Active Problem Solving and Applied Research Methods in a Graduate Course on Numerical Methods

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Abstract

 "Chemical Engineering Modeling" is a first semester graduate course traditionally taught in a lecture format at Oklahoma State University. The course as taught by the author for the past seven years focuses on numerical and mathematical methods as necessary skills for incoming graduate students. Recent changes to the course have included Visual Basic for Applications (VBA)/Excel and MATLAB demonstrations, activities, and assignments. These computer tools were employed by the students in solving algebraic, ordinary differential equations (initial value and boundary value) and partial differential equations (parabolic and elliptic).   During the fall of 2006, components were added to the course to expose students to case studies, active problem solving, team work, and experimentation with an overall aim of promoting creative and critical thinking as students identify and practice the art of modeling.

The 13 graduate students during the fall 2006 course were tasked with a semester project to "Design an encapsulated drug (of your group's choice) that effectively delivers an appropriate dose for an appropriate number of hours. Select the most cost effective method." The students began by creating an initial experimental protocol for their physical model (equipment/supplies needed, data collection procedure), developing computer modeling/numerical methods appropriate for solving the mathematical model, necessary simplifications made to begin the research, and expectations of future considerations that more appropriately model the real system. Throughout the semester the students improved their physical and mathematical modeling abilities to give them appropriate tools to reach the goal of successfully designing and presenting encapsulated drugs.

Assessments are presented examining the effectiveness of the team-based, active learning experience. Modeling, experimental design, experimental procedure and competence, and proficiency in applied numerical methods and computer programming are evaluated.

Background

For the past 20 years, educators in the engineering field have implemented ways of better engaging students, including active and cooperative learning, learning communities, service learning, cooperative education, inquiry and problem based learning (PBL), and team projects [1]. Pedagogies of these types have been shown to clearly be effective in allowing students to improve their learning. It is no longer important to consider simply the content covered in a course, but how the material is going to be taught.

Researchers at McMaster University [2] found that students need both comprehension of chemical engineering and what are called general problem solving skills to solve problems successfully. They developed workshops to explicitly develop skills deemed appropriate for improving students' problem solving skill and confidence.

Prince [3] in his article on active learning provides additional motivation for incorporating problem based learning in the classroom. One benefit that he shows is that PBL typically involves significant amounts of self-directed learning on the part of the students. The professor is no longer solely responsible for delivering course content. Prince provides extensive and credible evidence suggesting that faculty should consider non-traditional models for promoting academic achievement and positive student attitudes.

Based on the above evidence of the value of problem based learning and active problem solving, the instructors reconstructed their graduate course in Chemical Engineering Modeling. In Fall 2006, the instructors introduced components to the course exposing students to case studies, active problem solving, team work, and experimentation with an the aim of promoting creative and critical thinking as students identify and practice the art of modeling.

Modeling Course

The "Chemical Engineering Modeling" course has been structured to give the students experiences to meet the following objectives. At the end of the semester, the students should be able to:

(a) Develop mathematical models describing chemical engineering phenomena.

(b) Evaluate the assumptions, limitations, and restrictions necessary to solve practical problems by mathematics.

(c) Use classical numerical techniques to solve the equations that result from model formulation (ordinary and partial differential equations, linear and nonlinear simultaneous algebraic equations).

(d) Become familiar with available computational tools that incorporate these numerical techniques (specifically in MATLAB and VBA/Excel).

The course topics include:

(a) Classification of Equations
(b) Matrices
(c) Model Classifications/Concepts
(d) Nondimensionalization
(e) Taylor's Series
(f) Ordinary Differential Equations
(g) Linearization
(h) Linear/Nonlinear Equations
(i) Finite Differences
(j) Initial Value Problems (IVP-ODEs)
(k) Boundary Value Problems (BVP-ODEs)
(l) Partial Differential Equations (PDEs)
(m) Applications of Modeling/Numerical Analysis

All students in the class are graduate status and, more importantly, are also in their first semester of graduate school. The course is a requirement for all chemical engineering graduate students at Oklahoma State University. Students are concurrently enrolled in graduate-level thermodynamics and diffusional operations courses during this semester as well. The diffusional course covers the equations of continuity and focuses on analytical solutions to equations.

Activities, instructional materials teaching programming and problem-solving principles using Visual Basic for Applications (VBA) linked through Microsoft Excel and MATLAB have developed during previous semesters as course materials. These computer tools are employed by the students in solving algebraic, ordinary differential equations (initial value and boundary value) and partial differential equations (parabolic and elliptic).

The instructors predominantly use two references during the semester that help the students develop and set-up mathematical models of physical phenomena. The Smith, Pike and Murrill (SPM) [4] methodology employs an "IOGA" (input, output, generation, and accumulation) approach of building models using a control volume. The

Himmelblau and Bischoff (HB) [5] methodology relies on beginning with equations of continuity and "crossing" off of terms that do not apply for any specific situation. The course includes homework assignments in mathematical theory (paper solutions), computer exercises in numerical methods both programming with VBA and MATLAB, and exams evaluating student's understanding.

In past years students have worked on projects that have them evaluate the effectiveness of the ODE boundary value problem (BVP) strategies of matrix method, shooting method, and the successive overrelaxation method (see Hornbeck [6] and Riggs [7]). The students are given the opportunity to pick chemical phenomena that give rise to ODE BVPs. Prior students have stated that they learned a great deal from such projects but also have wondered if there were anyway to be given a project that allowed them to model actual experimental phenomena.

An Active Learning Environment

In modification to the course the instructors introduced a semester-long group project were the students perform experimental work in a lab, report and discuss their efforts via memoranda to the instructors, and apply mathematical theory, numerical methods, and developing modeling skills to reach a specific goal.

The students were presented with the following problem statement at the beginning of the semester:

> "Design an encapsulated drug (of your group's choice) that effectively delivers an appropriate dose for an appropriate number of hours. Select the most cost effective method."

This problem statement is intentionally both inadequately defined and open-ended. Defining the problem and the overall goals of the group projects is an aspect of the students learning.

Other educational objectives inherent in the problem statement include:

- Consider different types/scales of phenomena (microscopic, multiple gradient, maximum gradient, macroscopic).
- Understand what physical models and mathematical models are.
- Consider unsteady phenomena.
- Develop models that cover as many types of phenomena that are appropriate.
- Develop the maximum gradient model for spherical coordinates.
- Develop experimental protocol around simulating drug delivery with Tootsie Pops.
- Consider numerical techniques to solve the problem (ODE vs. PDE).

The class meets twice weekly (Tue-Thurs) and was structured so that Tuesday classes during the first third of the semester are in computer labs and students provided instruction in VBA/Excel and MATLAB. Thursday lectures provided instruction on mathematical principles and modeling methodology. Over the remainder of the semester, Tuesday lecture periods served as times for students to be engaged either in group work with instructors providing support and mentoring as sessions where specific content could be presented (lab safety discussion, review sessions, presentation skills, etc).

The students are initially daunted by the possibilities inherent in the project but also are willing, in some cases – quite eager, to rise to the challenge that the project represents. Two individual case studies, which are introduced at separate times, provide the basic impetus for the students' project development and direction. Discussions of projects during class periods and project status reporting (memos) provide additional mentoring moments for the instructors over the course of the semester.

To accommodate the extra time required in class and to minimize lecturing, a variety of reading pretests (administered as online quizzes in Blackboard) were given to ensure students comprehended material prior to class. Also, it allowed the instructors to shorten "lecture" time and increase active learning experiences.

The overall approach taken is intended to encourage critical thinking and creativity in the process of problem-solving by connecting applications of the mathematical and numerical methods taught in lectures more closely to other engineering research methods. The restructured course also mimics experiences that students should expect to encounter while working towards a thesis (MS) or dissertation (PhD) in a graduate program.

Homework assignments and exams were administered to the students to ensure that they were able to individually learn and demonstrate knowledge in the content.   The overall course grade was from exams (60%), individual homework (20%) and the group project (20%). This ensured that the students were learning all of the course objectives.

Project Groups

At the start of the semester, the students were put in groups. The questions in Table 1 were used to ensure heterogeneity in students groups based on experience, gender and ethnicity.

Table 1 – Questions used to group students

Encapsulated Drug Project, Aug 31, 2006
On the card, write:
Your name
Your home (i.e. China, Michigan, Antarctica)
Your degree (i.e. M.S. Chemical Engineering, Ph.D. Chemistry)
Your computer experience (High/Medium/Low)
Your experimentation experience (High/Medium/Low)
Your transport equation experience (High/Medium/Low)
Your numerical method experience (High/Medium/Low)

Introduction to Laboratory Methods

Once the students were in groups, the instructors led an experimental session where the students began their project work by examining a dissolution case study. A laboratory was set up that was designated for the students use (see Figure 1).

The experiments are driven by the goals and basis outlined in an initial case study – providing a starting point for the student projects. The intent of the initial lab period is also to provide instruction on lab notebooks, experimental concerns such as safety as well as experimental measurement and to outline the challenges that experimental work entails.

The class would later discuss and determine the safety rules for the lab with all students signing the resulting safety agreement as shown in Table 2.

A discussion of this nature resulted in a more open-ended perspective on safety along with a different rational for and understanding of other users feelings in a laboratory environment and their sense of safety.

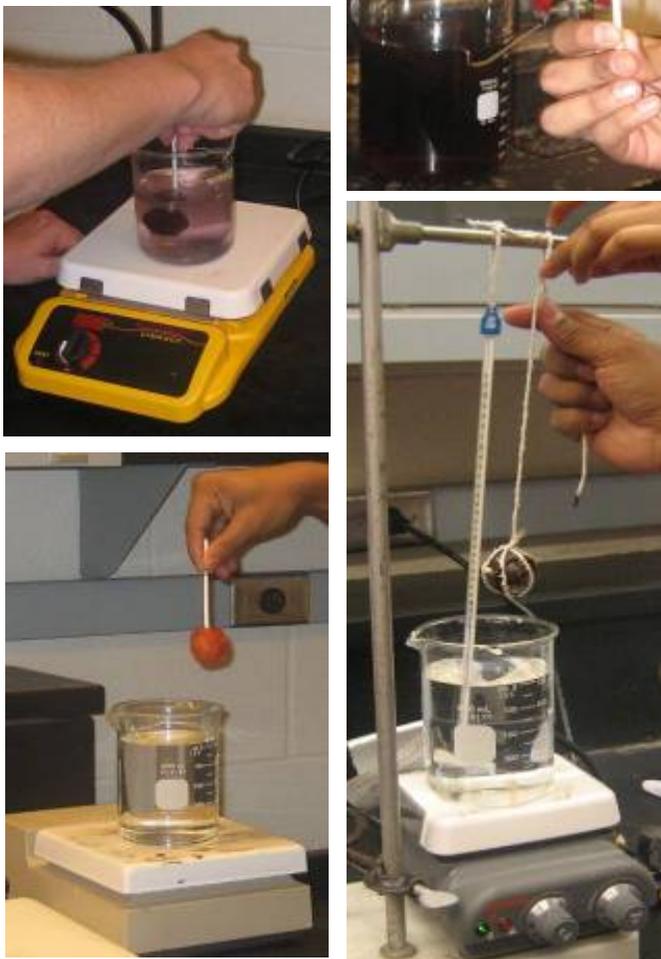**Figure 1 - Drug (Lollipop) Dissolution**

Table 2 - Laboratory safety/practices for 307 EN CHE 5743 Class Lab

1. Safety glasses (eye protection) are encouraged
2. Move deliberately – no running
3. No more than 2 groups and 1 individual in 307 at one time
4. No food/drink/gum
5. Closed shoes and full pants (or skirt) will be worn all times in 307
6. Keep lab clean and equipment stored in a neat fashion
7. Unplug all equipment when done
8. Close door and lock when the last person leaves

Name _____ (print)

Signature_____

Case Studies

Case studies served as the primary creative impetus for students' projects. While the students may be eager to undertake the challenge posed by the project they also need a sense of the structure that allows such studies to be successful. The initial case study provides their starting point.

Case Study #1 – Experimental Investigation and Modeling

This case study, from Jensen [8], is intended for freshmen students. The goal is for students to investigate the factors affecting the dissolution of a proposed coating for a new pharmaceutical. The story is written from the perspective of two Chemical Engineering students in "ChemE 101," a fictional course. The learning objectives for the students reading and working on the case study are: 1) describe the factors affecting mass transfer between phases, 2) collect and evaluate data on mass transfer; and 3) evaluate a model to describe mass transfer.

These objectives remain appropriate for the graduate students' projects as well. The intent of the case study is simply to first determine the appropriateness of the linear model for a lollipop (the students used Tootsie Pops) in order to experimentally investigate a system having an encapsulating material over an inner 'drug' material. The students were then tasked with developing and outlining their own project; developing a better model of encapsulated drug delivery, as can be seen in Table 3.

As students were completing the initial experimental aspects of the project, they were allowed to ask for materials to be provided for them to help solve various problems. This exposed the students to a Just in Time teaching [9] or Lecture by Demand strategy.

Table 3 – 1st Project Memo

To:	Students of Chemical Engineering 5743
From:	The Instructor
Date:	August 31, 2006

Subject: 1st group memo for encapsulated drug class project.

A 1-2 page memo is due September 7th at the beginning of class that answers/considers the following.

1) Initial experimental protocol for your physical model
   a. Equipment/supplies needed – your group will be responsible to procuring
   b. Data collection procedure
   c. Other information
2) Initial computer modeling/numerical methods for mathematical model
   a. Computer software to be used
   b. Numerical methods to be used
   c. Other information
3) Simplifications made to start the initial work
4) Future considerations that more appropriately model the real system
5) Questions for the Instructor.
6) A reference list to help in the project. Include at least 2 references per group member.

Once students' initial experimental and numerical techniques have been applied to Case Study #1 and they have begun further experiments of their own designs a second case

study is introduced.   The purpose of the second case study is to introduce the concepts of computational modeling and refocus students on the overall aims of encapsulated drug delivery. This case study is discussed after the necessary computer instruction (VBA/Excel and MATLAB) is complete.

Case Study #2 - Modeling and Numerical Simulation

The first step in any modeling process is to simplify the system of interest into essential aspects that can be mathematically described while still retaining essential features of the larger real-world system of interest. This case study provides an example of a model of a human body interacting with drugs delivered orally.

The second case study arises from an assignment previously developed and used in an undergraduate computer programming for engineers course taught at Oklahoma State University by the co-author. The case study outlines a model of the human body as a set of three interacting compartments where each represents a broader aspect of human physiology deemed important in drug delivery. The three interacting compartments are referred to as the oral, central and peripheral compartments.

The oral compartment represents primarily the mouth and stomach where a drug is gradually dissolving. The central compartment represents both the blood stream (circulatory system) and those organs that are highly perfused (liver, kidney, lungs, etc.). The peripheral compartment includes muscle and tissues where diffusion of medications is often slower and where drugs may build up in concentration over time.

Case Study #2 also defines the specific interactions among the compartments with governing equations for the transfer of a drug to and from compartments, as shown in Figure 2. These equations include rates/pathways for a drug leaving or entering the central compartment, where k_e is the rate drugs are eliminated from the body, k_r is the drug metabolizing, and k_c is the drug being further absorbed (to the peripheral compartment). All of the rates are dependent on the concentration of the drug currently in the central compartment, C_c. The central compartment balance also includes terms describing the drug entering from the oral compartment, k_aC_o, and returning from the peripheral compartment, k_pC_p.

The goal of the case study tasks students with creating a computer program capable of solving the drug delivery model, investigating simulated behaviors and discussing the results of their efforts.
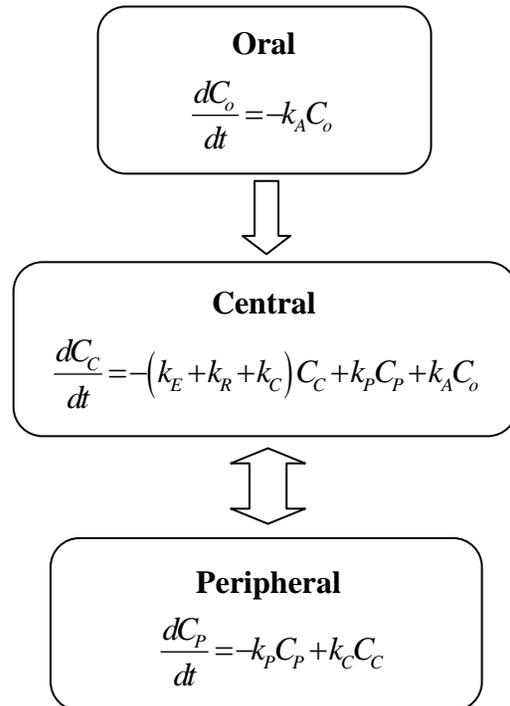
Oral

$$\frac{dC_o}{dt} = -k_A C_o$$

Central

$$\frac{dC_C}{dt} = -\left(k_E + k_R + k_C\right)C_C + k_P C_P + k_A C_o$$

Peripheral

$$\frac{dC_P}{dt} = -k_P C_P + k_C C_C$$

Figure 2 - Case Study#2: Drug Delivery Model

The overall perspectives and intentions of Case Study #2 prove valuable for the graduate course as well. In extending the basic principles outlined by the second case study

graduate students will explicitly consider multiple drug doses, statistical uncertainties inherent in human reactions to medications, the limitations and assumptions necessary for complex system modeling, and applications of numerical methods discussed in the course as tools for solving systems of equations.

Case Study Use

Case studies served as the primary impetus for students' projects in the course. Through use of the first case study students were provided an initial direction from which they could develop their own experimental goals and were presented with the realities inherent in both mathematical modeling and experimental work.

The second case study provided a different perspective for the students where the challenge became more open-ended and constructing better models, in tractable mathematical terms able to capture essential behaviors of the actual system of interest was a goal. These models and related simulations provided additional paths for examination of complex systems where important factors and influences can be estimated and examined computationally when experimental data or methods are difficult at best.

The modeling and numerical methods in computer simulation complimented the experimental laboratory work initiated with Case Study #1. The second case also served to remind the students of the overall project goal(s) as outlined in the original problem statement. Translating mathematical and conceptual models into computer simulations also tasks the students with understanding and integrating their previous experimental approaches (those completed as well as those underway) into a more complex system description. This aspect of applied numerical investigations asks students to determine a better overall 'picture' and to hopefully find a more effective resolution for the project goal(s).

The case studies used in the course are complimentary tools in engineering research. The implantation of the cases in the course provided introductions for students to the role of laboratory experiments along with computational numerical simulations.

Project Reporting

Over the course of the semester project status, learning, and student assessment (grading) is addressed by tasking the student groups to prepare memoranda at appropriate points during the project. Table 4 lists the additional project status memos that student teams were asked to prepare.

Table 4 – Project Status Memos

2nd memo due September 25th at the beginning of class.

1) Revise your 1st memo considering that your first experiment should take 1 hour and 15 minutes (class time). You should keep this very simple and consider using the physical and mathematical model in case study #1. You need a very detailed plan for your experiment. Where will you get the equipment for the experiments?
2) Develop the mathematical model in the case study using the:
   a. Himmelblau and Biscoff approach
   b. Smith, Pike and Murrill approach

3rd memo due October 6th (4:30 p.m. 423 EN)

1) Develop the mathematical model in **the case study** using the:

      a.   Himmelblau and Biscoff approach

      b.   Smith, Pike and Murrill approach

     Follow Example A approach.

2) Discuss your data and numerical model from your experiments on Sept. 28. Use the in class discussions from Oct. 3 as your guide.

4th memo due October 20th (4:30 p.m. 423 EN)

1) Find your initial experimental data from Sept 28. Plot the data r versus t. Does equation 20.1 of the case study "fit" your data?

2) Rerun your experiment with a solid lollipop. Plot the data r versus t. Does equation 20.1 "fit" your data?

3) Develop a next level model (mathematical and physical) that gets your group towards the ultimate goal of designing an encapsulated drug. Clearly plot your data from your experiment and show how well it "fits" your data from your experiment (physical model). Discuss the appropriateness of the models (physical and mathematical). Don't get too fancy yet!

5th memo due Friday December 1 at noon in 423 EN.

1) Tell us how your group is considering determining "cost effectiveness"

2) What are your aims (i.e. which drug are you using, how are you delivering the drug, where are you delivering it to)?

3) How are you focusing the problem statement into specific goals?

4) Progress on physical model and experiments.

5) Progress on mathematical model.

6) Back up your claims with references to literature. What are you using for your main references? Include an accurate and complete bibliography that you have been compiling since the start of the project.

Final Reports and Presentations

The written projects were due the second to last day of the semester. Presentations were on the last day of the semester. Four days before the final presentations were given, the instructors provided the students with instruction on creating appropriate Microsoft PowerPoint documents and delivering an effective presentation.

Student Work and Course Assessment

Student Project Examples

One group undertook an investigation of the design of a cost effective controlled-release drug delivery system for Digoxin (10). In their efforts they proposed a design – a four-layer delayed release pill, intended to sustain optimal blood-plasma concentration over a 24 hour period, the proposed four layer coating dissolution is shown in Table 5.

Table 5 - Student Designs: Four Layer Pill		
Layer	**Coating (hrs dissolve)**	**Digoxin (µg)**
1	.167	2.35
2	5.83	0.9
3	4.67	0.9
4	4.67	0.9

The students generated a conceptual model, determined simplifications and assumptions, and created numerical simulations of their system. An example is shown in Figure 3 (the graph is unedited student work).

In their final report the economics of proposed drug delivery method was outlined along with their current investigations to date.

The work shown represents only one example of the students' thinking and submitted work during the course.

Figure 3: Digoxin Concentration in Blood Plasma

Overall the work submitted during the course, along with the interactions the instructors had with the students showed students to be very actively engaged with course materials and found to be meeting or in many instances exceeding the instructors' goals for the reconstructed course.
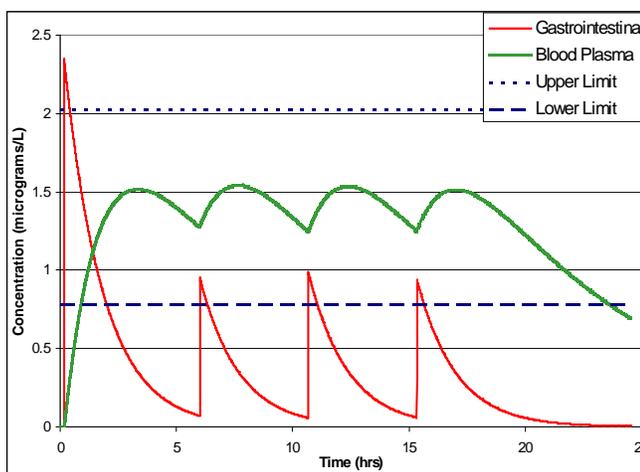
Survey Assessment

An end of course assessment was given to the 13 graduate students in the course. University Institutional Review Board approval was given for the survey. The students gave consent for the authors to use the results of the survey in presentations and publications. The survey was anonymous and examined after the conclusion of the semester. The survey had three sections.

Section 1

Q1.   I can appropriately use a lab book.
Q2.   I am confident with my experimental skills.
Q3.   I am comfortable working in groups/on teams.
Q4.   I am able to give effective presentations using PowerPoint.
Q5.   I feel confident that I can use VBA/Excel to solve problems in this course.

Q6.   My numerical methods skills are appropriate to solve problems in this course.
Q7.   I feel confident that I can use MATLAB to solve problems in this course.
Q8.   I am able to develop mathematical models that appropriately consider relevant phenomena.
Q9.   I understand the need to follow appropriate lab safety procedures.
Q10.   I enjoy a problem based learning environment.
Q11.   I can search the literature for relevant background material for projects.
Q12.   I understand the components of a research report / proposal
Q13.   I know what goes into a developing a good presentation

The students were given a 5 point Likert scale to evaluate their agreement with the above statements.   Table 6 shows the results for Section 1 of the assessment.

Table 6 Assessment Results for Section One

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
Value	4.08	4.23	4.31	3.69	4.23	4.31	3.38	4.00	4.31	4.46	4.23	4.31	4.38
Rank	10	7*	3*	12	7*	3*	13	11	3*	1	7*	3*	2

5=Strongly agree, 4=agree, 3=neutral, 2= disagree, 1=strongly disagree.

*Indicates where there is a tie in the ranking.

All scores listed were above neutrality, indicating a positive agreement of all questions. The students felt the most agreement with the statement "I enjoy a problem based learning environment." In the authors' opinion the students gained a lot from the active learning experience and agree that the students were engaged through the entire project and course. The next highest agreement was for the statement "I know what goes into developing a good presentation." The instructors felt that this is principally due to the class period four days prior where presentation skills were discussed.

The students had the lowest level of agreement for the statement "I feel confident that I can use MATLAB to solve problems in this course." This is not surprising since the co-authors spent a majority of the class discussing solution strategies in VBA/Excel. The next lowest level of agreement was for the statement "I am able to give effective presentations using PowerPoint". This was interesting given their strong agreement for knowing what goes into a good presentation. One possibility is that this result may be due to language challenges that many of foreign students experience. The students also had not given their presentation yet. The project was turned in on the same day as the assessment and the presentation was the next day. The students probably had anxiety about giving a presentation based on a project they just turned in and delivering a presentation the next day in a second language.

Section 2

Q1.   How would you rate your knowledge of MATLAB?
Q2.   Did you use MATLAB to solve problems in the course? Why or why not?
Q3.   How would you rate your knowledge of VBA/Excel?
Q4.   Did you use VBA/Excel to solve problems in the course? Why or why not?

Q5.   How would you rate your math skills, particularly eigenvalues and matrix calculations?
Q6.   How would you rate your knowledge of the transport equations (the equations of continuity for energy, mass, momentum)?
Q7.   How would you rate your knowledge of numerical methods (finite difference.)?
Q8.   How helpful were the MATLAB help sessions that Dr. High provided?
Q9.   How helpful were the VBA help sessions that Dr. Maase provided?
Q10.   How helpful was Blackboard to you?

All of these questions had room for student comments. Table 7 show verbatim comments of students.

Table 7 Assessment Results for Section Two

	Q1	Q3	Q5	Q6	Q7	Q8	Q9	Q10
Value	2.46	2.85	3.00	2.77	3.08	2.77	3.08	3.08
Rank	5	3	2	4	1	3	1*	1*

For Q1, Q3, Q5, Q6, Q7: 4=Extensive, 3=Pretty good, 2=Limited, 1= None

For Q8, Q9, Q10: 4=Extremely, 3=Very, 2=Somewhat, 1= Not helpful

*Indicates where there is a tie in the ranking.

The highest for the five questions where students rated themselves was in their knowledge of numerical methods (Q7). They also felt confident with their math skills (Q5). The lowest was for their knowledge of MATLAB (Q1), again this wasn't surprising considering that VBA was emphasized.

For the questions where the students responded to how helpful various resources were, they gave highest score for the VBA sessions and for Blackboard classroom management system and lower for the MATLAB sessions.

For Q2, did you use MATLAB, 8 students said yes, 3 said no and 2 didn't answer. Student comments for why they used MATLAB included:

"Only when we were assigned to"
"Sometime because it is easier to use"
"Its easy to use"

And for comments why they did not use MATLAB:

"Used VBA (more comfortable with)"
"I don't have enough experience to work on it comfortably"

For Q4, did you use VBA, 12 said yes and 1 didn't answer. Student comments for why they used VBA included:

"I love to use it."
"For numerical methods and solve diff. equations"
"Because I was trying to learn VBA.
"It's very simple.
"Easy to use and easily accessible".

"All problems because of ease of interface and prior background."

<u>Section 3</u>

This section was where students could write freeform comments to the questions. Student comments are added after each statement. See the Appendix for comments.

According to the assessment, it appears that the students appropriated developed their expertise in four areas: mathematical modeling; experimental strategies; numerical methods; and computer strategies on MATLAB and VBA/Excel. It is also clear that they enjoyed the problem based environment that the course was administered in.

Concluding Comments

This project proved invaluable for beginning graduate students to identify the connection between modeling, mathematical descriptions and experimental reality. It was also intriguing for the students to not only consider mathematical but physical models where experimentation with the real system is, at best impractical, as is the case in biological systems. The students gained valuable teamwork skills not common for many graduate students as well as improvement in communication skills. The assessments show that the students were particularly engaged in the course.

The approach taken encourages critical thinking and creativity in the process of problem-solving while connecting applications of mathematical and numerical methods more closely with other engineering research methods. The restructured course also mimics experiences that students can expect to encounter while working towards a thesis (MS) or dissertation (PhD) in a chemical engineering graduate program.

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Appendix

The following are freeform responses to the survey questions (comments are verbatim).

Q1. **Describe how well you thought the project allowed you to understand the use of physical models and experiments to simulate phenomena (particularly biological).**

"It made me understand physical and experimental drug dissolution."

"I never knew how to model physical phenomenon before I enrolled in this course. It helped me improve my computer skills."

"Oh great!!! Actually being new to grad studies, it was a welcome breeze of air."

"The project was useful in correlating the concepts of physical models and experiments."

"The project gave me some insight how to simulate a physical model and to develop mathematical model."

"I think this project is very helpful to understand how to construct the physical models, carry out experiments, construct and solve mathematical models."

"It helped me a lot in developing a good understanding about the phenomena and in visualizing the problem."

"I believe now I understand the concept of having a physical model and fitting mathematical model."

"Got a lot of knowledge about the mathematical model."

"Very well. Relating pure experimental work to comprehend modeling was good."

"The project idea was good. Saw relationship."

Q2. **Describe how well you thought the project allowed you to understand the use of mathematical models to simulate phenomena (particularly biological).**

"It was important as we can now understand that how important it is to make simple assumptions. They make almost-real models with less effort."

"The late equations could be easily coded in VBA, and the experimental results could be studied easily."

"Yeah, it helped a lot, but as biological systems are complex, so we had to make several assumptions to mathematically represent it."

"I think this project helped me to understand how to convert the physical phenomena into mathematical models and know the mechanism of the phenomena to make suitable assumptions and negligibility."

"It assisted me tremendously. Now I relate the methods learned to real life situations."

"This seemed a bit vague throughout….we had some difficulty relating physical to mathematical."

Q3. **Discuss how the project helped you to improve your numerical method skills.**

"I am not sure it helps me much of my numerical method skills."

"Not much, I was good at them."

"Gave me a better understanding of Runge Kutta and other methods."

"The project gave opportunity to solve numerically the ODE's."

"By solving project, I used a lot of numerical methods, like how to solve algebraic equations, differential equations, and regress the parameters."
"The project helped me in improving my numerical skills."
"I can now understand numerical analysis and relate to real life situations."
"Really helped us to model real time problems."
"I felt like the project was very numerical method light."
"I don't know how. But!!! It made my numerical method skill to improve!"

Q4.   **Discuss how the project helped you to improve your computational skills.**

"It helps me use Excel and VBA."
"Had homeworks, projects, and a good discussion in the lab."
"May have helped more had I been serious starting day 1"
"Yes it helped me to improve as we faced the real life problems."
"This program needs to use Excel and VBA to solve the program. It's helpful."
"Yes, it did improve my computational skills."
"I felt like the project required very little computational skills."

Q5.   **Describe your ability to develop a cost effective encapsulated drug.**

"A cost effectiveness is dependent on how many people need this and how I can optimize."
"At this point, on the basis of literature review, I can determine the factors which can/might affect the cost of drug, and they can be varied according to the requirement."
"I can develop a cost effective encapsulated drug considering mathematical models, economic evaluation models."
"I couldn't actually develop an exact cost effective project."
"No knowledge whatsoever. I wish you had given background info about drug analysis or economics."
"I search the related information and get a rough knowledge about the cost effective encapsulated drug."
"The cost effective part was difficult to evaluate."

Q6.   **Discuss the usefulness of the initial case study and Dr. Maase's case study to the final project.**

"The initial case study helped in understanding the aim of the project."
"Dr. Maase's case study was very helpful in writing the code + understanding the model."
"Very helpful. Great instructors and great interactive course."
"Very useful! Especially Dr. Maase's case study which gave me a better perspective of the model.
"It was helpful as it gave insight how to simplify the real system to develop mathematical models."
"They are all very useful to understand this project".
"Initial case study and Dr. Maase's case study are both give me an introduction details and hints to the final project."
"Helpful guide to know how to start."

Q7.   **Other comments.**

"Give us all a good grade finally, please."

"I felt like the project was at times taken to be more difficult than it really was. Many of the memo requests seemed identical."