INFORMS TutORials in Operations Research

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Active Learning for Quantitative Courses

James J. Cochran

To cite this entry: James J. Cochran. Active Learning for Quantitative Courses. *In* INFORMS TutORials in Operations Research. Published online: 14 Oct 2014; 237-256.
https://doi.org/10.1287/educ.1053.0012

TUTORIALS IN OPERATIONS RESEARCH
INFORMS 2005

 | ISBN 1-877640-21-2
DOI 10.1287/educ.1053.0012

Active Learning for Quantitative Courses

James J. Cochran
Department of Marketing and Analysis, College of Administration and Business,
Louisiana Tech University, Ruston, Louisiana 71272, jcochran@cab.latech.edu

Abstract This tutorial provides an overview of active learning for quantitative courses such as operations research, management science, production and operations management, probability, and statistics. The potential risks and benefits of active learning exercises are discussed, types of active learning exercises are reviewed, and several interesting and creative active learning exercises are described.

Keywords operations research education; active learning; cases; games

Introduction

Learning is a naturally active process—true understanding is developed through student interaction with concepts, the instructor, and other students. This view is the basis of *active learning*, an approach that has been embraced throughout history by such notable and progressive educator/philosophers as Confucius, Socrates, and John Dewey. However, somewhere the lessons of these great educators have been largely abandoned at colleges and universities as lecturing has become the dominant pedagogical method; college students are now routinely subjected to long lectures in which only the transfer of information is accomplished. Indeed, one could consider lecturing to be a process by which ideas are transferred directly from the speaker's notes to the students' notes without interference from intermediary thought!

A well-delivered lecture has value; it is an extremely efficient means for demonstrating concepts or transferring information. While lecturing is an important and useful tool, it generally induces passivity of thought and does not engage students in the concepts and ideas being presented (Hartley and Cameron [46], McLeish [59]). Holding the attention of a student audience throughout a long lecture is extremely difficult (McKeachie [56]). Hartley and Davies [47] conclude that the typical student's level of attention increases during the first 10 minutes of lecture and diminishes rapidly thereafter.

Continuous dependence on lecturing creates a stagnant and lethargic learning environment; students are not compelled to question and discuss ideas, listen actively, think critically, form opinions, or experiment with concepts. This results in a superficial understanding of concepts and ideas that frustrates both the instructor and the student (Russell et al. [68]). Furthermore, student attention levels can vacillate wildly and somewhat independently as the lecture proceeds; the differences in the students' attention spans and the independence of the vacillations in their attention levels only further exacerbates the problem, creating ever-changing pockets of disinterest and indifference. Fortunately, several research studies (as summarized by Chilcoat [13]) suggest that an instructor can recapture students' attention by changing the classroom environment during a lecture. While a simple break from the lecture can be used to achieve this change, such a break can be even more effective if augmented by a well-crafted active learning exercise (Brown and Atkins [8], Campbell and Smith [9], Cashin [10]). Chickering and Gamson [12] summarize this point very well:

> Learning is not a spectator sport. Students do not learn much just by sitting in class listening to teachers, memorizing prepackaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, apply it to their daily lives. They must make what they learn part of themselves.

There are many reasons why active learning exercises effectively help students "make what they learn a part of themselves." Student participation in such activities allows them to deal with concepts on their own terms and work through ambiguities and misconceptions. Active learning can be a particularly effective means for redistributing the responsibility for learning, reducing the emphasis on lecturing, and increasing the students' role in their education. Active learning is also effective over a wider range of learning styles relative to other classroom approaches.

In quantitative methods courses, the problem of holding students' attention is aggravated by their apprehension of the course material. Many students are intimidated by quantitative material because they are poorly prepared, have little prior knowledge or understanding of quantitative methods, and are anxious about the required mathematics. Fortunately, active learning exercises can also be used to address this problem; student apprehension can be eased by allowing for classroom opportunities to work with and process quantitative concepts and methods. This results in a deeper understanding and appreciation of quantitative material, which in turn builds students' self-confidence and tolerance for the frustration of studying relatively difficult concepts, which leads back to a deeper understanding and appreciation of quantitative material (Garfield [41], Giraud [43], Gnanadesikan et al. [44], Keeler and Steinhorst [52], Magel [55], Rumsey [67]). This developmental cycle is the ultimate goal all instructors should have for their students—successful learning propagates successful learning!

This tutorial provides guidance for and encouragement to instructors who wish to introduce or increase the emphasis on active learning exercises in their courses. It also includes a discussion of some common, effective, and interesting active learning exercises. Although the focus is active learning in quantitative courses, most of the content of this tutorial is general and could be applied in any course.

What *Is* Active Learning? What *Isn't* Active Learning?

Active learning is an elusive term, and several definitions are provided in the literature and on websites. McKinney [58] states that "Active learning refers to techniques where students do more than simply listen to a lecture. Students are DOING something including discovering, processing, and applying information." Bonwell and Eison [6] consider active learning to be "…instructional activities involving students in doing things and thinking about what they are doing." ActiveLearning Online [1] defines active learning as "…a multi-directional learning experience in which learning occurs teacher-to-student, student-to-teacher, and student-to-student."

While each of these definitions is unique, they have several commonalities. Each stresses (implicitly or explicitly) that

— students take a *participatory* role in their education,
— this participation should involve students in *higher-order* (not rote) thinking tasks, and
— *interaction* is a critical component.

The definition utilized in this tutorial synthesizes the following common traits.

Active learning: Instructional strategies that engage students through their interactive participation in exercises that involve them in higher-order thinking tasks such as analysis, synthesis, and critical evaluation of course material.

Given this definition, almost any learning exercise *could* be called active learning. This is not an incorrect characterization; it depends solely on how the exercise is conducted. Are students engaged and taking a participatory role in their learning? Are they involved in higher-order thinking tasks? Is there substantial interaction? If the answers to these three questions are *yes*, the learning exercise in question is an active learning exercise.

Several other terms are frequently used interchangeably or in conjunction with active learning—these include the following.

Experiential learning: This is a process through which a learner develops knowledge and understanding from direct experience. Models of experiential learning are generally comprised of three distinct phases: an initial experience or problem situation, a reflective phase in which the learner reviews the experience looking for insights and understanding, and a testing phase in which the new insights and understanding are applied to a new problem situation or experience and assessed. Osland et al. [61] refer to these phases as *concrete experience*, *reflective observation and abstract conceptualization*, and *active experimentation.* Cooperative education, apprenticeships, internships, and projects are examples of experiential learning activities that can (and should) involve active learning at some level.

Problem-based learning: This approach is advocated by Barrows [2] and Stepien and Gallagher [74], among others. The students' knowledge, skills, and understanding are developed through their efforts to solve a real and messy problem. The problem is chosen by the instructor with specific pedagogical goals in mind; it should compel the student to acquire necessary or critical knowledge, enhance her/his problem-solving proficiency, and develop the ability to learn independently. The instructor acts as a facilitator and gives guidance to the students without interceding in their attempts to solve a problem. Students are ultimately evaluated primarily on how well they solve the problem.

Cooperative or collaborative learning: Small teams, each comprised of students with different backgrounds and/or levels of ability, work together to enhance their understanding of a subject. This technique aims to create an atmosphere of cooperation and achievement by making team members responsible for their teammates' understanding and learning.

Each of these approaches engages students and requires them to take a participatory role in their learning; each involves students in higher-order thinking tasks, and interaction is a vital component of each. Thus, they are specific types of active learning exercises.

The Case for Active Learning

Several studies have demonstrated that active learning techniques can have a profound impact on student learning by enhancing both understanding and retention (Bonwell and Eison [6], George [42]). Many of these research studies have further demonstrated that active learning techniques can be both as effective as lectures in promoting mastery of content and superior to lectures in promoting the development of students' analytic and critical thinking skills (Felder and Brent [39], Johnson et al. [51]). Use of active learning exercises has also been shown to improve student attitudes toward studying and learning. Furthermore, some cognitive research (Claxton and Murrell [22], Felder [35, 36], Haller et al. [45]) has shown that a substantial portion of students have learning styles that are best served by pedagogical techniques other than lecturing (such as active learning).

Given the seemingly overwhelming evidence of the effectiveness of active learning, why is not its use more widespread? There are several possible and somewhat interrelated reasons.

Barriers to Implementation of Active Learning—The Student Perspective

While many students will welcome a break from the classroom routine and be curious about what the instructor has planned, some may initially resist the shift to a stronger active learning orientation (Kelley et al. [53]). Felder and Brent [38], and Woods [77] draw provocative analogies between the phases psychologists associate with trauma/grief and the stages a student may go through when required to assume more responsibility for her/his own learning:

Shock and astonishment—The student does not believe or will not accept that the instructor will deviate from exclusive reliance on lectures and assigned readings.

Denial and refusal—The student refuses to earnestly participate in the exercises and is certain the instructor will return to an exclusive reliance on traditional teaching methods.

Defiance and withdrawal—The student becomes more passive as s/he becomes convinced the instructor is committed to this new approach; s/he may even drop the class in the hope that a section taught in a more traditional style will be offered later.

Capitulation and resignation—Realizing that the instructor is committed to the new approach, the student is resigned to remain in the class and grudgingly begins to (somewhat earnestly) participate.

Struggle and exploration—The student observes other students succeeding with and enjoying the alternative approach and decides to reconsider her/his initial reaction.

Return of/increase in confidence—The student gains a better understanding of concepts through her/his participation and begins to feel positively about the alternative approach.

Acceptance and success—The student appreciates the value of the experience and fully supports the instructor's efforts to modify the classroom environment.

Not all students will experience all (or any) of these stages, but several may, and so the instructor must be prepared to deal with each stage. The keys to alleviating students' apprehension as they progress through these stages are (i) establishment of an open and sympathetic environment, (ii) maintenance of structure (that can be relaxed as students' apprehension diminishes), (iii) clear communication of the instructor's intentions and the goals of the exercise, and (iv) guidance that helps students understand and successfully complete the exercise.

Barriers to Implementation of Active Learning—The Instructor Perspective

Students are not alone in their apprehension over altering an established learning environment. Instructors also have several legitimate reasons for feeling anxious about such a change (Felder and Brent [38]). Reasons for this anxiety include:

Faculty mimic their instructors—because most faculty learned from instructors who used lectures as their primary mode, they have not been exposed to or seriously considered other options. Thus, lecturing is a large part of many faculty members' self-defined role as an instructor; it has become a self-propagating academic tradition.

I believe there are three distinct potential transition points in an instructor's career:

- the instructor realizes that s/he can teach differently than those from whom s/he learned;
- the instructor realizes that s/he has a learning style that differs from most of her/his students; and
- the instructor realizes that s/he can recover from *almost* any minor misstep in the classroom.

Not all instructors experience these transitions, nor do they need to in order to be effective teachers. Furthermore, an instructor can achieve these realizations in any order. Obviously, an instructor who is considering the use of an alternative approach to teaching has reached at least one of these transition points and is looking beyond her/his self-defined role as an instructor.

Faculty are apprehensive about trying something new or different in the classroom—many instructors who do not use active learning exercises are already successful in the classroom (some very much so). These instructors may view potential changes to their classroom approaches as risky. The alternate approach may not work as intended; students may not *earnestly cooperate/participate; the instructor may doubt her/his ability to use the alternate approach.*

There is certainly risk inherent in trying a new instructional approach such as active learning, but this risk can be mitigated. The instructor should make her/his first attempt at using active learning in a receptive class in which s/he has built a solid rapport with the students. S/he should think through the active learning exercises to be used. (What are the pedagogical goals? What could go wrong and how could the situation be handled? How long should the exercise take? How and where does this activity fit into the lecture? How will s/he re-engage the lecture at the conclusion of the exercise?) The instructor can start with a few simple active learning exercises (several potential exercises are provided later in this tutorial) and should explain to the students that s/he is going to give them a short break from the lecture and utilize a teaching approach that has been shown to improve student understanding and retention. The offer of a small inducement (i.e., credit for a missed quiz) for student participation may help. Students will generally appreciate the short break from the lecture and will be curious about what the instructor is going to do during this break. My experience also suggests that, if the instructor is well prepared, students will be very tolerant of small miscues in her/his early attempts at active learning.

Instructors often fail to comprehend that (i) *many* (*most?*) *of their students learn differently than they do and* (ii) *they* (*the instructors*) *are generally far more interested in their disciplines than are students. This intense interest usually dates back to the instructor's initial contact with the discipline; it is fueled by latent ability and fosters a high level of achievement. Students who eventually become college instructors generally experience less difficulty with the basics of her/his discipline, and as instructors they often expect* (*perhaps subconsciously*) *their students to understand the discipline with similar ease.*

Upon hearing such an explanation, an instructor may experience an epiphany—why expect students to learn the same way s/he learns? This sudden realization often results in a ready willingness by the instructor to incorporate active learning into her/his courses.

Many instructors already feel they do not have adequate time to meet their responsibilities, and active learning exercises take time to prepare and time to execute. These instructors feel rushed and do not feel they have adequate time to achieve the expected coverage of the material. A few minutes taken from each of several class meetings will represent a substantial portion of the course. What is to be sacrificed to facilitate active learning exercises?

Several studies have found that student comprehension and retention of difficult concepts is enhanced when the instructor pauses for a few minutes at 10-minute intervals throughout a lecture (Hartley and Davies [47]). Filling these short breaks with relevant and interesting active learning exercises can amplify these benefits (Brown and Atkins [8], Campbell and Smith [9], Cashin [10]). Even if the use of active learning exercises does result in a small loss of lecture time, is it not preferable to cover slightly less material at a higher level of student comprehension and retention?

Administrations generally provide little support for the development of alternative instructional approaches. The tenure process often encourages research productivity at the expense of all else. Furthermore, instructors who are considering the use of active learning exercises many fear their colleagues' scorn and ridicule (*s/he plays games in her/his classroom!*).

If used properly, active learning exercises can enhance student comprehension and retention at a very low cost (especially once the instructor has established several exercises that s/he likes to use). This does not require an immediate and absolute change—the instructor can integrate active learning exercises into her/his courses gradually, minimizing both her/his risk and the cost. Administrators and colleagues certainly cannot argue with a tremendous classroom enhancement that ultimately takes little time away from a faculty member's research efforts.

Thus, each of these barriers can be overcome with a small commitment and a little creativity!

Mischaracterization of the Nature of the Instructor/Student Relationship

While it is true that a student is an end user of her/his education, defining and dealing with a student as a *traditional* customer distorts and demeans the nature of the instructor/student relationship. A student who thinks of her/himself in this manner is more likely to expect to be "served" her/his education. Unfortunately, this type of instructor-student relationship does not result in effective education—the student must be engaged to learn.

The coproduction model proposed by Whitaker [76] for service industries and later applied by Chappell [11] to public education provides a far more appropriate paradigm for the relationship between students and instructors. In this model:

— the end user/customer (i.e., the student) has a physical or virtual presence and supplies some labor;

— information flow is facilitated through interaction with the service provider (i.e., the instructor) *and* other customers (i.e., classmates); and

— the end user makes indispensable intellectual contributions to the process.

The goal of this model is *customer efficiency*, i.e., customers who use *less* of the service provider's resources while accomplishing *more* for themselves. Factors that influence customer efficiency include:

— internal factors such as the individual customer's ability, preferences, background, etc.;

— external factors such as the design of the service delivery process, distribution channels for service delivery, etc.; and

— the customer peer group.

The insights into the role of service providers (i.e., instructors) is clear—they are primarily responsible for facilitating improvement of customer (i.e., student) efficiency through the design of service delivery process and service delivery distribution channels. Instructors can use active learning exercises to enhance the service delivery process and ultimately improve student efficiency. Furthermore, an instructor who gives assignments to be completed by student teams also has some control over the customer peer group in her/his classroom. This control can be used to ultimately improve student efficiency.

Integrating Active Learning into the Quantitative Courses

Once an instructor has decided to use active learning exercises in her/his course, s/he is faced with the tasks of finding or designing active learning exercises and integrating these exercises into the course. Careful thought must be undertaken at this stage to ensure the exercises will be effective and constructive. Whether the instructor is designing a new active learning exercise or using a preexisting exercise, s/he should consider the following.

The audience: The students' prior training, education, and experience are critical considerations. The active learning exercise must require students to consider concepts at an appropriate level. If the exercise is too simple, students will quickly lose interest; an overly demanding or complex exercise will frustrate students. In either of these cases, students will conclude that the instructor is wasting their time! While it is certainly important to consider the students' formal education and prior exposure to relevant concepts, it is also important to consider their prior classroom experiences. For example, extra care must be taken when assigning cases to students who have no prior case-analysis experience.

His/Her personality: The instructor must stay within her/himself. An instructor with an outgoing personality will likely be comfortable with and enjoy exercises that encourage instructor-student interaction, while an introverted instructor will likely be more at ease with exercises that stress student-student interaction.

Course material: Once the instructor has decided what concept(s) to emphasize with active learning, s/he must design or select exercises that are appropriate. The exercise must be suitable for the concept(s) the instructor wants to emphasize, and it must be executed at a point in the class meeting when it will be most effective.

Pedagogical objectives: The instructor must decide if s/he wants to use the active learning exercises proactively to encourage students to consider a concept prior to a class discussion, reactively to encourage students to give deeper consideration to concepts that have already been discussed in class, or intra-actively to help students understand a concept in lieu of a classroom discussion. Depending on when it is executed, an active learning exercise can be used to help students gain deeper insight into an important concept, integrate several concepts, or perceive similarities and differences in several concepts.

The classroom space: Some classrooms are designed in a manner that allows students to easily work in groups of four or five; some have tables in the front of the room; some have chairs and desks that are anchored to the floor. Classroom characteristics such as these can limit or enhance an active learning exercise.

Available equipment and materials: Again, this will vary across schools (and even across classrooms at a particular school). For example, I ask a student to collect responses and build a bar chart on the chalk board as the class plays the classroom version of *Who Wants To Be A Millionaire*. If I had access to a classroom with PDAs, I would certainly use them to electronically collect and summarize student responses.

Available class time: While most active learning exercises can be fully executed in less than 10 minutes, a few can take substantially longer. The instructor must weigh the benefits (in terms of enhanced student understanding and retention) and costs (in terms of class time) when designing or selecting an active learning exercise.

An instructor who is new to the active learning approach should consider using a simple preexisting exercise; several active learning exercises are presented in INFORM-*ED* (INFORMS forum for education—http://education.forum.informs.org/) sponsored sessions at INFORMS annual conferences, and several more are published in *INFORMS Transactions on Education* (http://ite.pubs.informs.org/). These exercises can often be used off the shelf or can easily be retrofit to meet the individual instructor's needs.

The instructor should prepare students for the active learning exercise by announcing what s/he intends to do in advance (perhaps in the class meeting prior to the use of the exercise). The instructor should explain clearly that s/he is going to use the exercise to give the class a short break from the lecture and reinforce one or more important concepts. Students should be made to understand that this is a serious assignment; a small inducement (i.e., credit for a missed quiz) may help. Finally, the instructor should acknowledge that this deviation from the usual classroom approach may cause students to feel somewhat uneasy (the instructor is not the only person taking a risk!)—this will help establish an intellectually and emotionally supportive environment in which the students feel more free to participate.

The active learning exercise can be integrated into the class in several ways. Perhaps the least risky approach is to modify the lecture (Penner [63]). The simplest modification is the *pause procedure*; simply pause for a few minutes to allow students to consolidate their notes at a few points during a lecture. Research (Ruhl et al. [65]) indicates that students learn significantly more information in classes that use this approach.

Another simple and effective way to engage students during a lecture is to follow a short demonstration or writing assignment with a brief discussion period; the discussion can involve the entire class, or the class can be broken into small discussion groups. Similarly, in the *feedback lecture approach* a lecture can be split into shorter segments by brief breaks during which student groups discuss what has been covered. The *guided lecture* is somewhat more radical; the instructor gives a relatively short lecture (perhaps 30 minutes) during which the students do not take notes. After the lecture, students are given five minutes to write what they remember from the lecture. In the remaining class time, students meet in small groups to clarify and elaborate on the lecture (as the instructor moves from one group to another, answering questions, and providing some guidance).

Note that these techniques achieve increased interaction (and the resulting enhancements to understanding and retention) through in-class discussion in reaction to the material covered in a lecture. Alternatively, proactive techniques can be used to encourage students to consider concepts prior to a lecture. In the *jigsaw approach* student teams are formed in advance; each team member is made responsible for reviewing a specific part of a topic or concept that will be discussed in the next lecture. At the beginning of the next class meeting, the students are divided into groups according to the specific part of the topic they were assigned. After these groups each discuss their specific findings, the students return to their original teams and integrate their results. Although not traditionally thought of in this manner, even *cases* can be used in a similar fashion; the case can be assigned prior to discussion of some or all of the relevant concepts, and the instructor can present student teams with a series of questions or issues to be considered when analyzing the case. Again, each of these questions or issues is assigned to a specific team member; on the day the case is to be discussed, a jigsaw-type approach can be used to help student groups reach some consensus. This is followed by a full class discussion that enables the instructor to (i) clear up any remaining misunderstandings, (ii) address any of the students' persistent concerns, and (iii) discuss issues that the student groups have overlooked. Even *group projects* can form the basis of an active learning classroom environment—as the project advances, each group can present regular progress reports in class, and the student groups can provide mutual support by asking questions and suggesting alternate approaches.

Although these active learning exercises are relatively simple, they can be extremely effective. As McKeachie et al. [57] found, discussion/interaction is more effective than lecturing for promoting understanding and retention of information, developing critical thinking skills, encouraging students to apply concepts and ideas in different circumstances, and motivating students toward further learning. Of course, there are much more elaborate active learning approaches that can be used once the instructor is comfortable using active learning exercises. These exercises are the topic of the next section of this tutorial.

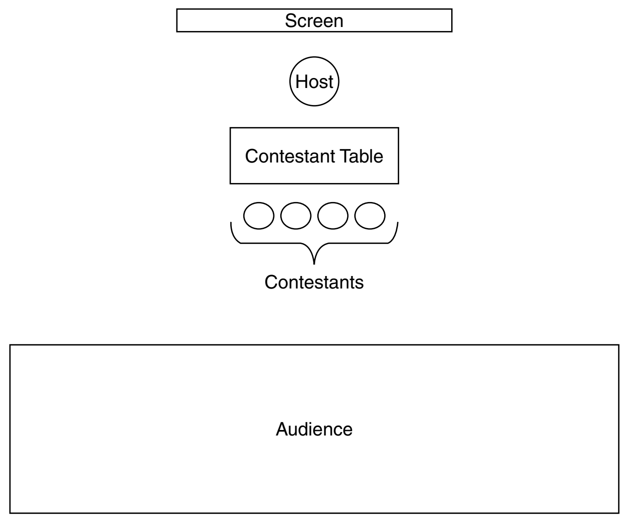
Some Active Learning Activities

Each of the previously discussed active learning approaches has several common traits: They engage students through their interactive participation in exercises; they involve students in higher-order thinking tasks such as analysis, synthesis, and evaluation of course material; and they are all built around a break from a traditional lecture. There are more elaborate activities, such as games and cases, that can be used in the quantitative classroom. These active learning exercises have the potential for extremely high return; thus, as the instructor becomes more comfortable with active learning exercises, s/he may wish to integrate some of these more elaborate exercises into the classroom.

Games

Games can be an important tool in the quantitative instructor's arsenal (Chlond and Toase [19], Cochran [28], Sniedovich [71]). Several authors have reported successful use of classroom games, including Biesterfeld [4], Bosch [7], Chlond [14, 15, 16, 17, 18], Chlond et al. [21], Chlond and Toase [20], Cochran [27, 30], Eckert [32], Erkut [33], Feldman and Morgan [40], Letavec and Ruggiero [54], Myers [60], Pendegraft [62], Rump [66], Sniedovich [71, 72, 73], Trick [75], and Yeomans [78]. Each has found games (and puzzles and paradoxes) to be very effective methods for developing their students' understanding of complex concepts. Although these games do not expose students to "realistic" problems, they are complex and require the students to engage in higher-order thinking about the concept(s) in question, which in turn does prepare students to attack practical problems they may encounter in later studies or in their career. An overview of a few classroom games follows.

FIGURE 1. Classroom layout for *Who Wants To Be A Millionaire-The Classroom Edition*.



Who Wants To Be A Millionaire-The Classroom Edition (WWTBAM-TCE)

WWTBAM-TCE (Cochran [27]) is a Microsoft PowerPoint-based classroom version of the internationally popular television game show *Who Wants To Be A Millionaire*. At an appropriate breaking point in a lecture, a student or team of students is invited to participate as "contestants" in the game. All other students in the class are instructed to put away their note-taking materials for the duration of the game (this enhances the perception that the class is taking a break). The contestants are seated in front of the class facing the screen with their backs to the audience (so that they cannot receive any unsolicited assistance), as depicted in Figure 1.

The contestants are presented with a question and four potential responses that appear on a screen image similar to that which is used on the television show *Who Wants To Be A Millionaire*; music from the show also plays at appropriate junctures of the game. The team of student contestants must collaborate, reach a consensus, and give a single response to the question. Ultimately, they may respond in one of three ways:

— Refuse to answer the question, quit the game, and retain all credit earned to that point. The team of student contestants is initially awarded three-fourths of a quiz credit for participating and receives one-fourth of a quiz credit for each correct answer, so a maximum of two quiz credits are earned if all four questions are correctly answered;

— Answer the question and continue to play if correct or forfeit their right to continue playing and lose all credit earned if incorrect. However, once the team of student contestants has earned one quiz credit (answered the first question correctly) they cannot lose that credit; or

— Use a lifeline (*Ask a Friend, Poll the Class*, or *50/50*). Each team of student contestants is only allowed a single use of one lifeline.

If the team of student contestants answers a question correctly, they receive the quarter quiz credit and are permitted to proceed to the next question. Because the game requires use of multiple choice questions with short answers, a four-question version (which can be executed in less than 10 minutes) gives students a short break from the lecture and provides a review of a few concepts while maintaining some class momentum. *WWTBAM-TCE* can be downloaded from *INFORMS Transactions on Education* at http://ite.pubs.informs.org/Vol1No3/Cochran/Cochran.php. This game takes approximately 10 minutes to prepare using *WWTBAM-TCE* as a template, and prepared sets of questions can certainly be recycled over several academic terms.

Jeopardy!

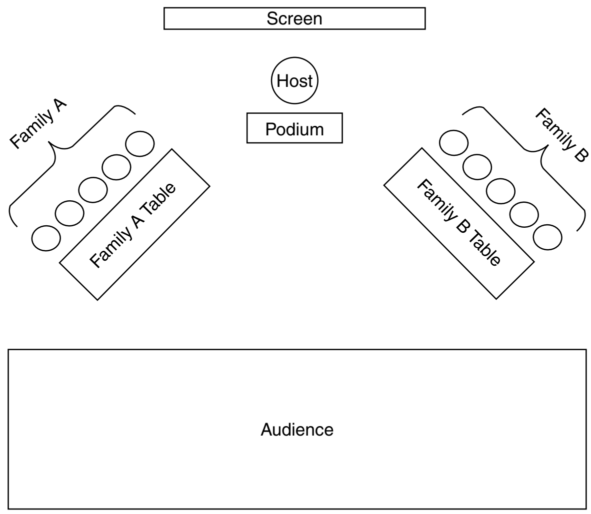
Jeopardy!, the television game show in which contestants compete for cash by providing the correct *question* when given an *answer* (responses not given in the form of a question are considered incorrect!), is the basis of a classroom game developed by Benek-Rivera and Mathews [3]. The authors divide a class into teams of three to five students and draw the *Jeopardy!* game board on the blackboard (using four category titles and five ascending point values for items in each category). One team is allowed to select the first *Jeopardy!* category and point value; when an item (a combination of category and point value) is selected, the instructor/host erases it from the board to indicate that the item is no longer available for play. S/he then reads the corresponding answer from an index card or script to the class. The first student to indicate s/he wishes to respond for his or her team is called on to play that item; that student is responsible for responding for his or her team. If the student gives the correct question within 10 seconds, her/his team is awarded the points associated with the question. If the student gives an incorrect question or fails to respond within 10 seconds, her/his team is penalized the points associated with the answer; at this juncture, any player on one of the other teams is allowed to indicate s/he wishes to respond for his or her team. The authors suggest a limit of two "attempts" per item to allow time for the instructor to provide further explanations (this is particularly important when an item is not answered correctly).

As with the television version of *Jeopardy!*, answers with higher values are considered more difficult, and the team that most recently provided the correct question controls the board and is allowed to choose the next item to play. The authors also suggest ways to incorporate the hidden "Daily Doubles" and the "Final Jeopardy" round. They estimate that the classroom *Jeopardy!* game takes 30 to 40 minutes to prepare and 30 to 60 minutes to execute, and they use the game for examination review sessions. Again, prepared sets of answers can be recycled over several academic terms. Linda Leon, Zbigniew Przasnyky, and Kala Seal of Loyola Marymount University have also developed a very good PowerPoint version of this game that works in a manner similar to *WWTBAM-TCE* (Seal [70]).

Family Feud-The Classroom Edition

In yet another electronic version of a television game show, *Family Feud* has been adapted for the classroom in a PowerPoint format with images and music from the television show. The actual premise of the *Family Feud* game show is simple—a survey is administered and responses to a question are collected. The responses to this question are then listed on the screen in order by their frequency and hidden from view of the contestants. The game is initiated when the first contestant from each the two families approaches the podium. The host reveals and reads a question, then waits for the two contestants standing at the podium to respond. The contestant who gives the answer associated with the greater frequency of survey responses wins control of the board for her/his family; they can then choose to play or pass. If they choose to play, individual family members (in order) continue to guess the survey responses (and accumulate points equal to the number of survey responses associated with their guess) until they either guess all responses on the list (and are awarded the points they have accumulated) or give three incorrect guesses. If they give three incorrect guesses, the opposing family is given one opportunity to guess at remaining unrevealed survey responses: If they correctly guess one of the remaining survey responses, they "steal" the points accumulated on this round by their opponent; if they fail to correctly guess one of the remaining unrevealed survey responses, their opponent retains the points they have accumulated in this round. Rounds are played until one family accumulates a predetermined

FIGURE 2. Classroom layout for *Family Feud-The Classroom Edition*.



number of points, is declared the winner, and is allowed to move to the “Lightning Round” (a timed, solo version of the game played by two members of the family for higher stakes).

The classroom version is similar. The instructor initially selects two sets (or “families”) of five students, and each family stands behind a table that is angled toward the audience in a fashion that still allows the family members to see the overhead screen (see Figure 2). A podium is situated between the two tables.

Student responses to open-ended quiz questions from previous sections of the course are used. Two families (sets of five students) are selected from the audience. Instead of playing until one family reaches a predetermined point total, the class plays up to three rounds (each round takes approximately three to five minutes). If a team correctly guesses all of the survey answers or successfully steals, they must still (as a team) identify the correct answer to win the round—even if the correct answer has not been uncovered! If they do not identify the correct answer, the points accumulated during the round are not awarded to either team. A team also must win two rounds to win the game; if neither team wins at least two of the three rounds, the game is declared a stalemate. Also note that no lightning round is played.

Because students are attempting to guess the most common answers, *Family Feud-The Classroom Edition* (i) allows students who do not know the correct answer to more fully participate and (ii) forces students to identify alternative (albeit incorrect) answers to questions. The nature of the game also allows for student consideration of answers of varying degrees of correctness. The instructor can and should briefly discuss the question and various answers at the end of each round. Because the questions and answers are taken from real surveys that have been administered to students in prior sections, students generally pay very close attention. Once the surveys have been administered and the data collected, preparation of this game takes 10 to 15 minutes, and prepared sets of questions can be recycled over several academic terms.

Trump or Monkey?

This game is a PowerPoint version of a routine often used on the *Late Night with David Letterman* television talk show. *Trump or Monkey?* is used to encourage discussion and insight into the value of random sampling. As Peter Gabriel’s 1982 hit song *Shock the Monkey* plays in the background, students are informed that they are about to see portions of three images (two of monkeys and one of Donald Trump). From this information, they are to guess which image is of Donald Trump. The top 20% (approximately) of the images are revealed, the class is polled, and the responses are tallied and summarized. At this point, the instructor uncovers the remainder of the image that received the most votes (and it is most often not the Donald Trump image). The instructor then shows the students the same images with a randomly selected 20% of each exposed and asks them if the new information is more insightful than the originally exposed portions of the images. Of course, it is—the random samples expose parts of noses, eyes, skin (or fur), ears, etc., and the value of a random sample over a convenience sample is established. Later in the course the information can be used further to support discussions on the binomial and multinomial distributions as well as estimation and inference for proportions.

Cases

Use of cases in quantitative methods courses can be problematic (particularly at the introductory level). While many disciplines use cases exclusively in certain courses (particularly in MBA programs), students in quantitative methods courses usually rely heavily on the instructor's explanations (i.e., lectures) and would be extremely uncomfortable if the course were entirely case-based (there are, of course, several notable exceptions). This is aggravated by differences in the nature of quantitative cases and cases from other disciplines; cases from other disciplines are generally managerially oriented, while the quantitative courses are problem oriented. Finally, there are relatively few quantitative cases available.

Despite these obstacles, cases can be an extremely effective active learning tool in quantitative methods courses—even at the undergraduate introductory level (Cliff and Curtin [23] and Cochran [26]). As a part of an active learning environment, they can be used to supplement lectures, provide opportunity for students to apply methods and integrate concepts, and review topics prior to examinations (Feinstein and Veenendall [34], Richards et al. [64], Herreid [48, 49]).

In the undergraduate introductory courses I teach, I generally give two interim exams and a final exam; written two-page analyses of two cases are due the class period prior to each exam. The class meeting immediately prior to each exam is devoted to discussion of the cases that are due, and students are instructed to come to class prepared to participate in the discussion; this forms the basis of a very revealing, effective, and somewhat unusual review session. I select and assign pairs of cases that reinforce different concepts, and the students are wholly responsible for determining how to complete their case analyses.

I have used this approach in classes with as many as 300 students; while managing the discussion is more challenging with large audiences, it can be done effectively. A powerful voice or a cordless microphone will enable the instructor to move around the classroom and encourage participation. Grading can also be a consideration—cases analyses can take a long time to grade. However, the task can be mitigated by

— putting students into groups and requiring a single analysis of a case from each group;
— requiring a subset of the students or groups to submit each case analysis; and/or
— grading the cases on a pass/fail basis (I was surprised that the quality of cases improved when he adopted this case-grading policy—apparently the threat of receiving no credit is a tremendous motivator).

I also consider the audience and its experience with cases as I grade cases; my expectations for seniors and master's-level students are much higher than my expectations for students in introductory undergraduate courses, and my expectations increase as the academic term progresses.

Case Discussion Formats

Once an instructor has committed to using cases and has chosen appropriate cases, s/he must consider potential class discussion formats. Because the class will eventually be expected, as a group, to reach some conclusion (with some possible dissention), consideration of various group approaches to strategic decision making is appropriate. Schweiger et al. [69] provide, compare, and contrast three common group approaches to strategic decision making (consensus, devil's advocacy, and dialectical inquiry) that are described briefly below:

Consensus decision making—The instructor works with the student groups throughout the discussion to help students reach a mutually agreeable conclusion or solution to the case. This type of discussion is easiest for the instructor to implement and maintain. Because the risk of being incorrect is spread throughout the class, it is also least intimidating for the students. Thus, the consensus decision-making discussion is best suited to instructors and/or students who are relatively inexperienced with the case method.

Devil's advocacy—An individual or subgroup is chosen to critique a proposed course of action and identify problems to consider before a final decision on the case problem is reached. Instructors who use this approach will often assign presentation of the case to one (or a few) student groups and appoint the remaining student groups to act as the devil's advocates. This approach is more demanding on the instructor and more intimidating to students, and so is better suited to instructors and/or students who have some experience with the case method.

Dialectical inquiry—The class approaches a decision from two (or more) opposing perspectives and debates conflicting views. When two (or more) student groups take opposing perspectives on a case, this approach can generate great creativity and insight. Of course, the instructor cannot rely on the emergence of two opposing perspectives during a case discussion; if s/he wants to establish this type of discussion, s/he must be prepared to take on the role of devil's advocate. This discussion approach is the most demanding on the instructor and most intimidating to students, and so is best suited to instructors and/or students who are relatively experienced with the case method.

Of course, these group discussion formats are not mutually exclusive—it is easily conceivable that an instructor may wish to interject or encourage some of each behavior in a single case discussion. Nor are they collectively exhaustive—several other models for group discussion and decision making exist and are worthy of consideration.

Facilitating a Case Discussion

These are several approaches to facilitating case discussions. Some common or interesting techniques include:

Standard (give-and-take) discussion—All students or student groups complete analyses and come to class prepared to discuss the case. The discussion spans all students or student groups.

Presentation-centered discussion—A student group is given responsibility for presenting and defending its case analysis in front of its classmates, providing the basis for the case discussion. Student groups rotate primary responsibility for presenting results (and providing the basis for the discussion).

Anchored instruction (or role playing)—Anchored instruction puts students into the context of a case. Each member of one selected student group assumes the role of a character in the case, and these students act out the case scenario for their classmates. The class then breaks into their student groups and discusses the case presentation. This is followed by a second performance with a few critical differences—a member of the audience may stop the performance at any time to

— ask any character a question or
— take the place of any of the student "actors" and assume the role of her/his character.

I was somewhat skeptical when I first heard of this approach. However, after participating (both as an actor and an audience member), I was amazed at how much insight I quickly developed into the potential motivations of the various characters in the case.

Box-and-one method—This approach is named for the special defense devised by college basketball coach Jim Valvano. Students are divided into teams of four or five; all teams are assigned the case and told to prepare to present the case for the next class meeting. The instructor further explains that the next class meeting will be somewhat unusual, and the students will participate in a case-related exercise that will enhance their abilities to "think on their feet" and react quickly to ideas presented by competing teams.

The students arrive at the next class meeting to find that separate projection stations (each with projection equipment and a screen) are set up in each corner of the room. Work stations with tables, chairs, blank transparencies, and pens are also set up and labeled for each student team, and a lone stool (hopefully one that swivels) sits in the middle of the room.

The instructor enters the room, sits on the stool in the center of the classroom, and instructs the students to begin presenting. At first, the students are confused. Who should present? Which team should speak? In what order? The instructor encourages any team to go to any projection station and start the discussion by explaining the case scenario, and also encourages the other teams to go to the other projection stations when they have additional points to make or take issue with something presented by another team. Within a few minutes, the projection stations are occupied by teams debating case issues and approaches, while the remaining teams are waiting for a turn at the projection stations. Teams race back to their work stations to create new slides (either electronically or manually, depending on the available projection equipment), using Excel to make calculations and create slides and tables. Order and energy emerge out of the initial anarchy. As with all case discussions, the instructor monitors (and sometime redirects) the discussion and ensures that all teams have ample opportunity to participate; these tasks are more demanding when using the box-and-one approach to facilitating case discussions.

The instructor must assume responsibility for maintaining decorum in the classroom and insisting that students treat each other with respect throughout the case discussion. S/he must also make decisions about how much time to spend investigating particular points raised by a student group and when to direct a wayward discussion back onto a more desirable path. Finally, the instructor must work hard to ensure the students do not feel ambushed at the onset of the first execution of this approach; s/he must again assure students that the approach has been adopted to enhance their abilities to think on their feet and react quickly to ideas presented by competing teams (critical business meeting skills that are difficult to develop or practice).

Example Cases

The three cases described in this section demonstrate how effective quantitative cases can be found in very accessible and mundane places. *You've Got Cocaine in Your Wallet* is based on a newspaper article, *Bowie Kuhn's Worst Nightmare* is drawn from my personal interest (baseball), and *Dynamo Automobile Alarms* was derived from a consulting project in which I participated.

You've Got Cocaine in Your Wallet. The *You've Got Cocaine in Your Wallet* case (Cochran [25]) is based on a newspaper article entitled "You're Carrying Cocaine in Your Wallet—Drugs in Britain: Special Report" (Dodd [31]) that first appeared in October of 1999 in *The Guardian*, a daily newspaper published in Great Britain. It eventually was sent out by a news service, and was first read by the author in the *Dayton Daily News* (a daily central Ohio newspaper) later that month. The article opens with the provocative claim that Prime Minister Tony Blair, Parliamentarian Jack Straw, and Sir Paul Condon (Britain's top policeman at the time) are almost certainly carrying cocaine-tainted bills in their wallets. The article then proceeds to explain that the BBC Newsroom South-East commissioned a study in which a sample of 500 British bank notes (supplied by the Bank of England's returned note centre) was tested for the presence of cocaine and ecstasy. After explaining that traces of a drug can be left on bills either by direct contact with the drug or transference through skin oils of users, the article reports some findings, including the following.

— More than 99% of the notes tested were contaminated by cocaine.

— Of the 500 notes, 4 tested were "clean."

— Nearly 1 in 20 tested notes were found to have high levels of cocaine (suggesting they had been in direct contact with the illegal drug).

— Of the tested notes, 4% contained traces of ecstasy.

— One in 100 notes tested positive for high levels of both cocaine and ecstasy.

Students must assess whether the results suggest that Britain has a serious drug problem (as is implied by the article). While presence of cocaine on 99.2% of the 500 bills sampled initially seems to imply a very serious problem, a closer look belies this conclusion. Suppose that 1% of the British population is using cocaine and could contaminate a bill; the distribution of the number of times a bill could be contaminated in its life is approximately binomial with a probability of success (contamination) of 0.01 on each trial, where the number of trials is the number of times a bill is passed throughout its circulation.

The class is actually interested in the probability that a bill is contaminated at least one time in a given number of trials. This can most easily be calculated by subtracting the probability of the complementary event (a bill is never contaminated in a given number of trials) from 1.0. Once a student decides on what s/he feels is a reasonable number of times a bill will be passed from one person to another during its circulation, it is easy to calculate this probability—for 1,000 trials under these conditions, the probability is approximately 0.0000432! Thus, given these assumptions, the results (if reliable) provide no evidence for (or against) the claim. Of course, solutions will vary across students, as they will each make their own assumptions about the number of times a bill will be passed in its circulation and the probability that it will be contaminated in any one of these passes. Students must also consider the reliability of the data: The observations may not be independent; the article does not indicate whether a probability sample was taken; presence of cocaine on a bill is likely a very poor proxy for usage; and cocaine could be spread to notes by bank sorting machines or contact with dirty notes during storage.

The author uses this case in undergraduate introductory statistics classes. It provides students with an opportunity to work with and develop a deeper understanding of basic probability and discrete probability distributions, and it requires them to make and explain assumptions in modeling this problem.

Bowie Kuhn's Worst Nightmare. In *Bowie Kuhn's Worst Nightmare* (Cochran [29]), the 1981 Major League Baseball (MLB) season provides the backdrop for a case that the author uses to help students simultaneously develop a broad understanding of integer programming and Simpson's Paradox. MLB players went out on strike after the completion of approximately one-third of the 1981 season. After another one-third of the MLB season had passed, the players and owners approved a new collective bargaining agreement. Both sides also agreed that games cancelled during the strike would not be rescheduled and the 1981 season would be divided into two "halves" (prestrike and poststrike). In each division (East and West) of each league (National and American), the team with the best prestrike record would play the team with the best poststrike record for the division championship. If the same team had both the best pre- and poststrike records within a division, that team would play the team with the second-best poststrike record for the division championship.

After devising their scheme for dealing with the playoffs, Baseball Commissioner Bowie Kuhn and the 26 franchise owners had to be concerned about whether either of two potentially embarrassing circumstances could arise:

— A team finishes with the best overall (combined pre- and poststrike) record in its division, yet fails to qualify for its divisional playoffs, or

— A team finishes first in its division in both halves of the split season but does not have the best combined (pre- and poststrike) record in its division.

Occurrence of either of these situations would further erode the fan base's diminished confidence in MLB.

Students are provided with the prestrike win-loss records and number of poststrike games scheduled for each team. As students use these data to answer both questions with relatively simple integer programming models, they have a few interesting issues to face:

— What is the criterion for comparing teams? One could use *games behind* (which is actually used by MLB and reported by newspapers) or individual team *win/loss percentages* (which is also reported by newspapers and better understood by many fans). It is important to note that these two approaches give the same results if the teams play an equal number of games.

— What happens if a team does not play all of its poststrike games (because of poor weather, etc.)?

It is easy to envision how a team could finish with the best overall (combined pre- and poststrike) record in its division, yet not qualify for its divisional playoffs (this actually happened in two divisions). On the other hand, it is much more difficult to foresee how a team could finish first in its division in both halves of the split season, but not have the best combined (pre- and poststrike) record in its division. If the student uses the games behind criterion, s/he will eventually prove that this cannot happen no matter how many poststrike games the teams play. However, if the student uses the win-loss percentage criterion, s/he will find that this can happen if there is a large discrepancy in the number of poststrike games the teams play—these students have used integer programming to demonstrate the potential for Simpson's Paradox and have gained tremendous insight into this phenomenon! This case is useful and appropriate for undergraduate and MBA introductory operations research courses (although the undergraduate students may need some guidance).

Dynamo Automobile Alarms. The *Dynamo Automobile Alarms* case is based on a small consulting project on which the author worked several years ago. The heart of the problem is a simple production-mix formulation; Dynamo Corporation produces a single product—automobile alarms—and must decide how many to produce during each quarter of the upcoming fiscal year. Dynamo's current inventory, per unit cost of maintaining inventory, and forecasted quarterly demand for the fiscal year are given in the case. The case also provides an explanation that, due to the competitive nature of the automobile alarm industry, Dynamo's customers will not place backorders. Dynamo's quarterly regular and overtime production capacities and per unit costs are provided. Finally, the case indicates that Dynamo's current labor agreement with the Automobile Alarm Workers' Union (AAWU) limits the amount of overtime labor (and overtime production) over two consecutive quarters, and the number of automobile alarms produced using overtime labor during the last quarter of the previous year is provided.

The case narrative then explains that Dynamo has the option of reopening its labor contract negotiations. Because Dynamo management believes that labor's limit on the amount of overtime production will constrict profit in the upcoming fiscal year, the company would like to negotiate a relaxation on the restriction on overtime in consecutive quarters. Students are instructed to use this information to provide Dynamo's executives with some guidelines for their labor negotiations, i.e., the amount they should be willing to pay per unit produced with overtime labor and how many units they should be willing to manufacture at that rate. This case, which can be used in undergraduate and MBA introductory operations research courses, requires the students to consider and use shadow prices to develop a strategy. It is particularly interesting because the nature of shadow prices allows for the development of several different stair-step negotiation strategies.

Miscellaneous

Several other active learning exercises defy categorization but are worthy of consideration. Descriptions of two such exercises follow.

Legos. One of the most well-known and popular active learning exercises for the operations research classroom is Pendegraft's [62] Lego exercise. The class is divided into small teams, each of which is given a bag containing eight small and six large Legos; these pieces represent the two inputs necessary to manufacture tables and chairs. Instructions on how to construct a table or chair from the Lego pieces are provided; tables are built from two large and two small Legos, while chairs are built from one large and two small Legos. After the teams are told that tables sell for $16 and chairs sell for $10, they are then given a few minutes to attempt to find a product mix that maximizes profits from the available resources (the Lego pieces).

If this game is played prior to coverage of linear programming, it serves as an excellent proactive exercise; although many student teams can find the optimal mix through trial and error, some teams will arrive at some suboptimal solution. The entire class can then work through the formulation, which then can provide the basis for discussions on graphical, algebraic, and/or spreadsheet approaches to solving the problem to optimality. Students quickly develop a basic understanding of linear programming and generally agree on its value. Of course, the game can be extended—the results provide a fertile and concrete example of how the marginal values of the various resources change as the class moves from the current extreme point to an adjacent extreme point on the feasible region. The game also provides a natural lead-in to integer programming.

Monty Hall (or Three Door) Problem. The Monty Hall problem is a well-known and interesting puzzle that can be used to teach several basic probability concepts. Monty Hall, the host of the popular television game show *Let's Make A Deal*, offers a contestant a choice of three doors. The contestant will receive the prize that is concealed behind the chosen door. Behind one door is a very desirable prize, while the other two doors conceal undesirable prizes. After the contestant selects a door, Monty opens one of the remaining two doors and exposes an undesirable prize (because there are two undesirable prizes and Monty knows their locations, he can always do this). Monty then offers to trade the remaining unopened door for the door the contestant originally chose. The contestant's optimal decision is to swap doors with Monty—her/his probability of winning the desirable prize increases from one out of three to two out three.

To use the Monty Hall problem in class, the instructor begins by dividing a deck of playing cards into sets of three; each set should contain exactly two cards with identical face values. S/he asks the students to find a partner and distributes one set of the cards to each student pair. One member of each student pair acts as Monty Hall and the other acts as the contestant, and the student pairs use the cards to repeatedly play the game while keeping track of how often the contestant wins when he (i) keeps his original card and (ii) swaps with Monty. After several executions (perhaps 20 times), the students reverse roles and play again for several executions. After both students in each pair have had an opportunity to act as the contestant, each student pair summarizes their results and writes a paragraph justifying what they believe to be the contestant's optimal decision.

This drill enables students to intuitively understand the solution to the Monty Hall problem, and by doing so also gain deeper insight into several basic probability concepts. The instructor uses this exercise in undergraduate introductory statistics courses.

Conclusions

Lectures are generally far more effective when they are periodically interrupted; a break can effectively recapture the students' attention and interest. When punctuated with an interesting and relevant active learning exercise, the break becomes even more effective. These activities do not have to be elaborate to be successful; a simple exercise can reveal subtleties, emphasize key points, expose similarities in and differences between concepts, and provide transitions to new topics. Such an exercise can also encourage students to think about a concept in an engaged manner, help them integrate ideas, and promote greater retention of course material. This can all be accomplished at a relatively small cost to both the instructor and the student—if they are willing to put forth a small amount of effort, the rewards can be tremendous. For lists of further readings on active learning, see the INFORM-*ED* website on active learning (http://education.forum.informs.org/active.htm), Charles C. Bonwell's *The Active Learning Site* [5], or Richard M. Felder's *Active and Cooperative Learning* Site [37].

References

[1] Active Learning Online. http://www.acu.edu/cte/activelearning/.

[2] H. Barrows. *Designing a Problem Based Curriculum for the Pre-Clinical Years.* Springer, New York, 1985.

[3] J. Benek-Rivera and V. E. Mathews. Active learning with *Jeopardy*: Students ask the questions. *Journal of Management Education* 28(1):104–118, 2004.

[4] A. Biesterfeld. The price (or probability) is right. *Journal of Statistics Education* 9(3): 2001. http://www.amstat.org/publications/jse/v9n3/biesterfeld.html.

[5] C. C. Bonwell. *The Active Learning Site.* http://www.active-learning-site.com/.

[6] C. C. Bonwell and J. A. Eison. Active learning: Creating excitement in the classroom. ASHE-ERIC Higher Education Report No.1. George Washington University, Washington, D.C., 1991.

[7] R. Bosch. Big Mac attack. *ORMS Today* 20(4):30–31, 1993.

[8] G. Brown and M. Atkins. *Effective Teaching in Higher Education*, Methuen, London, 1988.

[9] W. E. Campbell and K. A. Smith. *New Paradigms for College Teaching.* Jossey-Bass, San Francisco, CA, 1995.

[10] W. E. Cashin. Improving lectures. IDEA Paper No. 14. Kansas State University Center for Faculty Evaluation and Development, Manhattan, KS, 1985.

[11] R. T. Chappell. Can TQM in public education survive without co-production? *Quality Progress* 27(7):41–44, 1994.

[12] A. W. Chickering and Z. F. Gamson. Seven principles for good practice. *AAHE Bulletin* 39:3–7, 1987.

[13] G. W. Chilcoat. Instructional behaviors for clearer presentations in the classroom. *Instructional Science* 18:289–314, 1989.

[14] M. J. Chlond. Unconstrained peg solitaire. *INFORMS Transactions on Education* 2(3), 2002a. http://ite.pubs.informs.org/Vol2No3/Chlond/.

[15] M. J. Chlond. The traveling space telescope problem. *INFORMS Transactions on Education* 3(1), 2002b. http://ite.pubs.informs.org/Vol3No1/Chlond/.

[16] M. J. Chlond. A new kind of IP. *INFORMS Transactions on Education* 4(2), 2004a. http://ite.pubs.informs.org/Vol4No2/Chlond/.

[17] M. J. Chlond. Fantasy OR. *INFORMS Transactions on Education* 4(3), 2004b. http://ite.pubs.informs.org/Vol4No3/Chlond/.

[18] M. J. Chlond. Classroom exercises in IP modeling: Su Doku and the log pile. *INFORMS Transactions on Education* 5(2), 2005. http://ite.pubs.informs.org/Vol5No2/Chlond/.

[19] M. J. Chlond and C. M. Toase. IP modeling of chessboard placements and related puzzles. *INFORMS Transactions on Education* 2(2), 2002. http://ite.informs.org/vol2no2/ChlondToase/.

[20] M. J. Chlond and C. M. Toase. IP modeling and the logical puzzles of Raymond Smullyan. *INFORMS Transactions on Education* 3(3), 2003. http://ite.pubs.informs.org/Vol3No3/ChlondToase/.

[21] M. J. Chlond, R. C. Daniel, and S. Heipcke. Fiveleapers a-leaping. *INFORMS Transactions on Education* 4(1), 2003. http://ite.pubs.informs.org/Vol4No1/ChlondDanielHeipcke/.

[22] C. S. Claxton and P. H. Murrell. Learning styles: Implications for improving educational practice. ASHE-ERIC Higher Education Report No. 4. George Washington University, Washington, D.C., 1987.

[23] W. H. Cliff and L. N. Curtin. The directed case method. *Journal of College Science Teaching* 30(1):64–66, 2000.

[24] J. J. Cochran. A case methodology for introductory statistics & MS courses in undergraduate business programs. *INFORMS Annual Meeting*, Seattle, WA (October) 1998.

[25] J. J. Cochran. *You've Got Cocaine in Your Wallet: A Simple and Effective Probability Case. INFORMS Annual Meeting*, Salt Lake City, UT, 2000.

[26] J. J. Cochran. Successful use of cases in introductory undergraduate business college operations research courses. *The Journal of the Operational Research Society* 51(12):1378–1386, 2000.

[27] J. J. Cochran. *Who Wants To Be A Millionaire—The Classroom Edition. INFORMS Transactions on Education* (1)3, 2001a. http://ite.informs.org/Vol1No3/Cochran/.

[28] J. J. Cochran. Probability, statistics, and "playing games." *ORMS Today* 28(2):14, 2001b.

[29] J. J. Cochran. *Bowie Kuhn's Worst Nightmare. INFORMS Transactions on Education* 5(1), 2004. http://ite.pubs.informs.org/Vol5No1/Cochran/.

[30] J. J. Cochran. Can you really learn basic probability by playing sports board games? *The American Statistician* 59(3):266–272, 2005.

[31] V. Dodd. You're carrying cocaine in your wallet—Drugs in Britain: Special report. *The Guardian* (October 4) 1999.

[32] S. Eckert. Teaching hypothesis testing with playing cards: A demonstration. *Journal of Statistics Education* 2(1), 1994. http://www.amstat.org/publications/jse/v2n1/eckert.html.

[33] E. Erkut. Big Mac attack revisited. *ORMS Today* 21(3):50–52, 1994.

[34] M. C. Feinstein and T. L. Veenendall. Using the case study method to teach interpersonal communication. *Inquiry: Critical Thinking Across the Disciplines* 9(3):11–14, 1992.

[35] R. M. Felder. Reaching the second tier: Learning and teaching styles in college science education. *Journal of College Science Teaching* 235:286–290, 1993.

[36] R. M. Felder. Cooperative learning in a sequence of engineering courses: A success story. *Cooperative Learning and College Teaching Newsletter* 5(2):10–13, 1995.

[37] R. M. Felder. Active and cooperative learning site. http://www.ncsu.edu/felder-public/Cooperative_Learning.html.

[38] R. M. Felder and R. Brent. Navigating the bumpy road to student-centered instruction. *College Teaching* 44(2):43–47, 1996.

[39] R. M. Felder and R. Brent. Learning by doing. *Chemical Engineering Education* 37(4):282–283, 2003.

[40] L. Feldman and F. Morgan. The pedagogy and probability of the dice game HOG. *Journal of Statistics Education* 11(2), 2003. www.amstat.org/publications/jse/v11n2/feldman.html.

[41] J. Garfield. Teaching statistics using small-group cooperative learning. *Journal of Statistics Education* 1(1), 1993. http://www.amstat.org/publications/jse/v1n1/garfield.html.

[42] P. G. George. The effectiveness of cooperative learning strategies in multicultural university classrooms. *Journal of Excellence in College Teaching* 51:21–30, 1994.

[43] G. Giraud. Cooperative learning and statistics instruction. *Journal of Statistics Education* 5(3), 1997. http://www.amstat.org/publications/jse/v5n3/giraud.html.

[44] M. Gnanadesikan, R. L. Scheaffer, A. E. Watkins, and J. A. Witmer. An activity-based statistics course. *Journal of Statistics Education* 5(2), 1997. http://www.amstat.org/publications/jse/v5n2/gnanadesikan.html.

[45] C. R. Haller, V. J. Gallagher, T. L. Weldon, and R. M. Felder, Dynamics of peer education in cooperative learning workgroups. *Journal Engineering Education* 89(3):285–293, 2000.

[46] J. Hartley and A. Cameron. Some observations on the efficiency of lecturing. *Educational Review* 20:30–37, 1967.

[47] J. Hartley and I. K. Davies. Note-taking: A critical review. *Programmed Learning and Educational Technology* 15:207–224, 1978.

[48] C. F. Herreid. Structured controversy: A case study strategy. *Journal of College Science Teaching* 26(2):95–101, 1996.

[49] C. F. Herried. The case study: Can case studies be used to teach critical thinking? *Journal of College Science Teaching* 33(6):12–15, 2004.

[50] INFORM-*ED* website on Active Learning. http://education.forum.informs.org/active.htm.

[51] D. W. Johnson, R. T. Johnson, and K. A. Smith. *Active Learning: Cooperation in the College Classroom.* Interaction Book Co., Edina, MN, 1991.

[52] C. M. Keeler and R. K. Steinhorst. Using small groups to promote active learning in the introductory statistics course: A report from the field. *Journal of Statistics Education* 3(2), 1995. http://www.amstat.org/publications/jse/v3n2/keeler.html.

[53] S. M. Kelley, K. M. Shemberg, B. S. Cowell, and B. J. Zinnbaur. Coping with students resistance to critical thinking: What the psychotherapy literature can tell us. *College Teaching* 43(4):140–145, 1995.

[54] C. Letavec and J. Ruggiero. The n-queens problem. *INFORMS Transactions on Education* 2(3), 2002. http://ite.pubs.informs.org/Vol2No3/LetavecRuggiero/.

[55] R. C. Magel. Using cooperative learning in a large introductory statistics class. *Journal of Statistics Education* 6(3), 1998. http://www.amstat.org/publications/jse/v6n3/magel.html.

[56] W. J. McKeachie. *Teaching Tips*, 10th ed. Houghton Mifflin Co., Boston, MA, 1999.

[57] W. J. McKeachie, P. R. Pintrich, Y. Lin, and D. A. F. Smith. Teaching and learning in the college classroom: A review of the research literature. Regents of The University of Michigan, Ann Arbor, MI, 1986.

[58] K. McKinney. Active learning. http://www.cat.ilstu.edu/teaching_tips/handouts/newactive.shtml.

[59] J. McLeish. *The Lecture Method*. Cambridge Monographs on Teaching Methods, Cambridge Institute of Education, Cambridge, England, 1968.

[60] D. Myers. LETGO, Inc. *INFORMS Transactions on Education* 3(1), 2002. http://ite.informs.org/Vol3No1/Myers/.

[61] J. S. Osland, D. A. Kolb, and I. M. Rubin. *Organizational Psychology: An Experiential Approach*, 7th ed. Prentice-Hall, Englewood Cliffs, NJ, 2001.

[62] N. Pendegraft. Lego of my simplex. *ORMS Today* 24(1):8, 1997.

[63] J. G. Penner. *Why Many College Teachers Cannot Lecture*. Charles C. Thomas, Springfield, IL, 1984.

[64] L. G. Richards, M. Gorman, W. T. Scherer, and R. D. Landel. Promoting active learning with cases and instructional modules. *Journal of Engineering Education* 84(4):375–381, 1995.

[65] K. L. Ruhl, C. A. Hughes, and P. J. Schloss. Using the pause procedure to enhance lecture recall. *Teacher Education and Special Education* 10:14–18, 1987.

[66] C. M. Rump. Who wants to see a $million error? *INFORMS Transactions on Education* 1(3), 2001. http://ite.informs.org/vol1no3/Rump/.

[67] D. J. Rumsey. A cooperative teaching approach to introductory statistics. *Journal of Statistics Education* 6(1), 1998. http://www.amstat.org/publications/jse/v6n1/rumsey.html.

[68] I. J. Russell, W. D. Hendricson, and R. J. Herbert. Effects of lecture information density on medical student achievement. *Journal of Medical Education* 59:881–889, 1984.

[69] D. M. Schweiger, W. R. Sandberg, and J. W. Ragan. Group approaches for improving strategic decision making: A comparative analysis of dialectical inquiry, devil's advocacy, and consensus. *Academy of Management Journal* 29(1):51–71, 1986.

[70] K. Seal. Teaching with technology. *INFORMS Teaching of Management Science Workshop*, Marlborough, MA (July) 2004.

[71] M. Sniedovich. OR/MS games: 1. A neglected educational resource. *INFORMS Transactions on Education* 2(3), 2002a. http://ite.informs.org/Vol2No3/Sniedovich/.

[72] M. Sniedovich. OR/MS games: 2. Towers of Hanoi. *INFORMS Transactions on Education* 3(1), 2002b. http://ite.pubs.informs.org/Vol3No1/Sniedovich/.

[73] M. Sniedovich. OR/MS games: 3. Counterfeit coin problem. *INFORMS Transactions on Education* 3(2), 2003. http://ite.pubs.informs.org/Vol3No2/Sniedovich/.

[74] W. J. Stepien and S. A. Gallagher. Problem-based learning: As authentic as it gets. *Educational Leadership* 50(7):25–28, 1993.

[75] M. Trick. Building a better game through dynamic programming: A flip analysis. *INFORMS Transactions on Education* 2(1), 2001. http://ite.informs.org/vol2no1/trick/.

[76] G. Whitaker. Co-production: Citizen participation in service delivery. *Public Administration Review* (May–June):240–242, 1980.

[77] D. R. Woods. 1996. *Problem-Based Learning: How to Gain the Most from PBL*. Donald R. Woods, Waterdown, ON, 1996.

[78] J. Yeomans. Solving "Einstein's riddle" using spreadsheet optimization. *INFORMS Transactions on Education* 3(2), 2003. http://ite.pubs.informs.org/Vol3No2/Yeomans/.