "A."

- Analyzing analytics MSc. programs
- Online business analytics education
- Student task: recycling supply chain
- How to teach project management
- Italian students say 'Ottimizziamo!'



Also Inside:

Retail analytics & AI: adopt or die

ORMS TODAY

Ready, set, ottimizziamo!

Welcome to the annual special issue on "Innovative Education," a longtime series in *OR/MS Today* that has, from the beginning, sought to highlight some of the innovative professors, programs and courses that are shaping the way operations research and analytics are taught in schools around the world.

OR/MS Today readers might recognize, and many will know, the author of this year's opening innovative education article, Peter Bell. Bell is a professor at the Ivey School of Business at Western University in Ontario, Canada, and a recipient of the INFORMS Prize for the Teaching of OR/MS Practice. Bell, who has contributed many articles to similar annual special issues over the years, leads off this year's Innovative Education lineup by "Analyzing master's analytics programs" (page 24).

"The future looks very bright for analytics, but not all of the new analytics master's programs will survive," Bell writes. "Those that are innovative and designed to address the needs of a specific target market niche will be successful in meeting targeted enrollments without breaking the bank trying to recruit students."

Next up is Penn State Professor Terry Harrison, who teaches an online analytics course called "Prescriptive Analytics for Business Decisions" (page 28). A former president of INFORMS, Harrison makes a strong case that a first-class education from a leading university doesn't have to take place in a classroom. Instead, it can take place anytime, anywhere in the world. Along with background on the current state of distance learning and useful insight on how to launch and maintain a successful online analytics course, Harrison shares his longtime experience teaching such a course. "Quality is the only lasting differentiator in the distance education market," he says.

Switching gears, professors Alberto Ceselli and Giovanni Righini – O.R. professors with the Department of Computer Science at the University of Milan – describe a creative program they developed to introduce operations research to high school students in a country, Italy, where O.R. is rarely mentioned, let alone taught. The name of the program says it all: "Ottimizziamo!" which translated means, "Let's optimize!" Sounds like fun for everyone, and it is as you'll find out starting on page 32.

INFORMS President Nick Hall, a business professor at The Ohio State University, follows with one of his favorite subjects: "Teaching project management" (page 36). Hall walks readers through the why, what and how of teaching the course, including the many advantages, challenges and rewards. He starts off with some eye-popping numbers for anyone contemplating entering the profession, including this nugget: A decade ago, the annual value of economic activity managed as projects was $12 trillion, or approximately one-fifth of the economic activity of the world. Image how much it's grown since then. Hall also notes that project management is an important yet overlooked profession that is in the midst of filling an estimated 15.7 million jobs over a four-year period from 2016 to 2020.

This year's innovative education lineup concludes with the inspiring story of a grad student project at the University of Michigan's Tauber Institute that tackled a major global problem: what to do about the enormous amount of floating ocean plastic that is expanding at a rapid pace and threatening wildlife around the world (page 42). The students, Dan Partin and Allison Ward, teamed up with Dell Technologies to develop a unique supply chain system to collect and recycle ocean plastic.

Ciao for now and ottimizziamo!
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"Ottimizziamo!" ("Let's optimize!")

Creative program introduces operations research to high school students in Italy, a country where O.R. is rarely mentioned, let alone taught.

By Alberto Ceselli and Giovanni Righini

Operations research is not taught (or even mentioned) in Italian high schools, including those devoted to scientific education. Even worse, operations research (O.R.) is rarely taught or mentioned in Italian universities, where students can obtain a Ph.D. in any STEM discipline such as mathematics, engineering or computer science without having attended a single O.R. course.

STEM education has been recognized as a critical weak point in the Italian educational system since 2004, when the government took a special initiative called "Progetto Lauree Scientifiche (PLS)" ("Scientific degrees project"), offering incentives to students who enroll in STEM curricula. We took advantage of this opportunity to start offering seminars about O.R. to high school students and teachers. In particular, we organized one- and two-day stages on our university campus and we called them "Ottimizziamo!" ("Let's optimize!").

Recently, another education emergency arose on the Italian government agenda: the mismatch between education provided by the school system and demand for skills and competencies in the Italian economy. Two years ago, government reacted with another initiative, called "Alternanza Scuola-Lavoro (ASL)," which now compels all high school students to spend a prescribed yearly number of hours in companies and other institutions rather than at school. While many high schools were struggling with the question, "What should we do to accomplish this unexpected task?" we promptly offered them an answer: "Ottimizziamo!" The reaction from the schools in our region, Lombardy, has been astonishing:

In the school year 2016-17 we hosted 1,011 students in groups of about 50. On one hand this required a tremendous extra effort on our part, but on the other hand it gave us a very effective way to raise the awareness about O.R, not only in students but above all, in teachers.

Ottimizziamo! takes places in a computer lab, where each student (and each teacher) works on a PC.

Image © Thinkstock

The Activity

Ottimizziamo! takes places in a computer lab, where each student (and each accompanying teacher) works on a PC. The current format and content of Ottimizziamo! are the result of a sort of iterative improvement algorithm, since we continuously elaborated on the experience we were accumulating during almost 17 years. In a typical day, we alternate slides with exercises in four parts.

In Part 1, after proposing a definition of O.R. as the math discipline that studies how to solve complex problems with models and algorithms, we insist on the main difference with the typical scholastic approach to math education: From an O.R. perspective, math is not about how to do computations, but rather about how *not* to do them. Translating problems into math language allows us to define models and then leave the computational task to computers, empowered with suitable algorithms. This radical change of perspective always visibly hits our audience. Then we declare eight "steps" and we promise to put them in practice before lunch. The steps are eight reasons why math models are so important: (1) to really understand a problem with no ambiguity; (2) to communicate the problem to anyone else (including your computer); (3) to classify a problem; (4) to understand its complexity; (5) to choose the most appropriate solution method; (6) to possibly use existing software; (7) to identify subproblems, in case the development of a specialized algorithm is needed; and (8) last but not least, to keep the definition of the problem separate from the definition of the method.

As a first example of an optimization problem we use a linear programming (LP) instance taken from Denardo's book [1], an optimal production mix problem. First, we define its model in terms of data, variables, constraints and objective function on the blackboard. This takes a while because it is the first math programming model the students (and the teachers) develop in their life. We underline that we are translating a problem description from natural language into another language: mathematics. This new language is formal and universal, allowing us to eliminate ambiguities (Step 1) and communicate the problem to everyone else (Step 2).

Then we proceed to classification (Step 3) and the name "linear programming" is explained; complexity is briefly mentioned (Step 4) along with the simplex algorithm (Step 5). The climax is reached when everything has been put into a spreadsheet, and the students are asked to solve the problem without any further knowledge of O.R., just relying on the math education they have received so far. They quickly realize that, in spite of having been studying math for 15 years or so, they have no chance other than to proceed by trial and error. Typically, for some minutes a challenge takes place in which students (and teachers) compete at improving the solutions, using their spreadsheets as in a game, However, after some iterations they are all stuck with a solution that nobody is able to improve.

At this point, we arrive at the four "big questions" about the method:

1. How did you proceed? "By trial and error."
2. What did you do for each trial? "Computations."
3. Are you sure you have the optimal solution? "No."
4. Was this fast or time consuming? "Definitely time consuming."

Then we reveal the existence of the Solver add-in (Step 6), and we show them how to input all elements of the math model from the blackboard directly to the Solver mask in one-to-one correspondence. Clicking on the "Solve" button shows that

> We are **translating a problem** description from **natural language** into another language: **mathematics.**

> **Teachers clearly perceive** that their **students are discovering** an **unexpectedly fascinating face** of **mathematics,** and they **simply cannot ignore it.**

the optimal solution is different from the manually computed one and counterintuitive. At this point the four "big questions" come back again:

1. How did you proceed? "With no trials and no errors."
2. Did you do any computation? "No, we described a model."
3. Are you sure you have the optimal solution? "Yes! Now there is a theorem that guarantees optimality."
4. Was it fast or time consuming? "It was instantaneous!"

So, the triumphal conclusion is: "This is the difference between solving a problem with and without O.R.!" A 20-minute break follows, allowing the teachers to express their enthusiasm while we drink a coffee together. They clearly perceive that their students are discovering an unexpectedly fascinating face of mathematics, and they simply cannot ignore it.

In Part 2, the slides illustrate the difference between information technology and computer science and the strong relationship of O.R. with the latter. In spite of the widespread emphasis on "big data," often cited as a (magic?) technique, we insist that data have a value only if we are able to transform them into good decisions, which is no different than oil having a value only because someone discovered how to transform it into mechanical energy. This kind of transformation is the role of O.R. Value can be created at different levels: data, information, knowledge, decisions. But the more we go toward the top of this pyramid, the larger is the impact of science in value creation.

Citing Martin Groetschel's famous production planning example, we show how the progress in algorithm design has been orders of magnitude more important than the progress in hardware computing power. Computer science beats information technology despite the former being hidden in the labs, while the latter is omnipresent in marketing communication. At this point, we propose another LP exercise, in which the task is to decide how much money to bet on each of four horses, knowing their quotations, to maximize the gain in the worst case, given a budget (we are indebted to Professor Colorni for this exercise [2]).

The model is very simple, and the topic is intriguing. Students are typically quite happy to observe that the second model is produced in only a fraction of the time needed by the first one. But here the objective function is "max-min," and linearization is not obvious at all. That's why a teacher is needed! From this example, they learn that models can be expressed in several different ways, with different characteristics, and that one can work on models to improve them. These are totally new concepts with respect to traditional school education, where models are given *a priori* and immutable.

Another interesting point in this exercise concerns its classification as discrete or continuous. Decision variables represent amounts of money: Are they continuous or discrete? Can you bet 20/3 euro on a horse? This triggers some further questions: What are continuous variables in our models? What kind of numbers can be represented in a computer? What is the consequence of restricting the domain to integer multiples of one cent? What is the criterion to decide whether an approximation is tolerable? After some guided discussion, the conclusion we propose is the following: As a mathematician I say, "This problem is discrete." As an engineer I add "…but I can solve it as if it were continuous, because the resulting approximation is by far acceptable." As an operations researcher I further add "…and among these two alternatives I prefer to solve it as a continuous problem, because I have a very good algorithm for this."

Before starting the Solver, the students are invited to think about the expected structure of the optimal solution. The smartest ones sometimes grasp that all possible gains must be equal at optimality, although they cannot formally prove it. The point is that a very easy exchange procedure exists to improve any solution in which there are two or more gains with different value; therefore, it is immediate to prove that all gains must be equal at optimality. This is happily and immediately confirmed by the Solver. The instance is conceived so that the optimal value is larger than the budget, so a small gain is guaranteed! But it is easy to verify that the optimal value is smaller than the budget if different quotations are used – just run the Solver again. (How nice to work this way! The model is the same although data are different. In a typical school exercise, one would have been forced to re-do all computations from scratch.)

The students are then asked: Who will use this model first? Not the bettor, but the bookmaker. He will check that the quotations do not allow (O.R. skilled) bettors to enjoy a guaranteed gain. What is data for the bettor is a decision variable for the bookmaker. This introduces bi-level programming and observations on how many variations exist in the optimization world: problems with several objectives (multicriteria optimization), no objectives (constraint programming), several decision-makers (game theory), uncertain data (stochastic and robust optimization) and so on.

After these two exercises have been solved we can make a very important observation: Two completely different problems have been solved with the same method. This is counterintuitive, and it would not have been possible without their formulation in mathematical terms and without a proper classification of both of them as "LP models." This is the practical demonstration of Step 8, the last step. Time for lunch.

In the afternoon, Part 3 starts with some slides on the origins of O.R., where founding fathers such as Patrick Blackett and George Dantzig are brought to the attention of our students, who are already familiar with mathematicians like Alan Turing and John Nash, owing to the movies about their lives. At this point I always silently regret there is no movie about any O.R. fellow. (By the way, we have a suggestion: Professor Egon Balas' autobiography, "Will to freedom," would be perfect for a movie). The third exercise is a binary knapsack problem, which allows us to introduce binary variables and their use.

In Part 4, all the slides are devoted to illustrating the future of the O.R. profession. We introduce concepts such as "service-based" and "knowledge-based" economy, and we briefly show how global and long-term drivers like markets globalization, European integration, environmental concerns and energy cost are asking for optimization everywhere, and making problem modeling and solving skills more and more important. We also proudly show the recent "Best Jobs 2017" analysis, where the "operations research analyst" profession ranks third. This is like placing the students on a rocket and pushing the "Go" button.

The school teachers also receive better awareness of the growing importance of their role in education, provided they are able to play it well. This experience urges them to dismiss some old-fashioned, computing-oriented self-referential habits in math teaching and communicates to them that the future professional success of many of their students is likely to be strongly correlated with the kind of math education they are receiving at school.

The fourth and final exercise is a nonlinear programming one. One of our favorite examples is the Fermat-Weber problem: Find the point that minimizes the sum of the distances from three given points in the plane. The problem is formulated differently: There is a garden with three entrance points, and the gardener has been instructed to connect them with gravel paths of given width, using the minimum amount of gravel. In this way, the structure of the solution is not given *a priori,* but it must spring out of some geometrical reasoning on the problem.

By the way, the exercise is also suitable to remark that all notable points of triangles (that the students have studied years before without suspecting anything about optimization) are indeed optimal solutions of optimization problems. So, here are the inverse questions: given a triangle, what is minimized by the barycenter, the circumcenter, the incenter …? This suggests to the students and their teachers that every math concept they may have learned and taught in the past can (should) be revisited from the viewpoint of O.R. and optimization.

The Feedback

At the end of the day, we ask students and teachers to complete an online form about their experience. Owing to the large number of students attending Ottimizziamo!, in 2016-17 this feedback was especially significant. The 366 answers we collected from students (all in the third or fourth year) show that they appreciate working on realistic problems, learning a new software tool and approaching math in a different way. We also received 17 answers from math, physics and computer science teachers. All of them appreciated the educational value of a model-oriented approach coupled with realistic exercises and the use of computer lab and software.

On the negative side, they pointed out the difficulty of integrating this approach in the traditional school curriculum, where time is very scarce and some students have gaps in basic math concepts such as fractions, square roots and the like. For this reason, in the school year 2017-18, while keeping Ottimizziamo! active (on a bit smaller scale), we engaged ourselves in courses for teachers. The main purpose is not to insert additional math content under the "O.R." label, but rather to revisit the current math curriculum from an O.R. viewpoint. A lot of school time traditionally spent in computations can be saved and better spent in reasoning about models, and developing critical spirit and problem-solving attitudes in high school students. ORMS

Student feedback shows they **appreciate working** on **realistic problems,** learning a **new software tool** and **approaching math** in a **different way.**

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