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Teaching Business Modeling Using Spreadsheets

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Before spreadsheets, modeling of business concerns required some competency in mathematics (algebra, calculus, statistics, and probability) and in computer programming, skills that are rather intimidating for the average business executive and management school student. However, the spreadsheet and the personal computer revolution challenged that paradigm. With its simple intuitive interface, direct interactivity, and universal presence, the humble spreadsheet has made business modeling much easier and has been considered by many analysts as the tool of choice for exploring business opportunities. Many university professors have already adopted spreadsheets as their computing platform in support of teaching business mathematics, statistics, and management science courses. Though some business modeling skills can be learned when spreadsheets are used in the courses, they are often secondary to the task of delivering the main subject content. Working out business challenges in the real world, however, requires good spreadsheet modeling skills, in particular that of using the spreadsheet for rapid understanding of ill-defined and unstructured situations. It has been argued that basic modeling skills should be taught prior to management science methods. We agree and further assert here that modeling skills should be taught in a separate full course on “exploratory” modeling of general business challenges rather than “computational” modeling of standard problems relevant to the application of management science methods. We have designed and successfully delivered to thousands of undergraduates over the past four years a course in business modeling with spreadsheets. In this paper, we will discuss the novelty of our course content and approach and will elaborate on the key pedagogical challenges.

Key words: spreadsheets; business problems; teaching; exploratory modeling

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Introduction

Spreadsheets increasingly play an important role in corporate life for business modeling, analysis, and decision support. Undergraduates (from business, accountancy, information systems, economics, and social sciences at our university) doing internships in all business functional areas have told us that Excel skills are invaluable and that corporate recruiters demand spreadsheet skills when hiring fresh graduates. It is therefore worthwhile to examine how well spreadsheets are incorporated into management education and in what ways we can do better. Traditionally (and this is largely still true) most university undergraduate programs teach foundational courses in statistics, calculus, and computer programming; their main purpose is to equip undergraduates with the ability to analyze and solve problems. However, these efforts are lost on many students, who find learning such technical material dry and demanding and who usually do not continue to apply the

skills meaningfully beyond university course work. To ease the burden of equipping students with analytical skills, more professors teaching these courses, and also those teaching management science (Liberatore and Nydick 1999 and Winston 1996), have embraced spreadsheets as their primary computing and teaching tool.

Both Powell (1998) and Grossman (2001) noted the decline of the business school management science course. Grossman offered an analysis, quoting the Magnanti report on “the irrelevancy of algorithm- and model-focused courses” while arguing that demand still exists “for model formulation and interpretation and...quantitative reasoning.” Quantitative foundation and management science courses, even with the aid of user-friendly software like Excel, can only at best teach students to be better consumers of analysis (Powell 1997a). To make management education more relevant to the marketplace, students should be trained as active modelers to address immedi-

ate concerns and challenges. While some spreadsheet and modeling skills may be learned incidentally in courses taught with spreadsheets, they remain secondary to the delivery of the courses' main subject content (Powell 1997b), such as the well-established statistical, optimization, and simulation methods. We would also like to emphasize that just being exposed to many models in spreadsheet format does not necessarily mean that students automatically know how to construct these models. In fact, our experience suggests that without direct, explicit learning of spreadsheet modeling, most business undergraduates cannot translate real problems into spreadsheet models.

Gass et al. (2000) warned of "overreliance on spreadsheets" in teaching management science courses and that "...striving to get the spreadsheet right is taking precedence over what is right." They questioned the assumption that spreadsheet users "are ready, willing, and able" to solve management science problems on their spreadsheets. They (and also Liberatore and Nydick 1998) instead prefer using stand-alone software such as LINGOTM, ExtendTM, Stat::FitTM, and Expert ChoiceTM over spreadsheets for teaching management science. However, it is undeniable that spreadsheets are transparent to users, whereas other packaged software applications are like black boxes. According to Powell (2000), modeling is the activity of creating a "simplified representation of reality" in order to understand reality better. Developing models help people learn how they think about the problem and its solution model and in so doing, learn to think better in the future. Used in a group setting, the models can help unravel hidden mindsets, share individual knowledge, and drive common understanding. This can be helpful in team building and group learning. Powell went further to propose a hierarchy of modeling skills: basic quantitative reasoning, informal modeling (e.g., identifying critical assumptions), formal modeling (like Excel skills), understanding models from other disciplines, end-user modeling, and understanding and working with large-scale models. Since then, Powell (2000), Grossman (2002, 2006a), and others have added spreadsheet engineering and modeling to their courses by explicitly defining and teaching systematic approaches to develop spreadsheet models, as in well-managed software development, and specifying best practices for spreadsheet layout along the lines of good graphical user interface (GUI) design. Their call for a "standalone course on spreadsheet modeling" (Powell and Shumsky 2007) is a step in the right direction, but their actual response is still primarily the management science course, albeit modified to teach optimization and simulation via a spreadsheet modeling approach.

We would like to stress that clearer distinction should be made between "exploratory" modeling as a process to address less-structured problems and "computational" modeling for developing solutions of more-structured problems (Willemain and Powell 2006 and Sokol 2005). Working out business concerns requires good broad modeling skills (Grossman 2006b), specifically for rapid understanding of problems that are ill-defined and unstructured and for the effective managerial communication of the findings to non-technical people. Rather than algorithmic computations, discovering solutions to problems in real life usually include a process of negotiations among stakeholders, often best facilitated by spreadsheets. Recent "management science with Excel" textbooks (e.g., Kros 2007, Albright and Winston 2005, and Powell and Baker 2004) still place too much emphasis on well-structured classical optimization and simulation problems. They do not really address the challenge that to be competent in the marketplace, management students need to be able to do spreadsheet modeling, which is really a combination of strong spreadsheet skills and practical exploratory modeling, communication, and business consulting capabilities. Unless students are already fairly competent in modeling with spreadsheets, there may be in these revised management science courses and textbooks still too many models and not enough modeling.

As rightly put across by Grossman (2006a), the widespread perception that spreadsheets are easy is false; it would be more accurate to say that "spreadsheets are easy at the fundamental level, but difficult at the advanced level." He also states that having relevant context is essential to the effective learning of spreadsheet skills. Spreadsheets are for serious work, and serious advanced work does not necessarily involve either optimization or simulation. Business executives and managers face many small-scale unstructured problems that they need to work out regularly on their own. Constructing a spreadsheet for exploratory modeling of a simple problem is already quite a challenge. There is no lack of excellent, relatively simple real-life contexts for learning; all one has to do is to extract them from real practice. This assertion is consistent with the first author's personal experience in industry, having spent more than half of his almost thirty years' working life in junior engineering as well as senior management positions in reputable global organizations when he was away from academia. In our opinion, the main challenge to get management education back on the right track, for management science and more broadly for business education, is to first teach spreadsheet modeling of simple unstructured problems and to provide ample learning opportunities to firmly establish basic modeling skills before moving on to more advanced management science methods.

We reiterate that a course that teaches spreadsheet technicalities, spreadsheet modeling, and management science cannot do justice to improving students' spreadsheet skills or their appreciation of practical modeling, and it compromises to some degree the learning of management science. Hence, a truly standalone spreadsheet modeling course, uncomplicated by management science, is really the more appropriate approach. This course, however, should not be confused with a technical course on Excel and its use as a rapid development language and environment. To learn modeling, a problem-driven rather than technique-centered approach is vital. The rest of this paper describes the full-term undergraduate course we have designed and successfully delivered to thousands of students, one that is dedicated to guiding them to learn the effective application of spreadsheets and the practice of modeling and analysis of basic business concerns.

The CAT Course

To make students appreciate how much personal computing has advanced and how it may be employed more effectively to enhance their analytical abilities, the founding pioneers of our young university thought it wise to have in our curriculum a separate course on business modeling with spreadsheets. This is in addition to a management science course that also extensively uses spreadsheets. The "Computer as an Analysis Tool" course (CAT, as it is more affectionately known here) is originally based on a course with the same title offered at The Wharton Business School, University of Pennsylvania, was made mandatory for all business undergraduates. Our management university now comprises six schools: Accountancy, Business, Economics, Information Systems, Law, and Social Sciences. All these schools, with exceptions of the Accountancy and Law schools, require their entire undergraduate population to take CAT. The proportion of each accounting student cohort completing CAT has risen from 20% to more than 80% in recent years, because they too find the course useful enough to voluntarily take it.

With the desire to improve the skills of our students to address wider and more general business problems, we revamped the course to limit its focus to the art of business problem modeling and solution prototyping and trimmed away all other software applications to focus on only one, the Microsoft® Excel spreadsheet. Advanced problem analysis and optimization are deliberately de-emphasized. The curriculum review that preceded this sharpening in focus looked into issues such as how the course may be made more relevant to the modern business environment, better match students' abilities,

and complement other courses offered in our various undergraduate programs and at the same time be pedagogically enhanced.

Suggestions and criticisms were solicited from our colleagues in the School of Information Systems and also in other schools, senior academics and deans of well-known universities, and relevant industry advisors and partners. We have to date received no major criticism; many have given their unreserved praise of our curriculum and pedagogy. For example, following a desktop review of the course and an ad hoc class visit, Mr. Brian Cargille, APJ Manager of Strategic Planning and Modeling at Hewlett-Packard, commented: "HP's Strategic Planning and Modeling team has done analytic modeling work in Excel for more than 17 years. We have recently started offering spreadsheet modeling training to HP employees which has been very much appreciated by our colleagues and company management. Strong spreadsheet skills are critical to many job functions in today's business environment. I'm very impressed with the Singapore Management University's Computer as an Analysis Tool course. It provides exactly the types of skills I like to see in new recruits. Good job by SMU."

CAT teaches spreadsheet business modeling. Instead of continuing into statistics, optimization, or simulation like other so-called "modeling with spreadsheets" courses, it surrounds its spreadsheet technical core with more pragmatic issues like basic exploratory modeling and consulting soft skills, data manipulation and import from external sources, and prototyping spreadsheet solution models as decision support systems (Ragsdale 2000). Students who desire to further explore more sophisticated analysis and solution optimization can do so in the other courses they take in the accounting, business functional, economics, and management science areas. We therefore encourage our undergraduates to take CAT in their early years in the university. Anecdotal evidence suggests that in many other courses on our campus that use spreadsheets extensively, students who have taken CAT have a distinct advantage over others who have not. The business school has recently stated that students enrolling into the management science course should preferably have taken CAT.

While our university adopts a United States-style, broad-based undergraduate education curriculum, practically all of our students are from Asia. Most Asian students in our university live relatively sheltered lives and do not explore much learning beyond usual schooling. Moreover, their high-school mathematics tend to be more science and engineering directed. As a result, students we enrolled have very basic spreadsheet skills and hardly any entrepreneurial or business thinking abilities.

This is evident when we, in general observation, contrast our US and European foreign (regular and exchange) students against our Asian students. CAT is thus a very much desired foundational preparation as it also indirectly introduces students to many day-to-day business concepts like product pricing and demand estimation, time value of money, and impact of interest rate fluctuations.

Just as observed by Powell (1997b), our students actually want to improve their spreadsheet skills because they know that doing so will help them perform better in school and at future jobs. Acquiring spreadsheet skills helps students address the general concern of whether graduates from our new university can hit the ground running on their first day of work and thereby helps them get employer satisfaction ratings higher than those of graduates from the other, more established universities in our country. Because it has delivered on its promises, the CAT course is highly popular among students and university administrators alike. As reputation was carefully cultivated by refining the curriculum and pedagogy through student and faculty feedback and is therefore not something we take for granted.

Course Delivery

The course is being taught by a team of ten (and growing) faculty members, comprising practice, tenure-track, adjunct, and visiting professors. It is offered in both fall and spring terms to more than 600 students (or 15 class sections) each term. The practice faculty members, the largest group of the four types on the team, are people with a combination of strong academic scholarship in various disciplines and industry work experience. They have provided leadership for the CAT course. A few in our team, particularly tenure-track professors, have doctorates in information systems management and are active in research involving data analysis of IT industry behavior and the economic benefits of technology. As in Regan's (2006) experience, we find it very important to employ professors who have worked or directly interacted with industry and prefer those with strong business consulting exposure. The two authors of this paper, who both majored in operations management, also have extensive industry experience in engineering, supply chain management, and information systems project development and management.

All our professors teaching CAT follow one standard curriculum; we share the same course objectives, schedule, and week-by-week teaching guide, as detailed in the course outline document written by the first author as course coordinator (Leong 2008). We also have a common pool of class and self-learning spreadsheet exercises, contributed by the

authors and some members of the team. All the adjunct and visiting professors assigned to teach CAT found the course curriculum and material to be superbly developed and appropriate for the students. This positive feedback is particularly heartening because of the adjuncts' extensive current and past industry work experiences. Some of us do lament that we could have done a lot better in our past work assignments if we only had the same sophisticated computing technology and had known some of the spreadsheet modeling approaches we now routinely teach our students. CAT is thus an enriching learning experience for the faculty as well.

Our students are given a list of Excel features and functions (see Appendix A) and are encouraged to learn them on their own vis-à-vis the specified weekly textbook readings and online help in Excel and VB Editor. We put some of the burden to learn the basic spreadsheet technicalities on the students and constantly remind ourselves not to teach too much Excel but to focus on cultivating in students the business modeling thinking and practice. Teaching assistants are engaged to grade the assignments and provide out-of-class guidance to students on computer and spreadsheet skills. Course assessments include three take-home graded assignments, an open-book in-class midterm test, and a term project. For the graded real-world project, teams of three or four students must approach an organization in the community on their own to find problems that they can help model and analyze. Some instructors adopt a thematic approach so that the projects in each class section are clustered around an industry sector.

A few hundred projects have been completed so far. Students have helped organizations in civic clubs and social welfare, education, entertainment, food and beverage, health care and medical, manufacturing and logistics, personal and lifestyle services, business services, public services, sports and recreation, transportation, and tourism and hospitality sectors. Excel workbooks students produced in these projects typically become the "business systems" for voluntary welfare organizations and small and medium enterprises. For example, a limousine service company previously used mobile phones and a crude, pen-and-paper approach to coordinate the supply and rental demand for drivers and vehicles across two physically separated hotels. Our students provided a set of workbooks, electronically linked via their computer network, that the company now uses in daily operations to record, collate, and confirm rental requests. Another set of workbooks supports the operations of our local national blood bank, and another assists in the administration of a kindergarten. Yet another collates the business contact and client details of the

regional headquarters of a global public relations company, providing tools for quick lookups and statistical analysis. In general, the projects helped organizations, large and small, to collate data and provide business analysis for day-to-day activities as well as tactical planning and new business development decision making.

Pedagogical Novelty

The most critical aspect of our course is definitely the set of class exercises we use. Mostly extracted by authors of this paper from our actual experiences in real-world work situations, they cover a reasonable range of model structures (such as future projection, time series, birth-and-death process, interest compounding, and uncertainties and risk). Their purpose is to provide the needed business contexts, and they contain brief descriptions of business situations, sometimes without posing any questions or containing much data. Another distinguishing feature is that we try as far as possible not to provide step-by-step instructions on how to construct the spreadsheet models, unlike what others (e.g., Seref et al. 2007) tend to do. Students have to learn by doing spontaneously, working models out collectively as a class or on their own, applying spreadsheet skills and asking inquiring and what-next questions. The learning is therefore experiential; more is caught rather than taught, emulating the professor as a business consultant role model. We strongly believe that giving students comprehensive data, clear questions (as in typical homework assignments), and construction procedures (as in most modeling manuals and books) takes away the modeling experience we want them to go through to learn.

Undergraduates, especially during the first few lessons, are uncomfortable and may even dislike this open-ended, problem-discovery process. They are more accustomed to courses taught with class notes and PowerPoint® slides and to filling in given data into completed spreadsheet models. Unlike the regular lecture, our approach is similar to, but more challenging than, business case studies. We use the spreadsheet as our electronic whiteboard to interactively deliberate problem contexts, sketch the modeling diagrams, and collectively work out the appropriate conclusions and resolutions. This approach is similar to what has been referred to by Powell (1995a) as the “art studio” class. Where no data are given, we even have to directly search on the Internet or indirectly derive them via a process of Fermi questions (Mattimore 1997). The emphasis is on creating models that can be maintained and re-used and finding solutions that can be implemented, which means that they are not necessarily the ones with optimal numerical answers. “Soft art” issues of office politics and

turf battles are often discussed (as in Raisel 1998). The conclusion to the analysis may be a different work procedure or a new management policy.

It is not easy to convince students of the value of such an unconventional educational approach. Moreover, it exerts higher demand on the professor to be much more competent in spreadsheet modeling and conversant with the problem context. In short, the pedagogical philosophy is to condition students to deal with problems they likely have not encountered before and to seek good closure to the analysis with actionable recommendations. Some amount of compromise is needed though, as this may be too large a cultural shock for students and for faculty who have been themselves brought up the more traditional way and unable to cope overnight with this new learner-centric, problem-driven pedagogy.

Each class includes two or at most three exercises (as listed in Appendix B). For reasons of commercial confidentiality, identities of actual companies and business nature captured in these exercises have been disguised. Teaching notes (Leong and Cheong 2008a, b) and technical descriptions (Leong 2007a, b) of some of our exercises had been written up as academic journal articles to share our experience with other professors. When working out these exercises, we avoid algebraic manipulation (which is often not a strength of business students), choosing to flesh out the problems directly (almost arithmetic-like) by linking cells in spreadsheet formulas. The results can then be easily and quickly plotted, adding much visual appeal, and their summary statistics computed. We teach our students to do trade-off analysis and sensitivity analysis. There will also be some questioning of implications arising from changes in model structure—such as, what if one of the retail stores also functions as the distribution center in a distribution network? The “what-ifs” are therefore not restricted to parametric adjustments (Caulkins 2001) alone; they include structural changes related to environmental assumptions and business options. We also analyze data sets (referred to as data list in Excel) using Excel’s sort, filter, and pivot table functionalities.

We usually start each lesson with a small exercise to allow students to practice the needed Excel skills and some modeling concepts. With some confidence and competence established, we then progress to a more open-ended manner to develop a much larger, almost full-scale spreadsheet model for a real problem. We try to avoid add-ins (software supplementary to Excel) because they tend to obfuscate the modeling process, requiring additional instruction to learn and degrading conceptual learning of the model structure. So as far as possible, we use only native Excel features. This requires some creativity on our part to

devise the necessary alternative approaches, leveraging more advanced Excel features. For example, in a Monte Carlo simulation, it is easy for students to use simple random generators, but they cannot deal with realistic problems. Distribution function fitting and statistical data analysis (e.g., goodness of fit tests) would take too much course time and would be better addressed in a full-blown course in statistics or computer simulation. To address this issue without add-ins, we devised new spreadsheet-based methodologies and tools, like resampling (Leong 2007b), adapting Excel's abilities and exploiting its advantages. Use of resampling in Monte Carlo simulation is also advocated by Savage (see Erkut 1998), another pioneer in using Excel to bring management science closer to the audience.

Classes and Exercises

Powell (1997a) has two exercises, one on pricing and market share and another on cash flow analysis. Though we did not use either of them, these are the kind of exercises suitable for CAT. Other excellent exercises in the Powell and Baker (2004) textbook that may also be used are Retirement Planning, Draft TV Commercials, Icebergs for Kuwait, and Racquetball Racket. If we used them, we would de-emphasize optimization, leaving it for students to self-explore or even pursue later when they take the management science course. We once wrote Icebergs for Kuwait as a midterm test question in which we asked students only to formulate the problem and suggest a few good alternative solutions for comparison. In the remaining paragraphs of this section, we will briefly review two of the actual exercises we wrote and used in CAT, Alex Processing and Hotel Apex, and sketch out how we use them to teach modeling.

Alex Processing (see Leong and Cheong 2008a for detailed description and pedagogical discussion) explores the problem of equipment acquisition planning. In this exercise, historical demand and equipment holding numbers for a hypothetical food processing plant are given. The broad challenge is to determine the required number of machines of different equipment types for the next 10 years. We guide students to bring up the valid business concerns of why we should plan ahead. In this case, the need arises from the long new-equipment order lead times, which make buying machines only when capacity runs out a nonviable option. In particular, the most expensive equipment has the longest order lead time of three years. This should automatically attract management attention to how equipment acquisition decisions were made in the past and what should transpire for the future. The class is led to examine the possibility of filling (an Excel feature) down the equipment numbers for the future years. This

is equivalent to linearly extrapolating the equipment numbers, which inevitably is incorrect because the recommended projected equipment numbers take no bearing from the future projected annual demands.

The discussion then should wander toward examining what each equipment type can produce per machine, then tracking how the machine productivities changed over time to try to extrapolate the values into the future. This teaches students the need to introduce intermediate variables in their models. Excel's TREND function, or insert trend line in Excel chart, can be used to project the future equipment productivities. The projection could be based on correlating productivity to either aggregate demand, years of operating the equipment type, or number of machines in the equipment type. The productivities once determined can then be used in conjunction with projected future demand to yield future equipment requirements. After offsetting for order lead times, we can translate the projected equipment requirements into an equipment acquisition plan. We would then discuss the validity of results computed in such a way and how the news can be communicated to operations managers, who are the ones responsible for achieving the productivity targets. The underlying mechanism projecting machine productivities using TREND is, of course, still a linear extrapolation. The consultancy guidance here is that such a model would be difficult to implement because the extrapolated productivity numbers will be interpreted by the operations managers as new unrealistic performance targets.

The likelihood of such scientifically derived targets being accepted by management and operations personnel is therefore highly doubtful. A possible outcome is that management would have to give further guidance on revising the model and later negotiate with operations managers over the suggested targets. If these targets are for only one year, then management would have to use its best judgment for remaining years to cover the order lead times. The class could then be guided to discuss further managerial implications, such as whether the company should try to make some effort to reduce the lead times in the first place. The company can consider prequalifying suppliers, shortening internal (and if possible, vendors') equipment ordering and approval processes, evaluating the option of buying used machines, or devising clever combinations of early retirement of older machines and proactive purchase of new machines. The last option may trigger a discussion of how with better technology new machines may be cheaper, more productive, perform more functions, and require less maintenance cost than older machines. However, the machines once purchased are sunk costs. The discussion should stop here and is better pursued by students further in other courses.

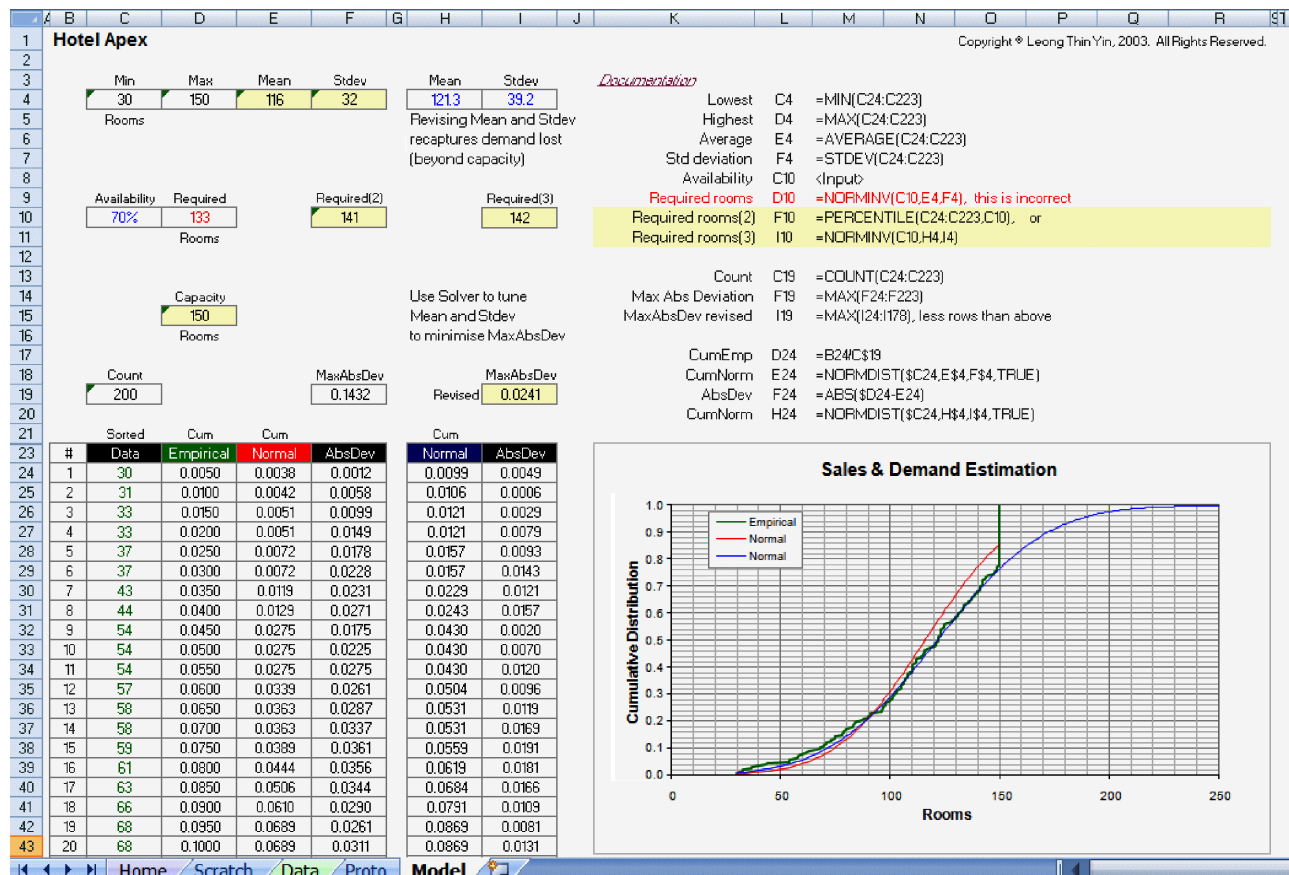
We highlight examples of publicly known best practice in world-class companies like Singapore Airlines in the acquisition of its airplane fleet. Other professors may raise from their past experience interesting observations for class discussion. For example, when the relative demand of a product increases and this product does not use much of a particular equipment type, the computed productivity of this equipment type would also change positively. This means that changes in the company's product mix and their relative demands can lead to false conclusions about changes in equipment productivity. The equipment acquisition planning model has so far implicitly assumed that the relative demands are sufficiently stable over time. Further analysis may be called for to verify if this is true. This should possibly be done in another class using another spreadsheet model. Going through the questioning routine in exploratory modeling, we learn to use Excel not only to model a business problem but also to examine the source and validity of the input values, model assumptions, and even modify the original intended purpose of study.

The Hotel Apex exercise (for details, see Leong and Cheong 2008b) illustrates how to fit the historical room demand data to the Normal distribution and

thereafter draw useful business implications. Figure 1 shows the completed worksheet for the exercise. After looking through the business context brief and data, the students have to build this model from scratch or continue from a partially completed "proto" worksheet model provided. The partially completed models are provided to save time and are used when students are able to understand the initial discussion points. The data are better understood if they are plotted, and we ask students to give the needed steps in Excel to do the plotting and to determine if there exists a better way to demonstrate the alternative approach as well.

After plotting the cumulative relative frequency of the given data and comparing it against the Normal distribution, we examine the fit by evaluating the size of the maximum absolute deviation (as in the Komolgorov-Smirnov test). The fit can be tightened by using Excel's Solver to tune the mean and standard deviation input values for the Normal distribution function. Reviewing the curves, the observant student will note that demand seems to bunch up at 150 rooms. This would lead to the discussion that we may need to reexamine the demand data. The correct conclusion would be that the so-called demand data

Figure 1 Hotel Apex Spreadsheet Model



are actually room sales. Room sales data are usually less than or equal to actual demand data. The consulting practice lesson here is to always clarify the source and nature of the data before committing them to final use.

The unusually high relative frequency at the highest room sale value occurs because the hotel has a maximum capacity of 150 rooms. So even though the hotel capacity was not given, the students now learn that it can be inferred. How then would one collect demand data? In practice, it is difficult to physically collect them. Because demand can be assumed to be equal to sales whenever sales are less than capacity, one approach is to fit the Normal distribution against the data less the 150 values, thereby permitting us to extrapolate the truncated tail to the empirical distribution. This tail corresponds to the distribution of lost sales, a valuable piece of information for the hotel management to ponder.

Spreadsheet Engineering

The Black-box diagram and the Influence diagram (like those in Powell 1997a) are used in our lessons to help students develop the business models systematically. The Black-box diagram aids the modeler to differentiate between controllable and uncontrollable inputs and between performance measures and intermediate variables' outputs. The Influence diagram shows students how to relate the various individual variables to each other, without being bogged down in specifying their precise functional relationships prematurely. Some textbooks suggest that the Black-box diagram be done first, followed by the Influence diagram. This, however, is not so applicable for exploratory modeling, when it is still not quite clear in the beginning what exactly the model is to determine. Our suggestion is therefore to reverse the order: work with the client to draw the Influence diagram first and then the Black-box diagram. After mastering these two basic diagrams, students can move on to other, more sophisticated artifacts like the Data Flow diagram, GUI design and storyboard, and even UML's (Unified Modeling Language) Use Case diagram. Because these are essentially more useful for larger system development projects rather than our smaller business problem analyses, we spend no class time on them. Instead, we post links on our course website for students to find reference primers so that they can progress further on their own.

We encourage our students to prepare their spreadsheet models in a standardized manner, particularly by separating data and model and using color-coding. From Figure 1, we can see that input data and key output results are normally placed at the top portion of the sheet, followed by working tables and then

documentation of key cell formulas (which may be placed at the bottom or to the far right). Color-coding is used to improve the visual representation of each data type so that users can easily distinguish between inputs, outputs, and intermediate calculations. Along with user-friendliness and professional sharpness, we are also stringent in other aspects of the model layout: the model must be screen-friendly, print-friendly, and photocopy-friendly. By screen-friendly, we mean that the sheet must be formatted in such a way that little or no scrolling is required. Print-friendly refers to formatting the model such that the model can fit nicely into sheets, specifically without cutting a table across multiple pages. Finally, photocopy-friendly means a careful selection of colors for fonts and fills so that the model looks impressive even in a grayscale printout.

One important skill we cannot emphasize enough to our students is proper documentation. Documenting key formulas of the model is critical because it facilitates the review of model correctness. We expect the formulas of a set of key representative cells to be written out in the model so that users can easily follow the business logic alongside the numerical solutions and understand how the model is defined, computed, and derived. Refer again to Figure 1 for an example of our documentation scheme. We keep stressing that a spreadsheet model should be built simply. Even for large tables, we set up the spreadsheet models such that the formulas of cells in their top rows (with appropriate relative and absolute referencing) can be copied and pasted down to the rest of the table to complete it. We also emphasize the need to ensure that worksheet cells, other than the input cells, are protected to avoid errors due to accidental tampering.

Our students also learn the difference between a dynamic "live" spreadsheet versus a static one; we teach them to explore and leverage the dynamic nature of the spreadsheet. For example, GoalSeek is a very powerful feature that allows users to find in reverse the input value for a desired output value. Doing this in a symbolic mathematical expression may be difficult, depending on how complex the original function is and whether it can be inverted. In Excel, we just need to enter the "set," "by changing" cell references, and the target value into the GoalSeek pop-up panel and let the computer do the iterative computation. This feature is somewhat interactive but not dynamic enough. Every time part of the spreadsheet model that may affect the input-output relationship is altered, one would have to consciously remember to redo GoalSeek to get the new desired answer. The same is true for Data Sort and Solver. We have since discovered that the SMALL function can be used to sort an array of values. Now, SMALL(dataArray, 1)

would give the smallest value among all the values in `dataArray`, which is the same result as in `MIN(dataArray)`. However, we can replace the 1 value in `SMALL` with a cell reference. So when we use `SMALL` against a column of $1, 2, \dots, n$, we sort the n values. This approach is better than using Data Sort because it will dynamically sort values in tables. The spreadsheet is thus made “live” again.

During the past few years delivering this course, we learn to understand Excel better and have found other very useful Excel features and functionalities that can solve seemingly complex issues. We share these with our students so that they can use the spreadsheet more effectively. In particular, Excel has many features found only in standard programming languages. It provides the If-Then-Else construct in the IF function. We can use logical expressions and functions like MIN and MAX to do computations that would have required many layers of nested IF formulations in regular computer programs. Excel spreadsheets can also do iterative, recursive, and loop computations. Iterative and recursive calculations are done by setting up circular referencing among the cells and selecting the iteration option in the Tools/Options/Calculation menu. Loop computation is provided by way of the DataTable feature. The two-dimensional DataTable would be equivalent to a pair of nested For...Next loops in Visual Basic. The DataTable, when used in a MonteCarlo simulation model, can be made to effortlessly collect the results of thousands of replications.

Comments

Because this course is taken by students from different schools and undergraduate programs, students join the course with greatly differing backgrounds, levels of mathematical preparation, computer literacy, and exposure to Excel. As professors, we need to pace our classes carefully so that the weaker students will not find it too hard to follow, while stronger students are not bored. Many students who joined the class with a strong background in Excel (e.g., those from our polytechnics—technical high school equivalents) have admitted that they have learnt tremendously from the course, while the mathematically weaker social science students have completed the course feeling confident and more equipped. The problem is mitigated with the good set of class exercises and employing professors with consulting experience to achieve the right balance of Excel and modeling in the lessons.

We understand that such a course must be taught in an interactive manner with lots of hands-on exercises. For this reason, we have deliberately kept our class

size small. In the studio atmosphere, we try to interact with the class as a whole and also with each student individually, giving him or her personal attention and getting feedback on how they are doing. We structure the lessons to make sure that each student has something useful to take away after each class, no matter what his or her prior skills and experiences may be. We find that students stronger in Excel are generally weaker in modeling and vice versa. We make use of this apparent difference to our advantage by letting the students help each other. First, we employ teaching assistants empathetic undergraduate students who have completed CAT in past terms, to provide supplementary out-of-class help to overcome fears and minor difficulties. In class, we create many 5- to 15-minute short student interaction “buzz” times. These typically take place after we introduce a new exercise with some discussion and a short demonstration. Students have the liberty to get or give assistance to people on their immediate left or right during these “buzz” times. To motivate them, we count this time toward class participation assessment.

We try to train students to take a professional practice perspective in all their work: reports should be short, worksheets slick, vocal delivery clear, and presentation slides impressive. In particular, students are expected to spend effort to improve the look and feel of their spreadsheets, to make them user-friendly, easily supportive of decision making, and simple to maintain (modify data, update, etc.). Improvement feedback is usually given on the spot in class, to cover all aspects, including communications style and political positioning, modeling effectiveness, and technical inadequacies. Each student team is assigned to evaluate another team’s project to practice their appraisal skills. We have anecdotal observations that some of our students do not appreciate the attention given to such issues and may prefer a straightforward technical class.

Modeling requires users to have some basic knowledge of statistics and probability. While the CAT course tries to integrate knowledge learned in the past and from other courses (like high school mathematics and statistics), the unfortunate thing is that often students have forgotten about or had not done well in those courses. So some remediation is required. We use Excel workbooks to review those concepts. Students can look at these workbooks, with their dynamic updating and animation features, on their own time. Examples of good practice and technical background knowledge are also given away in our course website as Excel workbook “tools” for students to explore at their own leisure and adapt for project work. They are also introduced to the wider spreadsheet research and Excel modeling community and

to various “cool” resources like Excel-based games, Google™ Earth, and open source software in the Internet, to introduce some fun elements into the course.

We believe there is yet no good textbook available for the course. Books available are either too Excel/VBA centric or are primarily statistics or management science texts (see Grossman 2007 for a good list of management science textbooks that use spreadsheets). In particular, Power and Baker (2004) has a few good chapters on spreadsheet engineering, but the book is mostly a management science text and also too advanced for undergraduates. Gips (2003) is our adopted main textbook because it teaches the use of Excel features simply, briefly, and better than the Excel manuals, but with a business modeling slant. Winston (2004) is a good recipe book full of interesting business models used as the basis to teach Excel. It is a possible alternative main textbook. We will be using this as our recommended text for the yet-to-be launched masters degree-level version of CAT. Barlow (2005) is another wonderful cookbook of models, more comprehensively covering most of the business function areas, especially operations. However, it is still a book of models and not about the art and process of business consulting modeling. For situations where much more hand-holding is required, this kind of recipe book may be needed. Walkenbach (2004) is our supplementary textbook. This relatively light book is an easy introduction and reference to Excel/VBA that students can use on their own, to help themselves in their project work.

Conclusions

Many of our students are saying (see Appendix D) that CAT is one of the best courses they have ever taken. The course itself is regularly rated high in term-end student evaluations. Students are challenged in class, find the workload heavy, but learn valuable practical skills. We do not take the undergraduates rigorously through computer programming, though they do get exposed to Excel/VBA and macros in the

class exercises and project work. Our students' Excel skills are not always great after the CAT course but are usually more than adequate. The important thing is that they always end up beaming with confidence—from having the ability to do their work and from the positive responses they get from their clients. This begins a new journey for them. We adopt the premise offered by Powell (2000) that “the heart of management science is not the science of optimization or simulation, but the art of reasoning logically with models.” Management Science can be an even better course if not the best course (Powell 1997b), if students first take a course on business modeling with spreadsheets.

Some people refer to the CAT course as a management science course; others may disagree (Wehrs 2000), saying that it is more information systems-related. With its strong dose of Excel spreadsheets, consulting, and information systems orientation, it just supports good business sense, no matter under which area it is classified. Does this mean that with CAT, the management science course in general does not need to teach modeling any more? No. We believe that the management science course offers more opportunity to practice the base modeling skills developed in CAT and take them to the next level. The same holds for other courses, like marketing research and financial analysis, which may now use spreadsheets even more extensively. Faculty in these disciplines may themselves need to acquire CAT skills to catch up with their students' new level of spreadsheet modeling competence.

But can business schools afford to have CAT as another “management science” course when many are dropping their introductory management science courses? With more business students finding it hard to deal with the mathematics in quantitative courses and the commercial world demanding stronger analysis and better spreadsheet skills, maybe the response should be “Can we afford not to?”

Appendix A. Excel Summary

Elementary

Files

New, Open/Close, Save
 Default directory and some file management, Properties
 Save as *.xls, *.xlt, *.xla, *.csv, *.htm; Tools/General File (password) protection

Rows, Columns, and Sheets

Insert/Move/Hide Row/Column/Sheet, Change col width, Change row height
 Rename Sheets (Tab name, color)

Cells and Ranges (Active Object)

Formulas (+ − */^, calculation order of $A1 + 2 * B1 / C1^2$), Editing formulas
 Number formats (general, fixed, scientific (E), \$, and %), Date/Time formats
 Font (size, type, color), Alignment, Border, Patterns, Protection (locked, hidden)
 Buttons (bold, italic, underline, 0.00, \$, and %)
 Strings and string arithmetic ("=A"&B6&"B")

Commands

Cut/Copy/Paste, Copy/Paste, Abs/Rel referencing (A1, \$A\$1, \$A1, and A\$1)
 PasteSpecial (Formats, Values, Transpose, Operations)
 Autofill (pull down one or more cells), Undo

Tools/Options (Gridlines, Row and Col Headers, Formulas, Page Break, Macro Security)

Drawing Toolbar (Draw, Group, Order, Rotate/Flip, Auto-shapes, Arrows, Shadow, 3-D)

Intermediate

Functions: Function wizard, Sum(), Count(), Average(), Max(), Min()

Functions: If(), SumIf(), CountIf(), SumProduct()

Goal Seek, Scenarios, Tools Formula Auditing

Charts

Chart Wizard, Types (Bar, Line, XY), Formats
 Series (add, delete), Legends, Axis, Titles

Windows, Menus, Views, and Toolbars

New (Multiple) windows, Freeze Pane, Split
 Customization (Toolbar, Views)

Print (Set/Clear Print Area, Print Preview, Header/Footer, Fit to Page)

Tools/Options/Calculation (Automatic, Manual, Iteration)

Advanced

Data/Sort (range, keys) and sort buttons, Validation, DataTable, Form, Filter, Pivot Table

Functions: Lookup(), VLookup(), HLookup(), Match(), Index(), Indirect(), Choose()

Functions: NormDist(), NormSDist(), NormInv(), NormSInv(), Exp(), Ln()

Functions: Array Function, Frequency(), Rand()

Functions: DSum(), DCount(), DAverage(), DMax(), DMin()

Tools/Add-in (Analysis Toolpak, Solver)

Forms (Button, Group, Options, Check, Spinner, Sliders), Control Toolbox

Macros Sub and Functions (CellFormula, ShowFormula)

Protection (Worksheet, Workbook, File, VBA modules)

Visual Basic Editor (Alt + F11), VB Help, VB Object Library, Project Reference

Appendix B. Class Exercises

Exercises

Basic Modeling in Excel

FinancialStatement	—Prices extrapolation and analysis
AlexProcessing	—Productivity projection and equipment acquisition
AchillesAndTheTortoise	—Logical resolution of a famous philosophical puzzle
MultiplicationTable	—Setting up a simple table using mixed referencing
CharityDonation	—Iterative computation of charity donation amount
F1 Night CityRace	—Relationship mapping, assumption testing, trends

Functional Relationship

TimeValue	—Time value of money
LoanCalculator	—Loan amortization
BlackScholes	—Complex functional relationship representation
FlexibleLoan	—Loan repayment management

Data Lookup

EchoOfficeSupplies	—Customer loyalty program
CCH Kindergarten	—Keeping expenses within two budgets
MyInvestmentPortfolio	—Tracking the performance of a portfolio of stocks
ListManagement	—Compares changes between two given lists of names
FormsAndLinks	—Examples of use of form features
DataImport	—Importing data from database tables and websites
TextDataImportExport	—Importing data from and exporting data to flat files

Monte-Carlo Simulation

MonteHall	—Marketing expense budgeting
DataSim	—Generation of random variable values
GoodnessFit	—Critical thresholds of goodness of fit
WonderCookies	—Effect of risk pooling
JohnLimRetirement	—Retirement planning
PortfolioSimulation	—Allocation of funds to asset types to minimize risk
Resampling	—Multivariate resampling to generate simulated data

It's About Time

TimerClicker	—Data collection tool
SimplerGc	—Queue analysis templates
GoldenCrossClinic	—Appointment planning
XDB Bank	—Inferencing queue properties from ATM data
CountDown	—Real-time countdown
InvestmentJournal	—Calendar pop-up for data entry

Data Analysis

StatsLies	—Interpreting graphs
StatsReview	—Review of basic statistical concepts
ProbFunctions	—Review of simple probability distribution functions
FrequencyDistribution	—Histogram and frequency distribution
DataFit	—Fitting data to statistical distribution
YankeeFruits	—Stock-out risk and service level
HotelApex	—Estimating missing demand information

Decision Support and Decision Making

GrandGrocery	—Pivoting data for better analysis
ABCServices	—Contract status monitoring
VideoMart	—New business evaluation (cash flow, replenishment)
SandakanMills	—Decision-matrix and Pareto-Optimality
Prisoners	—Resolving information disparity; random incidence
UsefulVBA	—Examples of VBA codes applicable for project work

Application Areas

Financial (time series, time value of money, impact of volatility, cash flow)
Marketing (price setting, loyalty program, contract follow-up alert)
General Management (evaluation of alternatives, tradeoff analysis, scenario planning)
Operations (queues, capacity planning, stock risk pooling)

Appendix C. Modeling and Analysis Consulting Skills

Scope

Model Framing and Problem Solving *(identify and resolve conflict)*

- Identify data requirement and relationships (complex and financial functions, time series)
- Ask probing questions, listing and clarifying assumptions
- Identify key drivers and backward relationships (goal seek, sensitivity analysis)
- Perform iterative computation (DataTable, recursive computation)
- Check and assure model accuracy (formula auditing trace)

Data Storage, Presentation and Retrieval *(small price list, customer list, sales report)*

- Data types (real, integers, time, date, character, and strings)
- Data analysis and visualization (function and statistical distribution fitting, chart, trend)
- Data management (simple inquiries and filtering—text and number data)
- Data lookup (Lookup/VLookup/HLookup, index, match)
- Data integrity assurance (validation, worksheet protection, data entry form)

Alternative Generation

- What-ifs (single input change)
- Scenarios (multiple input changes)

Alternative Comparison and Evaluation

- Tradeoff (DataTable and Chart)
- Sensitivity analysis
- Ranking (Sort, Small, Large)
- Best outcome and risk analysis (Solver)
- Decision Matrix (SumProduct)
- Pareto Optimality (Chart)

Prevention and Contingency Planning

- Monte-Carlo simulation (Rand and DataTable)
- Trigger setting and recourse actions (conditional formatting)
- Testing (macros, VBA, algorithms, pseudo-code)

Forget Not

Craft skills (soft skills)
 Model assessment (validity and usability)
 The client
 Wisdom (commonsense)

Modeling Heuristics (See Powell 1995b)

Decomposition: Divide-and-Conquer
 Prototyping: Get Something Working
 Sketch a Graph: Visualize
 Parameterization: Call it Alpha
 Separate Idea Generation from Evaluation (Quiet the Critic)
 Model the Data: Be Skeptical

Appendix D. Student Accolades

At our university, students at each midterm and term end evaluate the courses they take, rating them and writing their comments. We have so far been fortunate to have received mostly good ratings and positive supportive comments. Comments are also sent by past students in the occasional “thank you” and “encouragement” emails we receive, especially after they undergo a long summer of internship where they can show off their CAT skills. Verbatim comments are listed below as anecdotal evidence of the course’s effectiveness.

Midterm and Term-End Evaluations

“The subject matter is extremely helpful across other modules that require analysis. It’s probably one of the modules that I feel has been most educational, in terms of training my approach to problem solving. It’s probably the project more than the assignments or midterm that have helped in this ‘training’.”

“the most interesting and one of the most intellectual challenging course I’ve taken”

“The problem-solving approach taken throughout the course is very practical and useful even beyond the computer.”

“Course was very challenging and I learnt a lot. The project helped me understand the practical nature of the course and its usefulness in everyday life.”

“The course challenges me intellectually. Prior to joining the course, it did not come to my mind that excel is a powerful software instead of a software that does a simple spreadsheet. Not only that, the instructor teaches us how to do modelling instead of just excel. I believe this is a much important thing to learn compared to just learning excel because modelling is something that can’t be learn from the book especially the thought process involves in the modelling.”

“I’m able to learn so much more about excel and how it can be made useful in our everyday lives, especially at the work place. The professor has also made the lesson a whole lot more interesting and this has made me appreciate excel to a greater degree.”

“This is a very enriching course. Even, for me who is quite proficient in Excel, I find the course extremely useful as it focuses on problem solving using Excel.”

“The way Prof... looks at problems challenges me to look equally well at problems. This is what I like about CAT. I also like the way it makes you analyze problems and break them down, which helps me as an IS student in looking at problems I might meet as an information systems manager.”

“The course is a very useful course in terms of value-added skills. It has made me realize how powerful Excel is and how it can aid my future projects and work-life. The course is also quite interactive for the most part—probably because it is a more hands-on subject. There is a wide range of applications which is very good for an introductory course. Having assignments is an excellent way for students to really put what they learnt into practice and find out a lot more on their own!”

Past Students

“I took this course under you and would just like to thank you for all that you’ve taught me during the course. I am currently doing my internship with...and am really glad that I have taken CAT because it was simply too useful for me! One of my first assignments at work required me to work on simplifying and analyzing a financial model in MS Excel. And everything I learnt just came back to me!”

“I am an ex student of yours. I took CAT under you and found it to be so useful during my internship period at a foreign bank. I am really glad that the school made it a compulsory course. During my internship period, I also realized the importance of learning Macro. May I know where I can take a course on Macros?”

“I have just come back from Hong Kong. I really want to thank you for this course. I have learned a lot. It is one of a very few courses that is really practical and useful.”

“Thank you for making the classes very fun and enriching. Your lessons have taught me a lot. I can say this because only after the course have I learnt to use Excel in great detail. In fact, the internship I am doing currently has me making Excel spreadsheets for a cost-savings project, and I can do it fast thanks to your teaching!”

“I was your former student for the module, Computer as an analysis tool in Term I 2004–2005. Since then, I have graduated in 2005 and I am being employed by..., a market research consultancy firm. I am proud to say that I have applied many knowledge that I have gained from your class. Thank you for the invaluable knowledge you have imparted to me which have taught me how to handle my work efficiently as well as made me realize the value of contributing to a non-profit organization.”

“I had entered your CAT class with much doubt about my ability to handle the Excel programme. I am fortunate to have met a holistic and interesting professor as yourself, who gave meanings to the computer tool. However I felt that I benefited even more from your broad-picture perspective of education as a whole. You demonstrated the true spirit and meaning behind studying and learning. ...I assure you that I am putting into active use what you have taught in class, especially the real concept of problem solving.”

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