Student-Performance Enhancement by CROSS-COURSE PROJECT ASSIGNMENTS
A Case Study in Bioengineering and Process Modeling

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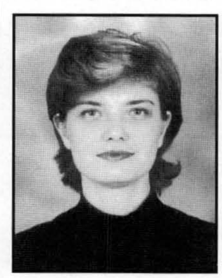
A wide range of practical, industrial, and medical applications has increased the demand for "bio-related" courses in the university curriculum. Students from biology, chemical engineering, and electrical engineering departments, all with different interests and expectations, enroll in these courses. Due to the diverse nature of the population in such classes, a variety of educational approaches and tools are necessary, both for accumulating knowledge and for implementing the theory.

The typical undergraduate student takes four or five courses per semester, but for many students this load may become too dificult to handle because of all the assignments, projects, and midterm examinations. From time to time, this necessitates a trade-off among the tasks in the "to-do list." This need led us to initiate a cross-course platform that offered a joint term project to those students taking the "Introduction to Bioengineering" (IB) and "Process Control" (PC) courses. With this initiative, we tested the hypothesis that integrating cross-course concepts in bioengineering and process control courses through a unified project could provide a stimulating learning environment. The integrated project would also challenge the students to think beyond each course in an isolated manner.

BACKGROUND

Biotechnology/biomedical engineering courses at the undergraduate and graduate levels are offered regularly in the Chemical and Environmental Engineering Department at the Illinois Institute of Technology. Among the undergraduate-level courses, "Introduction to Bioengineering" provides an introductory knowledge of biotechnology and biomedical engineering from a chemical-engineering point of view. One-half of the semester is spent on biomedical engineering, while the other half is used for biochemical engineering. Topics covered in the course are listed in Table 1.

Typically, two-thirds of the IB class population has a strong interest in biomedical engineering, while one-third is interested in biotechnology. The department offers a biomedical specialization program, and students interested in



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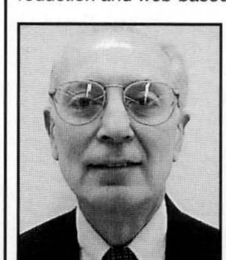

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careers in medicine and in the medical industries are expected to take this course. Many undergraduate students who take the IB course register concurrently for the PC course since it is a senior-year core course. Some students take the PC in their sixth semester to avoid potential conflicts in their schedules. Table 2 shows the content of the PC course.

There are roughly 10-15 students who register for the IB course each semester, while 25-35 students register for the PC course. In both courses, homework assignments are usually given on a weekly basis and form 20% of the course grade. Students are encouraged to discuss the problems and to exchange ideas with the instructors and teaching assistants. Since the number of students is relatively low, it gives them an opportunity to interact with the course instructors on a one-to-one basis.

In the IB course, the homework assignments are theory-intensive and can be solved using a calculator or an Excel worksheet, while in the PC course, homework problems are computation-intensive and knowledge of Matlab is required to solve them. In order to have a uniform student profile in Matlab competence, the instructor tutors introductory topics in a computer-laboratory environment, holds office hours in a computer lab, and assigns study hours under the supervision of the teaching assistant. Furthermore, supplementary web-based tutorial material about Matlab and a trouble-shooting service on the source codes are provided through the Internet.

SCOPE

We wanted to form a cross-course platform where students could use their knowledge from two different fields—bioengineering and process control—emphasizing the use of common tools from process dynamics, differential equations, and computer simulations. Concentrating on a unified project, students would then have an opportunity to analyze the results from a wider perspective.

To that end, glucose-insulin interaction was chosen as the model system to be investigated. Its dynamic behavior is interesting for process modeling and control, and the unique interactions taking place in various organs in the body are of importance in bioengineering. The choice of this model system turned out to be a very attractive project in both courses. Students were quite interested in the project, both because of its academic impact and because of the challenges that it offered in investigating a real-life problem. All of the bioengi-

TABLE 1
Course Contents: "Introduction to Bioengineering"

- ***Part I: Biomedical Engineering***
  - The History of Biomedicine: A Brief Review
  - Overall Description of the Human Body
  - Physical, Chemical, and Rheological Properties of Blood
  - Modeling the Body as Compartments, Sources, and Streams
  - Transport through Cell Membranes
  - Artificial Kidney Devices
  - Artificial Heart-Lung Devices
- ***Part II: Biochemical Engineering***
  - Review of Microbiology and Chemicals of Life
  - Kinetics of Enzyme-Catalyzed Reactions
  - Kinetics of Key Rate Processes in Cell Cultures
  - Design and Analysis of Biological Reactors
  - Transport Phenomena in Bioprocess Systems

TABLE 2
Course Content: "Process Control"

- Incentives for chemical process control, design aspects, and control hardware
- Analysis of the dynamic behavior of chemical processes
  - Fundamental models, input-output models, state space models
  - Linearization of nonlinear systems
  - Laplace transforms, transfer functions
  - Dynamic behavior of first- and higher-order systems
  - Time delay, inverse response
  - Empirical models from plant data
- Analysis and design of feedback control systems
  - Feedback control (PID control, time-domain criteria, internal-model control)
  - Stability analysis, root locus analysis
  - Frequency response techniques, Bode diagrams
  - Performance of feedback control
- Enhancements of single-loop control (cascade, feedforward, inferential control)
- Model predictive control
- Multivariable processes: interaction, multi-loop control, muiltivariable control
- Process control design

TABLE 3
Summary of Student Profiles and Project Descriptions
(UG-Undergraduate: G-Graduate)

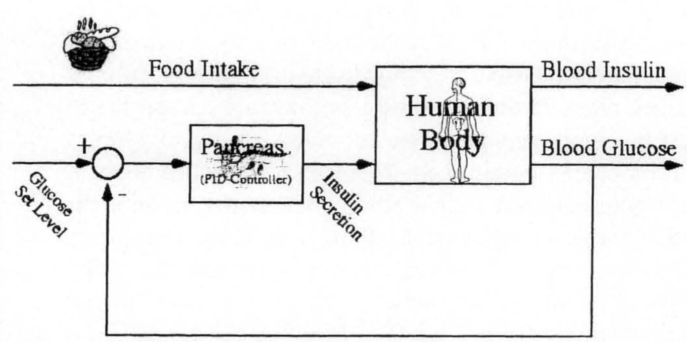
Students (Their backgrounds, special interests, specifications, etc.)	*Project ID*	*Courses: ChE IB*	*Courses: ChE PC Taking*	*Courses: ChE PC Taken*
UG Biology	1	✓		
UG ChE	2	✓		✓
UG ChE	2 and A	✓	✓	
UG ChE, Biomedical Program	3 and A	✓	✓	
UG ChE, Biomedical Program	3	✓		✓
UG ChE	3	✓		✓
UG ChE, Biomedical Program	4	✓		✓
UG ChE	4 and B	✓	✓	
G ChE, Interest in Transport Phe.	B		✓	
G ChE, Interest in Biotechnology	5 and B	✓	✓	
UG ChE, Attended Medical School	C		✓	
UG ChE	C		✓	
UG ChE	D		✓	

	Project ID	*Project Topic*	*# Students*
ChE IB	1	Comprehensive review of glucose-insulin interactions	1
	2	Effect of food on glucose insulin interactions	2
	3	Glucose insulin interactions in a healthy man	3
	4	Effect of exercise on glucose insulin interactions	2
	5	Studying metabolic pathways of liver	1
ChE PC	A	Modeling pancreas of a healthy man	2
	B	Modeling metabolic pathways of liver to control glucose level in blood	3
	C	Effect of daily activities on dosage of insulin	2
	D	Optimal timing and dosage of insulin	1

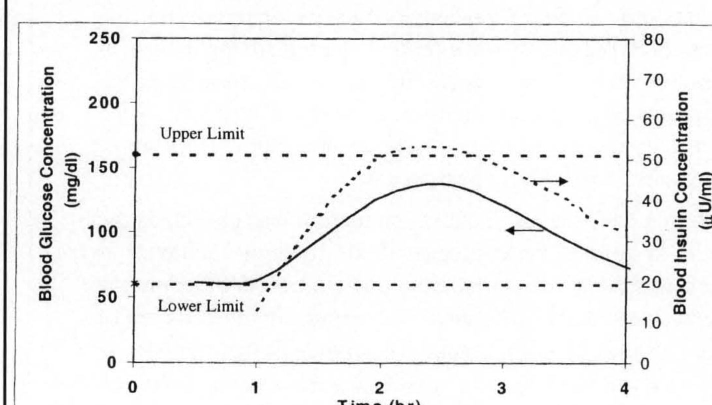
neering students and one-fourth of the process control students volunteered to work on this project.

PROJECT DESCRIPTION

The purpose of this project was to analyze the dynamic behavior of glucose-insulin interaction in a healthy person and/or in a diabetic patient. A pharmacokinetic model of diabetes mellitus originally developed by Puckett[1] had been used previously, and an MS student who was working on this project at IIT wrote Matlab codes for it.[2] These codes were given to the students so they could spend their time and energy in understanding the fundamental phenomena involved in the glucose-insulin interaction rather than writing and debugging code. A summary of the student profiles in both courses performing a project, along with the project topic, is given in Table 3. Students were grouped by taking into account their backgrounds and the status of their course registrations. In the IB course we tried to match students so that at least one of them was concurrently taking, or had already taken, the PC course. In the process control course, we rearranged them so that if all the group members were taking both



(a)



(b)

Figure 1.
(a) *Block diagram representing the pancreas as a PID controller and the human body as a multi-input-output process;*
(b) *The effect of food intake on blood glucose and insulin regulated by pancreas.*

courses they switched members to ensure that no student did exactly the same project in both courses.

Introduction to Bioengineering

The projects were assigned after the instructor covered the topics in the course, and the students were allowed five weeks to work on the projects. At the end of this period, students presented their findings in a ten-minute presentation session as a final project, worth 20% of their course grade.

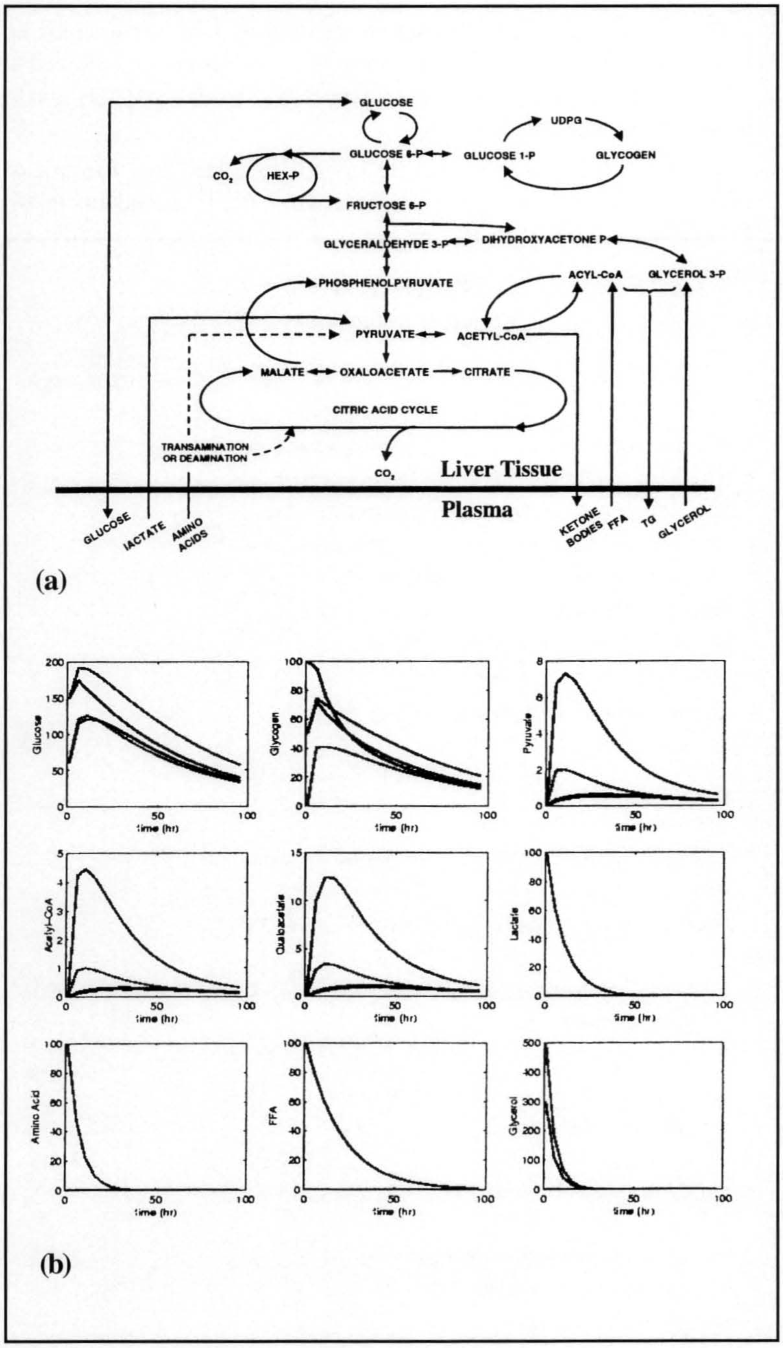


***Figure 2. (a)** A simplified metabolic pathway network of the liver; **(b)** Concentration profiles of intermediate metabolites for several sample runs.*

A variety of students from different backgrounds participated: there was one graduate student with biotechnology as his area of interest, seven chemical engineering undergraduate students, and one biology undergraduate student. There were also four graduate students auditing the course who did not prepare a project but participated in the work by giving feedback during the presentations. Four of the undergraduate students were registered in the Biomedical Engineering Program and were going to continue their education in medicine. The biology student was registered in the Biotechnology Certificate Program. A suggested timeline for these projects was

- *Literature review (1 week): Students were given a brief description for each of the projects and were asked to make a literature survey to provide background material on the specific topic of interest.*
- *Mathematical Model (1 week): A mathematical model in Matlab code was provided and the students were expected to spend a week on understanding the code and using it efficiently under the supervision of both the instructor and the graduate student who wrote the code.*
- *Modification of the Model (1 week): Depending on the project description, some modifications in the Matlab code were needed. Students made such changes to the original code.*
- *Testing and Validating the Results (1 week): The numerical results after the necessary modifications have been produced and validated against the available literature data.*[1,3,4]
- *Preparing the Report (1 week): Students were given a week to write their detailed final reports and to prepare their oral presentations. This enhanced their ability to support their work and ideas and provided immediate feedback on what the students learned from this experience.*

The student from the Biology Department carried out a comprehensive review on glucose-insulin interactions in the human body, with an emphasis on the interactions in different organs. The three Biomedical Program students concentrated on glucose-insulin interactions in a healthy person and tried to understand the underlying mechanisms (see Figure 1). The graduate student put her efforts into studying the metabolic pathways of the liver using metabolic engineering concepts, initiating a promising research topic[5] (see Figure 2). Other students worked on investigating the effects of exercise or food intake on glucose-insulin interactions in a diabetic patient (see Figure 3).

Process Control

In the process control course, students were asked to work for two weeks on the project and to report their findings through project reports and presentations. This would account for two homework assignments and 4% of their overall grade. The description of a suggested project on the control of glucose level in blood was

> *In healthy people, the pancreas controls the glucose level in blood. When the pancreas does not function properly, the person is diagnosed as a diabetic patient, and his blood glucose level is controlled by insulin injections. Such a patient has to be careful about his diet as well as his exercise.*
>
> *Investigate different cases on a model human body: a healthy person, a patient under nominal conditions, the food intake of a patient, and the exercise of a patient.*

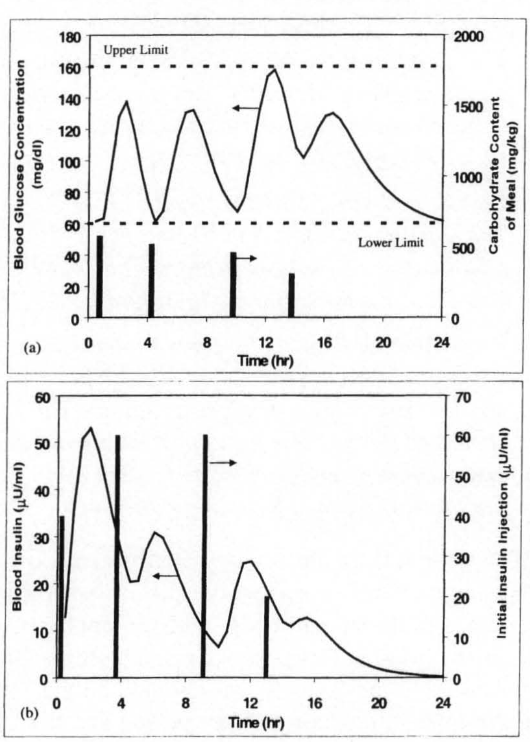


Figure 3. *A typical blood glucose and insulin concentration profile for repetitive intake of food.*

> *Test closed-loop and open-loop controllers on the model equations. Involve tasks such as finding the parameter subspace where the system works in a healthy regime, determine the appropriate dosage of insulin injection for a patient, and find the food and exercise tolerance limits for a patient.*

The other project titles in the PC course were "Search for a Power Law," "Internal Model Control," "Complex Systems," and "Population Dynamics."

Student groups were told to select one of these topics or to come up with their own project proposals. More than one group was allowed to select one title, but all groups were expected to work separately and to pursue different tasks.

Students in the IB course were invited to select the "Control of Glucose Level in Blood" project. Apart from the four students in IB,

TABLE 4
Project Questionnaire

		Low - High
1. What was your level of competence using Matlab before the project?		1 2 3 4 5
2. What is your level of competence using Matlab after the project?		1 2 3 4 5
3. What is the difficulty level of this project compared to other course projects?		1 2 3 4 5
4. What is the relevance of your project title to your area of interest?		1 2 3 4 5
5. How would you rate the challenge of the project?		1 2 3 4 5
6. Overall, how would you rate this project?		1 2 3 4 5
7. How many hours did you spend on this project?		
8. Are you taking Introduction to Bioengineering	No Yes	
Are you taking Process Control	No Yes	
9. Facilities/tools at IIT were okay.		1 2 3 4 5
10. If I had more time, I would prepare a better project.		1 2 3 4 5
I received help dealing with the project from the instructor and TAs...		
11. ...as exchange of ideas		1 2 3 4 5
12. ...as exchange of knowledge		1 2 3 4 5
13. ...as technical support		1 2 3 4 5
I received help dealing with the project from my friends...		
14. ...as exchange of ideas		1 2 3 4 5
15. ...as exchange of knowledge		1 2 3 4 5
16. ...as technical support		1 2 3 4 5
17. This project was a useful learning tool for me.		1 2 3 4 5
18. It is easily applicable to other areas.		1 2 3 4 5
19. The goals were reasonable		1 2 3 4 5
20. I used my knowledge from other courses		1 2 3 4 5
21. I would consider engaging further research in this field		1 2 3 4 5

four more students picked this topic, signifying the appeal of biomedical topics among the students. They formed a valuable "control group" similar to IB students involved in the project who were not taking PC, which gave us the opportunity to monitor cross-course interactions.

Student interest in this topic was also evidenced by the contribution of other class members during project presentations. Two of the eight students performing a project on this topic were graduate students with interests in biotechnology and transport phenomena. One of the undergraduate students had previously attended medical school and provided valuable perspective on the subjects.

Some of the PC students were assigned the task of devising a control mechanism centered on different organs, such as the pancreas and the liver, as well as investigating the timing and dosage effects of insulin injections. Other students considered projects on topics other than the glucose-insulin interaction.

. . . The project played an important role in triggering the scientific curiosities of the students and providing an opportunity to adapt their knowledge to different fields.

After the oral presentations in both classes, students were given a questionnaire to provide feedback to the instructors. They were carefully informed that the questionnaire (see Table 4) would be used only for course enhancement and educational research purposes and that it would not have any effect on grading.

Evaluation of the returned questionnaires indicated that all students showed improvement by at least one level in their competence in Matlab, accounting for an average increase of 70%. Although they find this project difficult (4.15 out of 5.00) and challenging (4.40) with respect to other class projects, they found it quite relevant to their own area of interest (3.50) and were willing to engage in further research in the field (3.47). Most of them reported that they needed more time to deliver a better project (4.20), which is an indication of their interest and willingness to be involved in it.

The students tended to receive help from instructors and TAs (3.60) rather than their peers (2.50). They found it a useful learning tool (3.75) with quite reasonable goals (3.45), although they were near-neutral to the applicability in other areas (3.35).

Overall, the students rated the project an average of 3.90. The fact that they have used their knowledge from other classes (3.70) suggests that the initiation of a cross-course platform may become a very useful learning tool, supporting our hypothesis.

CONCLUSIONS AND FUTURE DIRECTIONS

Diversity of interests, technical abilities, and states of knowledge among students provided unique feedback for future improvements in this cross-course project assignment. The choice of the project topic turned out to be an attractive one due to the popularity of biomedical engineering in education and research. The project played an important role in triggering the scientific curiosities of the students and providing an opportunity to adapt their knowledge to different fields. As a follow-up, we developed additional educational software in order to help students to explore many case studies.

The cross-course project approach to teaching bioengineering and process control described in this paper directly benefited four students taking both courses concurrently. The other four who had taken the process control class in the previous semester found that the project helped them integrate their acquired knowledge in process control to a bioengineering project. Hence, eight out of nine bioengineering students were served by this cross-course initiative. As a result of this experience, we are looking forward to offering such a cross-course platform in future courses.

ACKNOWLEDGMENTS

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