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Project MINDSET: High School Mathematics and Operations Research

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Abstract Can you imagine a more exciting high school math course than one driven by operations research and industrial engineering principles and applications? Project MINDSET (Mathematics Instruction using Decision Science and Engineering Tools) is a $3 million National Science Foundation-funded project designed to develop, implement, and evaluate a two-semester course for high school seniors based on the mathematics of operations research and industrial engineering. In this tutorial, we will discuss two forces driving efforts to raise mathematics proficiency at the high school level: (1) minimum state standards for a high school diploma and (2) state university admission standards or expectations to be competitive. We will describe how the course we are developing is ideally designed to meet this growing need as well as address widely recognized U.S. deficiencies in mathematics education.

The primary goal of this tutorial is to motivate you to take on the challenge of bringing Project MINDSET to your local school district or possibly statewide. We will provide you with the skills and support services that will enable you to make it happen. The two major elements of the tutorial will be (a) Project MINDSET course content and how it is aligned with trends in high school mathematics education and (b) strategies for building a social network of influence to deliver a Project MINDSET course into local high schools.

Keywords operations research; industrial engineering; education; K-12 education

Introduction—Project MINDSET

Can you imagine a more exciting high school math course than one driven by operations research (OR) and industrial engineering (IE) principles and applications? Project MINDSET (Mathematics Instruction using Decision Science and Engineering Tools) is a $3 million National Science Foundation-funded project designed to develop, implement, and evaluate a two-semester course for high school seniors based on the mathematics of operations research and industrial engineering. The three partner universities are North Carolina State University (NCSU) (Robert Young and Karen Keene), Wayne State University (Kenneth Chelst and Thomas Edwards), and the University of North Carolina at Charlotte (David Royster). It will be implemented in high schools in North Carolina and Michigan within the next four years. The first-semester textbook, which focuses on deterministic modeling, is already in draft form and being tested. The second-semester textbook, which focuses on probabilistic modeling, will be ready for testing in fall 2009.

In thinking about this course it is important to emphasize that the goal is to develop and enhance mathematics skills by using OR/IE concepts and examples. This point must be kept foremost, especially when speaking to local school district leaders. Despite this disclaimer, widespread adoption of this course will dramatically increase the public's awareness and knowledge of OR and IE. How far and fast this course spreads to high schools in other states is up to you, the reader. Imagine what it would mean for our profession if 10% of 2.7 million students who graduate high school each year or 10% of the subset of 1.8 million students entering college had taken an OR/IE-based mathematics course.

In this tutorial, we describe the project, the course, and the philosophy of implementation. We lay out a multifaceted strategy to bring the mathematics of operations research to your local area or statewide high schools. Finally, we challenge and guide you as to how to get started in your locale and spread statewide.

Trend, Opportunity, and Need

Two forces drive efforts to raise mathematics proficiency at the high school level: (1) minimum state standards for a high school diploma and (2) state university admission standards or expectations to be competitive. There is a growing trend both at the state level and university admissions level to require, or at least expect, four years of high school mathematics. The state of Michigan, for example, along with more than a dozen other states, is slowly phasing in a four-year math requirement for all students that will dramatically increase the need for a fourth-year course that appeals to a broad segment of the population.

The university expectation reflects the concern that a large number of students need a remedial mathematics course before placing into a college algebra course, typically the first college-credited mathematics course. North Carolina already requires a fourth year of mathematics with an Algebra II prerequisite for admission into any University of North Carolina system school. Other states' university systems provide incentives and strong guidance for students to take a fourth-year advanced mathematics course.

Broad flexibility exists at the school-district and state levels as to the specifics of the fourth-year course, but one of the critical concerns is the relevance and appeal of this course to students who in the past have not opted for a fourth year of mathematics. Driving our effort to achieve relevance is more than simply an answer to when "in the distant future" the student might need these skills. Rather, we will develop an interesting and innovative contextual placement for mathematical concepts that high school students can relate to now. These include examples such as standing in line, scheduling part-time jobs, forming project teams, developing a portfolio of college applications, buying a used car, or the selecting the size of the deductible on collision insurance.

As we develop a mathematically based decision-making high school course that builds upon the mathematics and models of *industrial engineering* and *operations research*, our *primary objectives* are as follows:

1. Develop a new one-year high school curriculum and textbook in mathematics using mathematically based decision-making tools to teach standard content.

2. Through a multistate, multischool-district assessment, show statistically significant improvement in students' mathematical ability, particularly in multistep problem solving and interpretation of results, and improvement in motivation and in attitude toward mathematics.

3. Develop an infrastructure to effectively train and support teachers who will teach the curriculum.

4. Demonstrate that this infrastructure is sustainable and sufficiently flexible that it can be successfully reproduced and utilized by others.

Our course will address the well-documented national deficiency in mathematics education that leaves U.S. students performing relatively poorly on multistep problems and in interpreting results. For example, on the 1996 and 2000 National Assessment of Educational Progress (NAEP), only 24% of American 12th-grade students were able to correctly solve a multistep problem involving multiple operations (Kehle et al. [2]). On the 2003 Programme for International Student Assessment, U.S. student performance was ranked 29th out of 45 developed countries (Organisation for Economic Co-operation and Development (OECD) [5]).

Although there is abundant information concerning the performance of American 12th-grade students in the area of problem solving, information regarding their ability to interpret the results of their computations in a problem-solving context is more scarce. However, there is the notable example from the third NAEP mathematics test (Carpenter et al. [1]):

> An army bus holds 36 soldiers. If 1,128 soldiers are being bussed to their training site, how many buses are needed?

Twenty-three percent of the students who worked this problem gave the correct response, whereas 29% responded "31 remainder 12." Clearly, interpretation of results was a problem for this item.

Multistep problem solving and interpretation of results are the *heart and soul* of operations research techniques, and the development of these key skills will be built into our operations research real-world problem contexts. We would expect that students completing an entire module on integer programming with Project MINDSET would be more likely to answer the army bus problem correctly. This hypothesis will be tested in our formal evaluation. Moreover, improvement in these two areas is likely to also improve students' motivation to study and achieve in mathematics, as well as improve their attitudes toward mathematics. Student motivation, attitudes, interest, and level of engagement are critical constructs related to learning (Singh et al. [6]).

Course Competition

In the United States, over 2.7 million students graduate from high school each year, with an estimated 1.8 million entering some form of college within 12 months of graduation. Many students planning science, technology, engineering, or mathematics (STEM) majors in college essentially feel pressured to take a calculus course in their senior year of high school to demonstrate their potential for college-level work. More than 200,000 students each year take the first AP exam for calculus. Universities view high performance in this one-year course as the equivalent of one semester of calculus. Less than 100,000 students take the second AP calculus exam, equivalent to the second semester of college calculus. The AP statistics exam most recently attracted more than 100,000 test takers.

Although a score of 3 on these exams is considered acceptable, many universities expect students to score a 4 or 5 to earn college credit or place out of a course. Typically, between 33% and 40% of the students achieve this level in STEM-type AP courses with another 20%–25% scoring a 3. Thus, significantly less than 10% of the college bound students take and perform well on these courses, and that number is less than 5% of all graduating high school seniors.

Mathematically capable students who are uninterested in calculus have few exciting options. They can take the above-noted AP statistics course or a college algebra course that revisits much of what they have already learned but at a more mathematically sophisticated level. One relatively new alternative is called Discrete Mathematics. Unfortunately, this course does not have a unifying theme as it mixes graph theory, routing algorithms, discrete probability distributions, and a hodgepodge of other topics. Students who have not mastered many of the algebraic concepts of Algebra II really have almost no option other than to retake a similar course to improve their skills. In none of the above courses can students see a clear connection between what they are learning and what they might use in their subsequent jobs and careers. The only answer often provided, at least for STEM career-oriented students, is that these mathematics topics are prerequisite knowledge for core courses in their college career.

Timeline

The project timeline is aggressive because we have adopted a philosophy of rapid prototyping coupled with continuous feedback and improvement. We have completed a 10-chapter draft of the first semester's textbook. In addition, a group of 37 teachers in North Carolina and Michigan have taken the equivalent of a three-credit graduate course in teaching a deterministic operations research course. Two-thirds of the course will focus on the course material and one-third will address pedagogical issues in delivering the course content. We will also have a website designed for teacher support and will train staff available to answer teacher questions as they prepare and deliver the material. We might even have some initial feedback. The full timeline is listed below.

- 2007–08
  - Write one semester text in deterministic modeling
- Summer 2008
  - Develop supporting teaching material and website
  - Train 30+ teachers from high schools in North Carolina and Michigan including the Detroit public schools
- 2008–09
  - Provide support for teachers using first-semester modules
  - Continually improve teacher support strategy and website
  - Write one semester text in probabilistic modeling
  - Develop supporting teaching material
  - Begin to recruit school districts to be part of the formal evaluation experiment
- Summer 2009
  - Train same group of teachers in the probabilistic modeling material
  - Rewrite deterministic text based on feedback
  - Expand program to states with local funding support
- 2009–10
  - 30+ teachers continue to use revised deterministic material
  - 30+ teachers test out the probabilistic modules
  - Finalize school districts that will be part of final evaluations
- Summer 2010
  - 30 more teachers receive training in course material and pedagogy
- 2010–11
  - 50+ teachers use the full year's material
- Summer 2011
  - 30 more teachers receive training in course material and pedagogy

- 2011–12
  - 50+ teachers with 1,500 students use the full year's material as part of the formal evaluation of learning and attitude
  - Carry out formal evaluation of the impact on learning and attitude toward mathematics.
  - Finalize textbook and publication with established publisher

Key to Success—Active and Timely Teacher Support

The key to the success of the project will be the teachers who implement the curriculum. At every stage of the project, the view and needs of teachers will be integral to the process. Project team members Tom Edwards and Karen Keene are professors of math education who each have more than 20 years of high school mathematics teaching experience. They will lead the effort of translating the OR- and IE-framed problems into text material for the classroom. They are supported by a group of high school math teacher-writers who work to finalize the text to be given to students and are part of the classroom user group. The text material will be presented to the teachers over a two-week period in the summer. In addition to working with the text, we will explore different pedagogical strategies for teaching multistep problem solving in general and OR analysis in particular. After completing this course, teachers will be provided continuous support as they bring modules into their classrooms.

To support teachers in the classroom, we will develop a Web-based teacher support community of graduate and advanced undergraduate students in engineering and in math education who will be available daily, including evenings and weekends, either online or by telephone. A practicing teacher will thus have immediate access to help and assistance. Their classrooms will receive onsite assistance through a *traveling help team*. The traveling help team is a "rapid response" group with education and technical expertise that will go to classrooms to work with teachers and students.

Web-based teacher support will be structured around a resource website for teachers where they will go to get course material and additional material and to find answers to questions. The additional material will include sets of slides for use in lectures, problems worked in detail, activities, teacher notes on the problems and activities, homework problems and solutions, quizzes and exams, teacher names and contact information indexed against material and modules they have used in class, discussion groups organized around modules and tools, frequently asked question (FAQ) repositories, messaging boards, and a mechanism to collect feedback through form-based surveys. Access will be public for some parts of the site and restricted for other parts. The site will shift and change as the project progresses and as new needs are identified and addressed. As such, it will not only be a resource to support teachers but will also track Project MINDSET's progress. The website address is http://www.mindsetproject.org.

The website will be hosted by NCSU's College of Engineering's Information Technology and Engineering Computer Systems (ITECS) group. The ITECS group has Web expertise and an extensive Web support infrastructure. This skill set includes expertise in building Americans for Disability-compliant websites, Web security, incorporating document-management support for Web content, and building Web-embedded form-based surveys.

We will establish a *teacher helpline* similar to the helplines available for computer technical support. Teachers will either telephone or e-mail questions or requests for assistance. These will be logged into the NCSU Information Technology and Engineering Computer Services' REMEDY System. Responses will also be placed into the REMEDY system as well as forwarded to the teacher. REMEDY is a commercial software system used by NCSU to track questions and responses to computer system problems. NCSU will make REMEDY available to the project. It is accessible from anywhere via the Internet, and project members at all universities will use it to log their help requests. In this way, we will have a mechanism to simultaneously track teacher support activities at Wayne State University, North Carolina State University, and at the University of North Carolina at Charlotte.

Using the REMEDY system, we will catalogue questions and responses, archiving them into a searchable FAQ system. When a question is entered into the system, a project member will be assigned to it. The project member will first search the FAQ system before responding to ensure consistency in our responses to teachers. If the project member cannot answer the question, it is passed along to one of the project principle investigators (PIs). The PI's response is also logged into REMEDY. As the project progresses, the FAQ system will contain a rich array of questions and answers that will provide quick and consistent responses to teachers.

REMEDY's information management system will identify what modules and techniques have the most questions, who is making the requests, how long it takes for the project to respond to a request and the efficacy of the response (e.g., are their many call-backs on the same topic by the same teacher). It will also help us determine if the requests taper off as teachers gain experience and as teacher experts begin to play an increasing role in the project. This will provide the project with a powerful tool for identifying problems with material and to identify teachers who may need additional support.

First-Semester Course Design—Deterministic Methods

The first-semester course of Project MINDSET explores deterministic methods and topics that would appear in a first semester undergraduate operations research course. It will have a prerequisite of Algebra II and basic exposure to Excel. The second-semester course will explore variability and uncertainty in the context of planning, managing, and decision making. Its main goal will be to develop an appreciation for variability and uncertainty. As a result, it will diverge from many classic introductory stochastic courses that tend to focus on classes of models rather than the underlying randomness. There is no specific prerequisite other than the expectation that students have been introduced to basic tools for displaying data such as histograms. The two courses will be linked. The second course will revisit some first-semester problem contexts to explore what happens to the model, and subsequent analysis when randomness is a greater factor than was assumed in the first semester.

The proposed two-semester coursework has major advantages over all of the existing options for high school graduating seniors, whether college bound or not, with a STEM or non-STEM focus. The competitive advantages of the first course, many of which apply to the second course as well, are listed below.

- Broad range of relevant contexts
- Expand algebraic modeling skills to a more complex environment
- New algebraic modeling skills
- Role of mathematical assumptions
- Link data, modeling, and uncertainty—potential impact
- Multistep problem solving
- Interpretation of results
- Math models as an exploratory tool—sensitivity analysis, what if
- Computers and Excel spreadsheets
- Multicriteria—no right answer

What is in a course name? One issue for which we do not as yet have an answer is what to name the high school course. At present, we are thinking of a dual-track strategy: one name to be used to sell students and teachers and another name to appear on high school transcripts. The high school transcript must have the word mathematics and should not hint at it being business mathematics. The word business with mathematics is too often associated with a less-demanding mathematics course. Schools can simply use the name mathematics of operations research. Student applications to selective universities should include a brief explanation of the mathematical power of the course. However, this image is not likely to be a selling point to students. For them, problem context and relevance are the key. One name we have toyed with is Mathematics for the Service Economy of the 21st Century. We are open to suggestions and look forward to feedback from teachers, students, and our peers from around the country.

Interesting and Relevant Contexts

First and foremost, both courses will offer a broad range of easily recognizable problem contexts that will backed up by a plethora of *Interfaces*-reported case study summaries. In every section of teaching a model or methodology, the text will begin with a realistic context for students to explore. All of the examples will be selected because they are immediately relevant to student life or demonstrate the inherent usefulness of mathematics. We think many achieve both goals. As a result, teachers will not have to face the dreaded question, "When will I ever need to know and use this?" The exploratory problem will be followed by a larger problem that incorporates more facets and grows problem complexity. The third problem in each module will present a totally worked-out example whose results students will be asked to interpret, and then they will respond to a series of what-if questions.

The relevance that students see in the mathematics they encounter in school and their interest in the material are important considerations for the development of instructional materials. When instructional materials are designed to increase their relevance to students, both student learning and motivation have been observed to increase (Means et al. [4]). Moreover, interest in mathematics is also related to motivation and learning (Singh et al. [6]). German researchers have found that interest in mathematics is an important factor in later academic choices (Koller et al. [3]). Interest in mathematics and science is also related to educational and career aspirations in mathematics, science, and engineering. Finally, positive student experiences in mathematics are associated with increased interest in mathematics, and increased interest is associated with higher levels of student achievement (Singh et al. [6]).

Some sample problem contexts are as follows:

- Maximize profit of a product mix for manufacture of skateboards or sports shoes
- Minimize cost of pollution control in a watershed
- Minimize calories in a diet, meeting minimum nutritional goals in an underdeveloped country
- Minimize cost of schedule for workers at a fast-food restaurant
- Maximize effectiveness of political advertising
- Form project teams for a high school class
- Select a portfolio of applications to college
- Locate a network of disaster response agencies
- Locate a mobile food stand
- Plan a project for a high school event
- Select the college to attend

These examples can be seen on our website, http://www.mindsetproject.org. Our earlier supplementary work is maintained at http://www.hsor.org.

Expand Modeling Skills and Introduce New Skills

At the high school level, students rarely explore problems with more than two variables and two or three constraints. Their thinking horizon is generally limited to the two-dimension graphical domain. Usually all of the constraints take on a common form with differing coefficients. Our problem contexts quickly grow to include six or more decision variables and a similar number of constraints. These constraints will not be cookie-cutter types but will represent diverse sources of constraints. For example, the workforce schedule problem has minimum manning constraints as well as constraints regarding the ratio of supervisors to workers. In addition, students will be using Excel Solver to find the optimal solution and are therefore no longer restricted to tackling two-variable problems that can be solved graphically.

Students in a college OR course all learn about 0-1 binary variables. They move into this domain naturally without stopping to think—Wow, this is a powerful new modeling concept! It enables a decision maker to model yes-and-no decisions. High school students and their teachers have never seen this concept. We motivate the need for this capability by exploring the development of a portfolio of colleges to apply for admission. Students are expected to balance their application portfolio by considering schools with different acceptance rates that reflect their risk of not being accepted. We also develop a budgeting problem by placing a group of students working in the summer in a family-owned business of buying up homes in need of repairs. They rapidly fix them up and attempt to resell them at a significant profit. The 0-1 variables correspond to the houses to be bought, each of which has a different profile of required repairs and potential profit.

Role of Mathematical Assumptions

It is hard for us to recall when we were first introduced to the importance of mathematical assumptions. Issues of concavity and convexity arise in differential calculus and affect the search for the local optimal. An introductory statistics course will mention the impact of sample size on whether to use the normal or t-distribution. In a probability text, there also could be a discussion as to when it is appropriate to use the Poisson approximation to the binomial distribution or the normal approximation to the binomial. The importance really sinks home in a stochastic process course as exponentiality directly affects solution complexity.

Mathematical programming offers an unusual opportunity to allow students to explore the assumption as to whether decision variables are linear or restricted to being integers. The first integer programming example in the text was constructed such that there are no integer solutions on the boundary set. Students can easily see that the optimal solution is no longer at a corner point, because none of the corners is feasible. In addition, they discover that simply rounding the decision variables will not necessarily yield the optimal and, in fact, could generate an infeasible solution. As a result, they discover the counterintuitive result that restricting the decision variables to a smaller subset of the feasible region makes the problem harder to solve.

The integer programming section is followed by binary variable problems for which again the optimal is not at a corner point. However, the students are then introduced to a special class of 0-1 problems, the assignment problem. In this problem setting, because of the matrix structure, the linear programming (LP) solution is the optimal solution to the binary decision problem. This is then followed by the transportation problem, and again the optimal will automatically have integer values in cases where supply and demand are integer values.

Link Data and Modeling

All of the modeling concepts are introduced with real-world contexts. Thus, the students immediately see where the numbers come from. In many examples, the problems require a series of steps to determine the model parameters. For example, the advertising effectiveness example discusses target populations and the relative effectiveness of different media. The diet problem requires the students to understand the nutritional content of various foods. The skateboard manufacturing example provides an overview of skateboard manufacturing. In a number of examples we identify the specific website that provided the data for the problem. The farming problem uses data for Missouri, and students can choose to use analogous data from their state. The computer assembly product mix example sends students to a data source with current pricing information for critical components.

In a number of examples, we raise the issue of data sources, data accuracy, and data relevance. For example, in the college application example, we explore the census definitions of urban and suburban and point out that these do not necessarily align with what a college student might mean when looking for a school in an urban setting. We also begin discussing the issue of uncertainty. The transportation examples discuss the accuracy and uncertainty of travel-time information and the relationship to travel distance. The workforce example raises concerns about estimates of relative productivity for different classes of workers.

Multistep Problem Solving, Interpret Results, and What-If Analysis

As discussed at the beginning of this tutorial, U.S. students have historically fared poorly on international exams that emphasize multistep problem solving and interpretation of results. Every example in this deterministic modeling course will enhance these problem-solving skills. Students in college and graduate courses in OR routinely carry out the following multistep tasks:

1. Identify decision variables
2. Write different types of constraints
3. Determine coefficients and right-hand-side values
4. Create an Excel representation in standard format
5. Determine optimal solution
6. Interpret the solution, identify binding and nonbinding constraints
7. Carry out a what-if analysis

Our challenge is to develop these same skills in problem contexts that are relevant to high school students.

For example, in the workforce-planning example for a fast-food restaurant, after finding the optimal solution, students explore what happens to the optimal if the wages of one or more work categories increase. They are also asked to determine what happens to the optimal as the workers become more experienced and require less supervision.

Computers and Excel Spreadsheets

Over the last 15 to 20 years, graphing calculators have become an integral part of algebra instruction. However, at the high school level there is limited need for computers as anything more than a word processing tool or a platform to develop spreadsheet skills. They are rarely an integral part of education for the vast majority of students. Math programming offers a natural conduit for demonstrating the role and need for computers as scientific problem-solving tools. Students will be able to solve two-dimensional LP problems by hand or with a calculator. However, the solution of problems involving six or more decision variables and a similar number of constraints is rendered much easier by computer computation. In addition, the software packages facilitate answering what-if questions. The first package they will learn is Solver, which will be used to solve math programming problems. While using the tool, students will gain added proficiency in organizing information in a spreadsheet.

Multicriteria—No Right Answer

Almost all of the mathematics education up through the early years of college involves finding the right answer to a question or problem. The same is too often true of science and engineering courses. It is not until a capstone project or design course that students are expected to use mathematics as a tool to evaluate and create alternative good answers. Multicriterion decision contexts offer a unique opportunity to use mathematics to tackle problems for which there is no right answer. When applying Multi-Attribute Utility Theory, every student will have his or her own set of measures and weights to be used to determine the most preferred college to attend or used car to buy.

Your State and Local Challenge—OR/IE Entrepreneurial Spirit

Because each state's mathematics curriculum has its own guidelines, implementation of Project MINDSET must be tailored to the state environment. In a state such as North Carolina, there is not only a requirement for a fourth-year math course to graduate, but there are also specific guidelines as to what is an acceptable fourth-year course. In contrast, Michigan, which has also adopted a fourth-year requirement, provides little or no guidance to local school districts as to what the fourth-year math-related course should contain. As a result, the project team will need to develop a strategy to sell each individual Michigan school district on the value of this new course.

The Project MINDSET team is committed to implementing the new course throughout Michigan and North Carolina. However, to reach other states will require partnering with industrial engineering, operations research, and math education departments who have good contacts in their locale. We are eager to lend support and guidance to any state or local initiative, but the key will be local OR/IE leadership and excitement in adapting Project MINDSET to local needs and opportunities.

Where to Begin?

To get started, the typical professor of operations research or industrial engineering will need to find and engage a partner who understands the mathematics education environment of the state or locale. An established professor of mathematics education is an ideal first choice. That individual would understand state requirements and have local contacts through the many math teachers who have been his or her students. In addition, this individual would be charged with the responsibility of adapting our course to become a regular part of the math education curriculum of the school of education.

The OR/IE project leader should also reach out across the university to identify individuals or groups that already have strong working relationships with local school districts. This relationship could be with a specific high school or the mathematics coordinator for an entire district or region of the state. There is no one right answer as to where to start. The key is identifying people with credibility and influence.

When searching for and engaging an academic partner or school district, the primary selling point for Project MINDSET is the unquestioned need for relevance in the mathematics curriculum. This need applies to both college-bound and noncollege-bound students. In meetings, emphasize real-world contexts and not OR techniques. Bring along examples from *Interfaces* to demonstrate that these are not just techniques that might be used but are, in fact, routinely used by companies and governmental agencies across a broad spectrum. Applications range from healthcare providers to manufacturers, from the military to agriculture, from telecommunications to logistics, and so forth.

In pursuing this initiative, it is important for the state project team to understand and accept the responsibility for providing ongoing support for high school teachers using this material. We do not anticipate that high school mathematics teachers responsible for senior-year math courses will have difficulty with the mathematics content of our course. They have all seen basic linear programming in Algebra II (although some of the linear programming likely was actually integer programming). However, the whole approach to solving complex problems will be a fundamentally new experience for the vast majority of teachers. The in-class dynamics will be different from what they are used to as students work in teams on many of the activities. Students will be expected to develop their own what-if questions and answers as to what they consider important will vary. In addition, it will take time for teachers to develop intuition as to what are the most common mistakes and misconceptions and how best to address them. It will require a new mindset.

It is the ongoing support that will likely require the most resources. We can provide the website structure for providing answers to FAQs and a framework for receiving new questions. The website will also have extra homework problems, quizzes, and exams. In the end there will likely be a need for trained OR/IE staff to answer specific questions, visit classrooms, and provide ongoing training and feedback as the course is implemented. The local project team should seek support from a local foundation, company, or state funding agency. Given the universally recognized need to encourage more students to pursue STEM careers, there should be numerous funding alternatives. The entrepreneurial OR/IE professor may view this as an ideal opportunity to provide funding for doctoral students who will provide support services. Imagine the possibility of obtaining funding for one doctoral student for every five to 10 high schools supported.

After gaining a foothold in a major school district, the project team can leverage the experience to begin cascading to other school districts. Expert teachers from the first district conquest can be a critical resource in branching out. They can help sell the idea and mentor new teachers. There should be funding to compensate them in this role.

For Project MINDSET and its local variations to be sustained long-term, the responsibility of training and education must ultimately reside in the schools of education. The course will become a fixture of high school mathematics, when schools of education regularly teach courses in the mathematics of operations research and industrial engineering as part of their master's degree programs in mathematics education. Ideally, a two-course sequence makes sense: one in deterministic modeling and a second in probabilistic modeling. However, because of course credit limitations, a one-course goal may be more realistic. Each course taught may reach 20 or more high school teachers who can offer to teach two high school sections or 50 students per year. Thus, each school of education in your state that annually offers an OR-based graduate course can impact 1,000 more high school students each year than the year before. Do the math. Five schools of education can teach 100 teachers a year, who in turn can teach 5,000 students. In just five years, your project team could see as many as 25,000 students in your state enrolled in an OR/IE-based mathematics course each year. In addition, the excited and engaged teacher will likely bring the concepts of OR and IE into some of their lower-level courses as well.

We are already exploring partnerships in Georgia, Kansas, and Missouri. These states, along with Michigan and North Carolina, represent 12% of the U.S. population. Current plans assume that these other states will lag a year, or at most two, behind our efforts in Michigan and North Carolina. How far and fast Project MINDSET propagates across the rest of United States is up to you, the reader. Are you interested? Are things changing in your state's math curriculum that make this an ideal time to introduce OR into your high schools? Last, do you have the entrepreneurial spirit and leadership ability to make it happen in your locale and ultimately throughout your state?

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