It's a New Ballgame – Again!

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A. Introduction

Technology redefined the calculus ballgame in the late eighties and early nineties. Graphing calculators and PCs operating computer algebra systems (CASs) brought a laboratory component to calculus and forced the deeply entrenched symbolic approach to share the field with numeric and graphic approaches and representations. The role of graphics moved from illustrating the result of analysis to informing the analysis. Today qualitative solutions are as important as analytical solutions. These changes complimented and enhanced the effects of the Calculus Reform Movement [1], begun a few years earlier. This Movement advocated pedagogical changes to replace "active" lecturer with active classroom, introduce small group work, and, in general, refocused attention from instructor lecturing to student learning. The Movement's emphasis on conceptual understanding aided by the graphical, numerical approximation, and symbolic capabilities of CASs lessened the role of rigor, drills, and computational skills in calculus courses.

In order to make room in the syllabi for small group activities and projects, discovery work, and to gain depth in conceptual understanding, the Calculus Reform Movement advocated reducing coverage. Techniques of integration were a fertile area for cutting. Trig substitutions, special techniques, and partial fractions were dropped. However, the line was drawn with respect to integration by parts. This was deemed to be an essential technique. This semester we dropped integration by parts from the curriculum! Why? Because the new graphing calculator we are using this year can symbolically integrate all of the integrals that required the use of parts. Moreover the calculator does the job quicker and more accurately than we ever did. Calculators operating CASs along with sophisticated computer software have become primary tools for offering insight as well as for computing. Technology is once again forcing us to redefine the calculus ballgame.

B. The New Ballgame

Thomas Friedman in his book The Lexus and the Olive Tree said the following about technology [2]

> There are many ways to sum up what the Information Revolution did to the marketplace. But for me it comes down to two simple concepts: It greatly lowered the barriers to entry into almost any business. And, by doing so, it radically increased competition and the speed by which a product moved from being an innovation to being a commodity. (p. 65)

Similar comments can be made about the impact of technology on education. Technology has lowered the barriers to accessing content. For example, typical optimization problems found in calculus I courses are now found in college algebra courses. Another example, one that illustrates how technology can be used to surgically access content, involves Euler's formula. Twenty years

ago, the calculus II course that I taught devoted the last third of the semester to the topics of sequences and series. The course concluded with the development of Euler's formula. Last September in the first semester of our Core program, we needed Euler's formula in our study of higher order recursive sequences. Relying heavily on technology we were able in two days to develop the aspects of Taylor series that were needed in order to obtain Euler's formula. In the words of business, technology has reduced algorithmic computation to a commodity. Lowering the barriers to accessing content opens up possibilities for reducing the hierarchical or building block aspect of our curriculums.

Potential for providing insight, not computation, is the most valuable aspect of technology. Visualizing flow lines, simulating behavior, and observing graphically, numerically, and symbolically the effects of recursion are examples of how technology provides insight that enhances both the conceptual and theoretical understanding. Through the process of What-ifing, technology offers the potential for introducing a discovery component into each of our courses, if not into every assignment. The growth of technology has also greatly accelerated the rates of change in society and business over the past ten years. Globalization, the integration of capital, technology, and information across national boundaries, engulfs us in an environment of data. Explosion of data in all walks of life calls for front loading our curriculums with statistics and probability.
This, in turn, will require interdisciplinary cooperation as interpretation of data analysis typically involves different disciplines. These three educational facets of technology:

1. Lowering content barriers
2. Providing insight
3. Promoting interdisciplinary cooperation

have profound consequences for the core curriculum, especially for the future role of calculus in the curriculum.

C. Modeling Displaces Calculus

The primary goal of mathematics curriculums will remain to develop students to become confident, creative, and competent problem solvers. For the past forty years or more, this goal was pursued under the calculus umbrella. The historical roots of applications in physics, the building block nature of mathematics, and the need to develop algorithms for computing supported the central role of calculus in the curriculum. Technology has changed this scenario within the academic disciplines as well as in the societal demands facing our graduates. Today, I believe that developing the art of inquiry and developing skill in modeling real world situations addresses the goal of developing confident, creative, and competent problem solvers more effectively than does the calculus

<u>Developing the Art of Inquiry.</u>

Learning how to learn is an essential skill for a person to successfully contribute in today's rapidly changing society. Learning how to develop new skills (ideas?) and adapt old ones "on the fly" has become standard fare in our society. The explosive growth of niche companies over the past few years underscores the importance of discovery learning in preparation to compete in a global economy whose only constant is change.

Developing the art of inquiry has always been an (idealized) objective of

mathematics programs. However because our subject is computationally dependent, our courses have often focused on developing computational skills and algorithms rather than inquiry. Integration by parts, is an example. Technology in the form of inexpensive, hand-held calculators running CASs frees us from the computational yoke and offers us the opportunity to redefine our program to emphasize inquiry. Modeling is the vehicle for doing this.

Developing Skill in Modeling

Modeling should replace calculus as the core umbrella for the first two years. Change and accumulation will continue to be central concepts, however the settings will be different. The subject matter will not be constrained to continuous functions defined over intervals. Discrete and continuous scenarios will be considered and discrete and continuous models will be used to approximate each of these scenarios. In contrast to today's programs, these modeling courses will be distinguished by their integrated and interdisciplinary nature. Here are three examples from within mathematics. Differential equations will be integrated into the study of change without drawing the dividing lines as we do today between differentiation and differential equations. Probability and statistics will be integrated through out the core program as needed to support data analysis and interpretation. Functions of several variables with supporting work in matrix theory will be included as the need arises without artificially separating them from the study of functions of one variable as we do today. Topics, skills, and resource personnel will also be drawn from other disciplines, as modeling is inherently interdisciplinary.

This is more than the present seven-into-four program [3] in which a two-semester calculus course and a probability and statistics course are augmented with topics from discrete math, differential equations, and linear algebra. The difference is that the focus is on learning how to model real world situations rather than studying a sequence of calculus topics and techniques. Changing the core umbrella from calculus to modeling raises several concerns, including those that were seeded to the Goals and Content group.

1. What are the important and difficult content choices? Content choices should be decided on the needs of downstream courses served by the core mathematics courses and their suitability for developing modeling skills. Because the "downstream" courses include those in partner disciplines, the proposed modeling program will be interdisciplinary in its development as well as in its content.

2. How to Balance Theoretical Understanding with Computation Skills? Choosing topics from different courses and using technology to surgically transplant techniques raises legitimate questions concerning the level of conceptual and theoretical understanding. Motivation followed by discovery and application is the essential ingredient in developing conceptual understanding. Because motivation and interpretation are basic aspects of modeling, the proposed modeling environment is better suited to developing conceptual understanding than is the traditional calculus setting. "Basic skills" should refer to inquiry and modeling skills, not computational skills. The calculus reform movement advocated emphasizing conceptual understanding in the introductory courses and theoretical understanding in the upper level courses. This trend will continue.

3. What are "High Standards" and How Can They be Achieved? High standards should be described in terms of student growth with respect to problem solving, inquiry, and taking responsibility for one's own learning. Developing effective ways to assess student growth is one of the most important challenges we face in reforming our curriculum. Focusing assessment on how well a student brings past experience and information to bear on a new

situation, requires radically changing our present assessment practices. Although there is still a place for quizzes to spot check development, the fifty minute hour test needs to be replaced as the basis for determining student achievement.

The impact on student attitudes toward mathematics and its applications needs be seriously considered as a component of high standards. In 1987, Robert White, President of the National Academy of Engineering, in his address to the "Colloquium, Calculus for a New Century" challenged us to make calculus instruction "a pump, not a filter in the pipeline" for developing the technical manpower this country needs [4]. We need to apply this challenge to the proposed modeling program. Furthermore in evaluating our programs, we need to incorporate a measurement of our success in meeting this challenge.

4. How Do Modeling and Applications Fit into the Program? My premise is that modeling and applications are the program.

5. When Should Calculus be Taught and What Other Courses Should be Taught? Calculus should not be taught as a course, as it is today. Some calculus topics, such as change and accumulation, will be included in the proposed modeling program. The modeling problems in the program should be selected, in part, on the needs of downstream courses. The problems selected should then determine the content to be included, rather than the content determine the problems to be selected. The focus must be on problems solving, not on developing tools for problem solving.

6. One Size Does Not Fit All. Students bring different backgrounds and different motivations to our courses. Our society needs to educate everyone from robots to free thinkers. High schools send us students who have not studied mathematics beyond algebra and geometry as well as those who have successfully completed a rigorous BC calculus course as well as everything in between. Student interest in taking our courses runs from strong interests to just fulfilling a requirement. We need programs to accommodate all the students, although not necessarily the same program. We need to develop variations of the modeling program for different categories of students. These courses will address the same central concepts of modeling and inquiry, but do it in different ways, with possibly different content, and with different levels of student discovery. Fairness considerations require that we offer courses that challenge the majority of the students in a class, not that we offer the same course to every student.

7. The fundamental role of textbooks will change from recipe books to resource books, whether they are printed or electronic. Traditional textbooks do not support inquiry and independent study, nor do they provide the flexibility required in a modern program. The inquiry goal is better served through mini research projects than by following a text [5]. Future texts may consist of annotated outlines and a collection of modeling topics supplemented by mini research projects. The outlines provide coherence to the course, the modeling topics address down stream course needs, and the mini research projects address the inquiry objective.

8. The securing of algebraic and trigonometric fundamental skills will not be a priority of the modeling program. (Securing these skills is sometimes given as a rationale for offering calculus.) If it continues to be important to master these skills, another means will need to be developed to do it. I believe, however, that the importance of these skills in the mathematics, science, and engineering will fade in the presence of technology.

9. The time factor. Changing programs and developing new courses, particularly modeling courses takes a great deal of time. Institutions need to provide faculty with time and support to develop programs and materials as was done in the calculus reform. An important role for foundations is to provide support for curriculum and faculty development.

D. Adapting to Change

The development of technology for teaching and learning initiated a revolution in our curriculums ten years ago and is today forcing us to redefine our programs again. During the nineteen nineties we essentially played catch up in adapting our curriculums to the capabilities of graphing calculators and CASs. Now, before we have finished adapting to these changes, we are faced with another technological revolution with respect to teaching and learning. How long will it be before the next major technological breakthrough? Five years, maybe? How can departments and programs prepare for change? How can we become proactive rather than reactive in developing curriculums?

Experimental Courses.

Departments need to create an environment for (curricula) change. One way to develop such an environment is to institutionalize one or more experimental courses in major programs. Faculty teaching these courses should be encouraged to experiment with the curriculum while still addressing the departmental goals for the course. Institutionalizing experimental courses provides a laboratory for change, for developing new courses as well as for adapting courses to meet changing situations. The existence of experimental courses in the curriculum sends a message that the department expects the curriculum to be in a constant state of evolution. This contributes to establishing an environment for change. Collins and Porras in their book *Built to Last* cite the willingness to experiment and expectation to change as characteristics of visionary companies [6]. These need to be characteristics of our departments as well.

Curriculum Retreats

Departments need to hold retreats where faculty can focus on curriculum, freed from the restrictions of their normal schedules. This experience is enriched if it can be done with teams of faculty from other schools. Although each team works on its own program, the synergistic effects of discussions during social times enhance each program. In 1994, West Point held such a Curriculum Retreat for seven schools [3]. Five of those schools are now in the process of disseminating major curriculum projects that were initiated at the Curriculum Retreat.

Curriculum Consortiums

Consortiums offer many benefits to curriculum development. They provide opportunities for like minded faculty from different institutions with different restrictions to come together to work on a common task. Equally important, the existence of a consortium provides legitimacy to its members and their task. Furthermore, it may provide the “critical mass” necessary to produce change. The differential equation consortium and the liner algebra consortiums are examples.

E. Summary

The continuing technological advances are radically changing access to information, how we learn, and how we compute. These changes are forcing us to reexamine our curriculum goals and the content of our courses. The lowering of access barriers to content has lessened the hierarchical

structure of mathematics and CASs has freed us from the need to teach algorithmic computation. The information age demands a greater emphasis be placed on interdisciplinary problem solving and inquiry in our educational programs. Modeling with a strong focus on inquiry provides a better environment than calculus for addressing these educational demands.

Changes are on-going. Changes in society and the business world, in technology, in educational delivery systems, and in our understanding of the learning process require departments to establish environments for change. Departments need to become proactive agents for curricula change. Institutionalizing experimental courses, holding curriculum retreats, and forming consortia are three endeavors that contribute to a change environment.

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