AC 2007-1423: ACTIVE PROBLEM-SOLVING IN A GRADUATE COURSE ON MODELING AND NUMERICAL METHODS

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Active Problem Solving in a Graduate Course on Modeling and Numerical Methods

Abstract

Chemical Engineering 5743, "Chemical Engineering Modeling," traditionally has been taught in the lecture format at Oklahoma State University. Dr. High (the instructor) has taught the course as such for seven years. In the fall of 2005, Dr. Maase (co-instructor) developed EXCEL/VBA demonstrations, activities, and homework, and Dr. High did the same with MATLAB. These computer tools were used by the students to solve algebraic, ordinary differential equations (initial value and boundary value) and partial differential equations (parabolic and elliptic). Traditional courses focus on numerical and mathematical methods as necessary skills. In the fall of 2006, the authors decided to introduce components to the course that expose students to case studies, active problem solving, team work, and experimentation with the overall aim of promoting creative and critical thinking as students identify and practice the art of modeling.

The 13 graduate students in 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 graduate students were introduced to the problem with a case study described in "User's Guide to Engineering" by Jensen[1], a freshman introductory engineering text. This "Dissolution Case Study" has been developed based on a series of several Chemical Engineering Education articles. In the case study, a lollipop simulates the coating of a new pharmaceutical. A simple first order ODE describes the rate of change of the lollipop radius with respect to time. This rate is dependent on the mass transfer coefficient, the concentration gradient, and the molar density of the lollipop. Students are asked to develop experimental procedures to test the proposed model. This was the case study that the graduate students used as a starting point for their projects.

For the graduate course, the students were put in heterogeneous groups by considering their country of origin, the degree they are pursuing (M.S., Ph.D.), and their background experience in computer applications / programming, experimentation / lab work, and numerical method experience. The students began by creating an initial experimental protocol for their physical model (equipment/supplies needed, data collection procedure), their initial 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 complexity to give them appropriate tools to reach the goal of successfully designing encapsulated drugs. Teams gave final presentations of the results of their efforts. Assessments are presented examining the effectiveness of our 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.[2] 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.

McMaster University[3] found that students need both comprehension of Chemical Engineering and what we call 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[4] 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. Evidence provided[4] show extensive and credible evidence suggesting that faculty should consider a non traditional model for promoting academic achievement and positive student attitudes.

Based on the above clear evidence of the value of problem based learning and active problem solving, Dr. High and Dr. Maase reconstructed their course in Chemical Engineering graduate modeling. This redesign allows for team-based, active learning towards a proposed project for the students.

Modeling Course

The "Chemical Engineering Modeling" course has been structured to give the students experiences to meet the following objectives. All students in the class are graduate status. 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 incorporates these numerical techniques (specifically in MATLAB and Visual Basic/EXCEL).

The course topics include:

(a) Introduction
(b) Classification of Equations
(c) Matrices
(d) Model Classifications/Concepts

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

The course is a requirement for all first semester graduate students. The students are concurrently enrolled in a Graduate Thermodynamics course and a Diffusional Operations course. The diffusional course covers the equations of continuity and focuses on analytical solutions to equations.

The authors predominantly use two references during the semester that help the students set up mathematical models of physical phenomena. The Smith, Pike and Murrill (SPM)[5] approach uses an "IOGA" (input, output, generation, and accumulation) approach of building models using a control volume. The Himmelblau and Bischoff (HB)[6] approach involves taking the equations of continuity and "crossing" of those terms that don't apply for a particular situation.

The students generally find the HB approach to be easiest for situations where there is diffusion, but the SPM approach is easiest for the situations where there is heat convection in one dimension and heat conduction in other. Also the SPM approach is easiest for one-dimensional phenomena or non-steady state phenomena that gives rise to ordinary differential equations (ODEs). The HB approach works well for multidimensional problems that give rise to partial differential equations (PDEs).

The students are then exposed to numerical solutions methods for ODEs and PDEs.
In past years, the Dr. High has had the students work on a project that has them evaluate the effectiveness of the ODE boundary value problem (BVP) strategies of matrix method, shooting method, and successive overrelaxation method (see Hornbeck[7], Riggs[8]). The students are given the opportunity to pick chemical phenomena that give rise to ODE BVPs. The students in past semester have claimed they learned a lot from the project but have always wondered if there were anyway to be given a project that allowed them to model actual experimental phenomena.

The author designed a semester project that involved a active problem solving strategy of designing a cost effective encapsulated drug. The student would be responsible for determining "cost effectiveness" on their own. The primary basis for the project comes from Jensen[1] and is described in the next section. This project allows the students to develop their expertise in four areas: mathematical modeling; experimental strategies; numerical methods; and computer strategies on MATLAB and EXCEL/VBA.

Case Study #1

The Case Study as written in Jensen[1] 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 overall objectives remain appropriate for a graduate course as well. The physical model that is used for the drug coating is a lollipop and the mathematical model is a linear model that shows that the rate of mass transfer is proportional to the concentration gradient. This model describes the rate that the radius of the lollipop decreases.

Active Learning Project

The graduate 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."

The educational objectives of the problem were to:

- Consider different types of phenomena (microscopic, multiple gradient, maximum gradient, macroscopic-Himmelblau and Bischoff [3]).
- 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 course was structured so that Tuesday lecture periods for the first third of the semester were presented in computer labs where students were provided instruction in VBA/EXCEL and MATLAB. For the remainder of the semester, Tuesdays served as periods for students to be engaged either in group work with the instructors providing support / mentoring or as sessions where specific content could be presented (review sessions, presentation skills, lab safety discussion, etc). 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.

Once the students were in groups, the instructors led an experimental session where the students started with the dissolution case study to 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. A laboratory was set up that was designated for the students use. The class discussed and decided safety rules for the lab with all students signing the resultant safety agreement as shown in Table 2.

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)

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____

The students were then tasked with starting to develop their own project 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. To accommodate the extra time required in class and to minimize lecturing, a variety of reading pretests were given to ensure students were reading the material prior to class. Also, it allowed the professor to shorten "lecture" time and increase active learning time.

Once students' initial experimental and numerical techniques have been applied to Case Study #1 an additional case study is introduced. The second case study reintroduces the concepts of computational modeling and is provided after the necessary computer instruction (EXCEL/VBA and MATLAB) is complete.

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.

Case Study #2 - Modeling and Numerical Simulations

A second case study (Table 4), previously developed for and used in an undergraduate computer programming for engineers course taught by Dr. Maase at Oklahoma State University, provides another source of material for the modeling course. This case study provides a different approach to the overall project goal in the graduate course. Before introducing Case Study #2, the class discusses the overall idea of modeling human physiology and how complex systems might be simplified into approachable mathematical terminology while still capturing essential system behavior.

The methods outlined in the second case study extend the original aim presented to the students into discussions and considerations of multiple drug doses, complications of modeling of the human body, the issue of complex system modeling, and the concerns and factors involved in determining "how" to modeling *severely* complex systems.

Through use of the first case study the students have been facing both mathematical and experimental complications in the project and with the addition of the second case study the overall project goal(s) are reinforced. The simulations students construct provide additional paths for examination of behaviors in a very complex system where important factors and influences can be estimated.

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).

Table 4 - Case Study #2 – Modeling Drug Delivery (Condensed)

Modeling the entire human body and all the associated complexities is both beyond the reach of current simulation technology (computer power), complicated by uncertainties in human physiology (chemical reaction pathways – how reactions relate to one another – as well as a lack of knowledge of all of reactions that may take place; chemical diffusion; external influences on the body, and other factors), and also additional uncertainties arising simply from differences between individuals (even humans of a specific age, gender, and race can differ a from one another).

The first step in the modeling process is to simplify the system into components that might be mathematically described. Following this idea we divide the human body into regions. In one approach the body could be considered as three interacting systems, this is also called the three compartment model. The three common systems considered are termed 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 (the 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.

Figure 1 provides a representation of the compartments and the balances, or governing equations for the transfer of drugs to and from the compartments, or parts of the body. The current balances includes rates/paths 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.

Build a computer program modeling drug delivery. A program user should be able to specify the desired run length (up to 3 years of medication). At the conclusion of each simulation average concentrations of the drug in each compartment are reported.

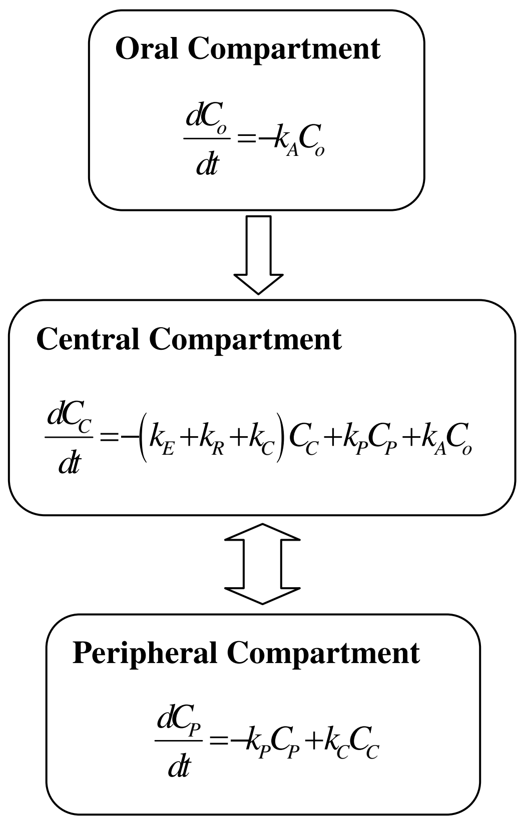

Figure 1 Three-Compartment Model & Interactions

Project Status and Student Evaluations

Over the course of the semester project status, learning, and student assessment (grading) is addressed by tasking the student groups to prepare memorandum at appropriate points during the project. Table 5 lists the four additional project memos that the student teams were asked to prepare.

Table 5 – Subsequent 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 the case study. 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? Compile an accurate bibliography.

Project 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 content about how to make a good POWERPOINT document and how to deliver an effective presentation.

Course 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 survey was anonymous. The survey had three sections and the assessment was evaluated after the semester was over and after course grades were turned in.

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 Power Point.
Q5. I feel confident that I can use EXCEL/VBA 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. Strongly disagree was 1 and strongly agree was 5. 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." The coauthors feel that the students really got a lot of out of Active learning/PBL 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." Dr. High and Dr. Maase think that this is 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 EXCEL/VBA. 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. Dr. High and Dr. Maase hypothesize that this might be due to language challenges that many of the new to U.S. students had. The students also hadn’t 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 language that they weren’t entirely comfortable with.

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 EXCEL/VBA?
Q4. Did you use EXCEL/VBA 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 EXCEL/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 shows the results.

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 for their knowledge of numerical methods (Q7). They also felt pretty good about their math skills (Q5). The lowest was for their knowledge of MATLAB (Q1), again this wasn’t surprising considering that EXCEL/VBA was emphasized.

For the questions where the students responded to how helpful various resources were, they gave highest score for the EXCEL/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 confortably"

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

Section 3

This section was where students could write freeform comments to the questions. Student comments are added after each statement. See 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 EXCEL/VBA. 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 gained improvements in communication skills.

Bibliographic Information

(1) Jensen, J., "Chapter 20-Dissolution Case Study," *A Users Guide to Engineering*, Prentice Hall Source, Upper Saddle River, NJ (2004).

(2) Smith, K. S., Sheppard, D. Johnson, and R. Johnson, "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education*, 94 (1), 2005, pp. 87-101.

(3) Woods, D., A. Hrymak, R. Marshall, P. Wood, C. Crowe, T. Hoffman, J. Wright, P. Taylor, K. Woodhouse, and C. Bouchard, "Developing Problem Solving Skills: The McMaster Problem Solving Program," *Journal of Engineering Education*, 86 (2), 1997, pp. 75-91.

(4) Prince, M. "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, 93 (3), 2004, pp. 223-231.

(5) Smith, C., R. Pike, and P. Murrill, *Formulation and Optimization of Mathematical Models,* International Textbook Company, Scranton, PA (1970).

(6) Himmelblau, D., and K. Bischoff, *Process Analysis and Simulation*, Wiley, NY (1968).

(7) Hornbeck, R. *Numerical Methods,* Prentice Hall, Upper Saddle River, NJ (1982).

(8) Riggs, J, *An Introduction to Numerical Methods for Chemical Engineers*, Texas Tech University Press, Lubbock, TX (1994).

(9) Novak, G., A. Gavrin, W. Christian, E. Patteson*, Just-In-Time Teaching: Blending Active Learning with Web Technology*, Benjamin Cummings, San Francisco, CA (1999).

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 modeols 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 Kutter 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 knowledgement 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."