Web-based Implementation of Discrete Mathematics

Tanzy Love Fritz Keinert Mack Shelley

Iowa State University

Abstract

The Department of Mathematics at Iowa State University teaches a freshman-level Discrete Mathematics course with total enrollment of about 1,800 students per year. The traditional format includes large lectures, with about 150 students each, taught by faculty and temporary instructors in two class sessions per week and recitation sections, with about 35 students each, taught once per week by a teaching assistant. In this format, the course experienced the standard academic problems associated with the multi-section large lecture format: over 30% D/F/Withdraw rates; lack of uniformity and inconsistency in course objectives, delivery, and testing; low student morale and performance; and insufficient individualized feedback from instructors. In addition, students failed to see the connection of the material to subsequent courses and real world problems; spent great effort on repetitive calculations and little or none on computing; lacked skills in analyzing problems, data presentation, and graphical analysis; and often had substantial gaps in basic algebra skills that were not addressed properly by course content.

Discrete Mathematics was redesigned to address these challenges with a Web-based, self-paced model. The Web-based environment integrates WebCT as learning management software, MapleTA as an online testing program, and textbook and related materials by Barnett, Ziegler, and Byleen (Prentice-Hall) as the content basis. The redesigned course includes weekly small recitation sections, additional office hours, availability of the Math Help Room, and peer-mentoring through study groups and Supplemental Instruction. Integrated and proactive student support includes Web-based feedback through online office hours, a Web-bulletin board for each class, and Web-published individual current scores and class standing. The redesigned course syllabus is divided into manageable modules, with clearly communicated learning outcomes and objectives. Expansion of learning and understanding through the application of technology are achieved through incorporating Microsoft EXCEL spreadsheets for instantaneous graphics and simplification of extensive repetitive calculations. The Web environment also includes a new fourth main course topic of basic algebra skills early in the material as preparation for the other sections.

Assessment of the course redesign was performed by the Research Institute for Studies in Education (RISE), in the College of Education, at Iowa State University. The general assessment strategy included a pre-test-posttest control group design and long-term study of academic success. Student performance data were used to determine which differences in learning outcomes may be attributable to specific course components. Students in the Web-based sections performed no worse, and usually performed better, than did classroom-based students. These results are based on student performance on learning outcomes in Fall 2002, Spring 2003, and Fall 2003. In a straight comparison, the design sections did significantly better than the control sections on eleven out of thirteen exams compared, with comparable results on the remaining two exams. This difference exists despite significantly higher cumulative GPAs for students in the control sections for two semesters and insignificant differences in the third semester. This suggests that the Web-based course design is able to enhance the performance, and hence the chances for retention, of even less-highly achieving students (as determined by their lower GPAs). A longer-term study of academic success has tracked students through subsequent courses for which Discrete Mathematics is a prerequisite. These results are also positive, though less conclusive.

The traditional course used 12 faculty and 15 teaching assistants to deliver the course at a cost of $129 per student. The redesigned course is staffed with 3 faculty and 9 teaching assistants. The redesign costs $77 per student, resulting in savings of $93,600 per year.

1. Web-based Implementation of Discrete Mathematics

Discrete Mathematics was redesigned as a Web-based, self-paced course. The content of the course is covered in several best-selling textbooks, all of which cover fairly similar topics. A course with the same role within the curriculum and with comparable enrollment numbers is taught at all large universities. Therefore, a redesign of Discrete Mathematics has wide applicability, and hence a substantial impact on mathematics learning in many colleges within Iowa State University and at public universities across the nation.

Section 2 of this paper describes the traditional course components. Section 3 describes the goals of the course redesign and Section 4 describes the final course structure. Section 5 discusses the comparison of impact on students in the traditional and redesigned classes. Section 6 concerns the lessons learned from the course redesign.

2. Traditional Discrete Mathematics Course

A course on discrete mathematics had played an important role at Iowa State University in its traditional format. This structure has both useful and concerning aspects that influenced the redesign. We looked at the context of the course in the university during our redesign.

2.1 Role of "Discrete Mathematics" within the Curriculum

The Department of Mathematics at Iowa State University teaches a number of introductory courses that have very large enrollments. These courses serve as the entry level to the mathematics curriculum and/or as foundation courses for other disciplines. The single course with the highest enrollment is Discrete Mathematics, which typically is taken by over 1,800 students each year. Discrete Mathematics is a required college-level course for all business and social sciences majors. Subsequent courses for business majors (total College of Business enrollment at Iowa State is over 3,400 students) depend on much of the material presented in Discrete Mathematics. The course is also taken by many majors in the humanities and in education studies to satisfy the general mathematics graduation requirement. Most of these students, as well as the business and social sciences majors, later take a required introductory statistics course for which parts of Discrete Mathematics are an excellent preparation. This course therefore is a gateway for a large number of students in the social sciences, education, and humanities. The content of the course in its traditional form was standardized through best-selling textbooks, all of which cover fairly similar topics. A course with the same role within the curriculum and with comparable enrollment numbers is taught at all large universities. Our survey of 23 large state universities throughout the country shows that this course is always ranked number one or two in terms of student enrollment in mathematics.

2.2 Desired Learning Outcomes and Difficulties

Discrete Mathematics is often considered an obstacle by students taking the course as a requirement. Business and social sciences majors often have low prior aptitude in mathematics (Table 1). In their first semester on campus, they are confronted again with a challenging mathematics course that has the potential to restrict whether they can enter their major of choice. Other students take Discrete Mathematics to satisfy core requirements for study in a mathematical discipline. For these students the course may be the last hurdle before moving into their program of choice. The majority of all students are then confronted with a required statistics course, for which a solid foundation in Discrete Mathematics is desirable.

Discrete Mathematics is also a challenge for the Mathematics Department and for departments that depend upon the course as a building block for their curriculum. First, of course, is the challenge to ensure that students understand and can apply the principles of discrete mathematics and linear programming. Second is the need to have students make a smooth transition into subsequent courses and to be successful in those courses. Maintaining the prescribed sequence of courses throughout these undergraduate programs benefits the student as well as colleges and departments. Students can expect to graduate on time without the additional costs of extra semesters; departments can control costs by minimizing the number of repetitions and sections of subsequent courses.

College	Agriculture	Design	Education	Engineering	Family & Consumer Sciences	Business	Liberal Arts and Sciences
Average Math ACT	21.60	22.21	21.24	23.76	20.81	20.54	22.47

Table 1: For students in our survey, Business College students had the lowest average Math ACT scores, followed by students from the Family & Consumer Sciences and Education Colleges.

2.3 Concerns with the Traditional Course Format

Traditionally, Discrete Mathematics has been delivered in lecture/recitation format. Under this format, over 30% of students have received a grade of D or F or withdrawn from the course. The course typically was taught by a combination of faculty, graduate teaching assistants (TAs), and temporary instructors, and represented a very heavy resource investment for a single course (about $130 per student). Together, this and several other high-enrollment courses taught in the typical lecture/recitation mode had resulted in faculty and TA teaching loads that were higher than national and local norms. In addition, reliance on temporary instructors and TAs contributed to a lack of uniformity and inconsistency in course objectives, delivery, and testing. As a consequence, the overall quality of instruction in these courses suffered, as did student morale and performance.

Many strategies could have been implemented to address these concerns. However, limited departmental resources prevented any action such as faculty-only instruction or non-web-based course redesign. After receiving extra grant funding to redesign a course for web-based delivery, faculty time was released to focus on this project.

Because any redesign of a service-type course should include input from stakeholders, focus groups were conducted with faculty, students, and advising staff from one of these stakeholder groups, the College of Business. A total of 15 participants were involved in three separate focus group sessions (one session for faculty, one for advising staff, and one for students). The purpose of these focus group meetings was to gather information from these different stakeholders about learning outcomes and their opinions about potential benefits and drawbacks associated with the course redesign. The following list represents the most important problems and concerns identified by these stakeholders—we will address related learning objectives in the next section.

- Students lack skills in analyzing problems, decomposing cases, and formulating solutions,
- Students perceive very little connection between the Discrete Mathematics course and their later coursework and professional aspirations,
- Students lack data presentation and graphical analysis skills,
- Students often lack basic mathematics skills, such as algebra,
- Students and advising staff feel that the lack of prompt feedback on student learning and performance leads to less motivation, higher drop rates, and lower grades,
- Students and academic advisors are emphatic about the need for increasing the amount and/or quality of student-instructor interaction.

3. Learning Goals and Objectives for the Redesigned Discrete Mathematics Course

The intended learning outcomes identified for Discrete Mathematics are to have students gain a thorough understanding of basic concepts and the ability to solve problems and break problems or questions down into manageable parts. This knowledge then needs to be available for application in other mathematics, statistics, and business courses. Quantitative and analytic understanding becomes increasingly important as students progress through their course work. Thus, central to our intentions for this course is not only that the students gain knowledge about discrete mathematics and are able to apply this knowledge, but, equally important, that they are able to retain and apply it.

We have other goals for the redesigned course, which we believe are related to and will aid in achieving our intended learning outcomes. These include having the students enjoy the course, appreciate its importance, and take a more active role in the learning process. These often are not achieved with traditional course formats, but may be achieved in a thoughtfully redesigned learner-centered course.

Specifically, we have identified the following learning objectives for the problems and concerns formulated by the focus groups. Additionally these intended learning outcomes, as well as other instructional components of the course redesign, were further refined by concepts presented in Huba & Freed (2000).

- Observed Problem or Concern: Students lack skills in analyzing problems, decomposing cases, and formulating solutions.

  o Related Learning Objective: Students completing the course should be able to analyze, decompose, and identify solution strategies for solving sophisticated problem scenarios and cases involving course content.

- Observed Problem or Concern: Students perceive very little connection between the Discrete Mathematics course and their later coursework and professional aspirations.

  o Related Learning Objective: The content of the redesigned course should be related more closely with the types of problems that students would face in their subsequent courses and in their careers.

- Observed Problem or Concern: Students lack data presentation and graphical analysis skills.

  o Related Learning Objective: The redesigned course needs to incorporate information about not only how to interpret various data presentations, but also how to create and present data in visual format.

- Observed Problem or Concern: Students often lack basic mathematics skills, such as algebra.

  o Related Learning Objective: The redesigned course needs to incorporate modules or capabilities for students to relearn or refresh their skills on basic mathematics concepts.

- Observed Problem or Concern: Students and advising staff feel that the lack of prompt feedback on student learning and performance leads to less motivation, higher drop rates, and lower grades.

  o Related Learning Objective: The redesigned course needs to provide prompt and frequent feedback, which should encourage students to pace their learning and give the students and instructors a realistic picture of content mastery and/or weaknesses. Additionally, ongoing monitoring of student progress and course satisfaction will allow quicker intervention with lagging students and fine-tuning of course design while the course is in progress.

- Observed Problem or Concern: Students and academic advisors are emphatic about the need for increasing the amount and/or quality of student-instructor interaction.

  o Related Learning Objective: The redesigned course needs to be designed to provide a means by which faculty can interact efficiently with large numbers of students through a variety of information channels in a customized manner.

In summary, the information that we have drawn from the focus group participants suggests that one of the most important learning outcomes for the Discrete Mathematics course is to have students not only gain a thorough understanding of mathematics concepts, but also to develop the ability to break problems/questions down into manageable parts and use these skills to solve complex and/or non-obvious problems. In addition, the delivery of the content needs to be designed to accommodate different learning styles and needs. For example, it is important that students who lack skills in certain areas such as basic algebra or software (e.g., Microsoft EXCEL) can utilize self-paced learning to improve their skills. Finally, it is also important that students be provided with timely and useful feedback on their performance.

4. Redesigned Course Structure

For the redesign of the Discrete Mathematics course we used some of the successful format of our Web-based Trigonometry and College Algebra courses from a previous round of mathematics course redesign, and modified that format where course content or stakeholder feedback suggested doing so. Student feedback from ongoing online Discrete Mathematics and other courses, gathered though focus groups by our Academic Success Center, also was used to guide the Discrete Mathematics course redesign.

Additionally we have incorporated, where appropriate, best practices outlined in the publications “Quality On the Line: Benchmarks for Success in Internet-Based Distance Education,” by the Institute for Higher Education Policy and National Education Association, and the “Seven Principles for Good Practice in Undergraduate Education” (Chickering & Gamson, 1987).

4.1 Course Content Changes

The main topics of the traditional Discrete Mathematics course (basic linear algebra, linear programming, and probability and statistics) remain unchanged. The primary addition—a new main topic of algebra review, functions, and graphing—has been added to address concerns about preparedness. Further, we have made some changes that reflect concerns voiced in our focus groups and by other faculty:

- De-emphasis on repetitive hand calculations. Instead we concentrate on setting up story problems and solving those using Microsoft EXCEL spreadsheets. An introduction to EXCEL is included in the class.
- Spend some time on learning to generate and interpret graphical data using the EXCEL environment. This is integrated into homework problems and, more extensively, into the case studies.

We reviewed 15 commercial texts that could serve as the basis for our redesigned course. They were (basically) interchangeable in terms of content, but only two of them offered significant material that could be integrated into a Web-based course: Rolf, "Finite Mathematics," 5th Edition (Harcourt), and Barnett, Ziegler, and Byleen, "Finite Mathematics," 9th Edition (Prentice-Hall). Both of these books had extensive Web sites to accompany the text, with additional examples, Web links to related sites, online self-test quizzes, etc. We used the book by Barnett, Ziegler and Byleen (1999), because it offered two features that make it more appropriate for our purposes:

- Web content that could be loaded directly into WebCT,
- Content available before the beginning of the implementation.

4.2 Web-based Environment

The online learning management software WebCT (www.webct.com) is used to present course material and manage course communications and administration. Students are able to log into WebCT to look up what they need to study (learning objectives, sections to be read, assignments, upcoming quizzes, and exams), and to find links to additional material, extra problems, self-test quizzes, and case studies.

Among many similar course presentation environments, WebCT was chosen because Iowa State University actively promotes this system and centrally provides server hosting, software training, and a user help line. WebCT is also integrated with the campus user ID system as well as databases in the Registrar's Office. A number of the reviewed textbook publishers provide WebCT-compatible content as well.

For the online homework assignments and tests, we use MapleTA (www.maplesoft.com/products/mapleta/), an online testing program written by John Orr at the University of Nebraska, Lincoln. This program was originally called eGrade and is now marketed under various names by Brownstone. This program has performed very well for several years in all of the online courses in the Mathematics Department. We evaluated competing products, including the testing system built into WebCT, and found that they are limited to multiple-choice and simple numerical answers. MapleTA accepts formulas and is able to recognize mathematically equivalent forms. For example, if the correct answer is "sin(2x)", MapleTA would also accept "2 sin(x) cos(x)", or "cos(2x-pi/2)."

The course material is divided into four modules (algebra, functions and graphing; basic linear algebra; linear programming; and counting, probability, and statistics), with each module subdivided into weeklong segments. Each module includes clearly defined expected learning outcomes, an Excel project, and eight or nine homework assignments to be completed through the online testing system (without supervision). Each module concludes with an exam that is taken in a supervised computer lab.

One of the main concerns we found when analyzing the environment of our previous Web-based courses in Trigonometry and College Algebra through surveys and focus groups was that students tended to fall behind more frequently than in (small) lecture courses. Once they have fallen behind, they often lack the support to catch up in time. The redesign of Discrete Mathematics uses a strict timeline to measure student progress. The material is presented in weekly chunks: between 2 and 4 assignments per week, all with the same deadline one week later. One exam and one large Excel project are given for each module, with strict deadlines. This weekly/module frame restricts students by determining the last day for the delivery of certain assignments; in return, we expect that this structure will contribute to retention.

The online testing system is able to break down students' scores by topic. Identifying these difficult course topics also allows us to monitor the course design and further refine the course content in these problem areas.

4.3 Student Support

As noted above, we have conducted a survey and focus groups with students enrolled in Discrete Mathematics and our other Web-based courses. The main concern expressed by these students was the lack of availability of a course assistant who would be available at least once a week to discuss individual questions and to keep them up-to-date in the course. Such regular meetings also would facilitate forming study groups and coordinating and exchanging information about larger case studies. In response, we offer the following student support net:

- Weekly small recitation sections, where a TA demonstrates problems similar to the homework and answers questions,
- Additional office hours for the course TAs,
- Study groups formed by the students, encouraged by faculty, with support in connecting and communicating from the course Web site,
- The availability of the Math Help Room, which is staffed during weekday daytime hours,
- Supplemental Instruction, a peer instructor system at Iowa State University organized by course and supported by the Vice Provost for Undergraduate Programs, and
- Technical support for network connectivity through the campus Solution Center and WebCT software orientation through the Iowa State 'Computer Survival School.'
- Continuous communication of support options through the recitation sessions as well as multiple online information channels.

In addition, we offer the following Web-based support

- A Web-bulletin board for each class, to foster collaboration and communication,
- A Web-based help file, sorted by topic, where students can try to find quick answers to common problems,
- Instant feedback to students of their homework and quiz performance,
- A computer bulletin board, which students can use to find study partners and ask questions.

4.4 Guiding Principles of the Redesign

Sections 4.1—4.3 describe a set-up that addresses the shortcomings of the traditional course format and meets the learning goals and objectives described in Section 3. Specifically, the redesign was guided by these principles:

- Self-paced modular approach: The course syllabus is divided into manageable modules with clearly communicated learning outcomes and objectives. Self-paced learning promotes a more active role for students in their learning process through Web-based materials, large problem data banks, and practice exams, which provide students with programmed feedback for review.
- Elements of collaborative learning: These include group learning in regularly scheduled sessions, student-created study groups, and an electronic setup to create virtual communities of learners.
- Flexible learning environment: Course materials including problems and (practice) exams placed on the Web with 24/7 access from any Web-enabled computer. Students are able to work when it best fits their schedule and take exams when they are ready, with deadlines that monitor student progress.
- Integrated and proactive student support: One regularly scheduled class session per week, online tutoring, help rooms on campus, and feedback in graded assignments. Monitoring of student progress includes Web-based problems and exams that allow instant evaluation of student progress and identification of difficult concepts and calculations. Electronic formative evaluation is conducted to adjust, if necessary, delivery design and technology between semesters.
- Expansion of learning and understanding through the application of technology, for example, by incorporating EXCEL spreadsheets for instantaneous graphics and simplification of extensive repetitive calculations. This also may include using graphical representations and interactive simulations to explain complex concepts or providing content via multiple media to meet a variety of student learning styles.

The faculty responsibilities for a given academic year are summarized as follows (more faculty have participated in early semesters for training purposes):

- Two full-time faculty in fall and one in spring semester supervise the redesigned course having the following responsibilities:

  o Enhance the test banks in the online testing software,

  o Hold 5 office hours per week, and

  o Conduct meetings with TAs.

- Nine TAs assist the three faculty. Each TA has the following responsibilities:

  o Conduct 6 recitations per week, and

  o Hold 4 office hours and online help sessions per week.

5. Results of Course Redesign

The Web-based Discrete Mathematics course has changed the landscape of mathematics education at Iowa State. Of concern are the specific effects on learning, retention, future success, and cost.

5.1 Detailed Statistical Analysis of Learning Outcomes

Students in the redesigned sections, taking the Mathematics 150 course on the Web, performed no worse, and usually performed better, than students in a traditional section. This is clear from examining the scores of students on directly comparable questions asked on exams during the semester and on final exams.

For four semesters, Spring 2002 through Fall 2003, students at Iowa State were allowed to enroll in either a traditional classroom-based section of Math 150 or a redesigned, Web-based section. Thereafter, Discrete Mathematics was available only as a Web-based course. Comparable exam results and grades were collected from students in both types of sections for Fall 2002 through Fall 2003 (the section in Spring 2002 was a small pilot class and not conveniently comparable to the traditional section). Table 2 contains the number of students in each of the comparable sections. Additional demographic and academic information was collected from the University Registrar for all of these students. Each of the sections included

Semester	Control Group Size	Design Group Size
Fall 2002	125	572
Spring 2003	123	315
Fall 2003	313	695
Spring 2004	0	577

Table 2: Sample sizes for each semester.

students from all of the undergraduate colleges at Iowa State as shown in Table 3. In the following analysis, we will refer to students who enrolled in the redesigned sections as design students and those in traditional sections as control group students.

In Fall 2002 and Spring 2003, the design section included a review of basic material that was not covered in the control sections. Comparisons on that material are omitted. In Fall 2003, we modified the syllabus for the control sections to include this material, and all sections have since covered the same content named in Table 4 and given identical exams within a semester.

Comparing learning outcomes between the control and design students, we found that the design students generally learned more than the control students and never learned significantly less than them. In Fall 2002, design students scored 15.0%*** higher on the linear algebra content, 6.7%** higher on the linear programming content, 4.7%** higher on the statistics content, and 13.0%*** higher on the comprehensive exam than did the control group. Spring 2003 design students also significantly outperformed the control students on the linear algebra (15.6%***), linear programming (20.0%***), statistics (25.8%***), and comprehensive content (6.8%**). In Fall 2003 the results were a bit less stark — design students again had higher mean scores on much of the content (review of algebra 14.9%***, linear programming 2.9%**, and comprehensive 4.2%*) exams and no significant difference on the linear algebra (2.0%) and statistics (-2.7%) content.

There are several possible confounding variables which could be causing the difference between the design students and the control students. An important one is the self-selection of students into either the design or control sections prior to Fall 2003. It might be expected that more computer-savy students might choose the web-based course and also have higher math ability. To control for the previous knowledge of students, we added effects for high school mathematics experience (algebra, geometry, and trigonometry), high school rank, and ACT scores in algebra/geometry, elementary algebra, geometry/trigonometry, and general mathematics. After this adjustment of the model, the exam performance advantage for the design students persisted for some content (review algebra in Fall 2003, linear algebra in Fall 2002 and Spring 2003, linear programming in Spring and Fall 2003, statistics in Spring 2003, and comprehensive in Fall 2002).

It is important to note that the consistently enhanced performance of design-section students over control students occurs despite cumulative grade point averages for the design students 0.1989** lower in Fall 2002, 0.0220 higher in Spring 2003, and 0.1773*** lower in Fall 2003 than the control students. This suggests that the Web-based course design is able to enhance the performance, and hence the chances for retention, of even less-highly achieving students (as determined by their lower GPAs). These differences in cumulative GPA and in pre-class preparation probably are related to pre-college preparation, and are not significant after controlling for high school rank for Fall 2002 and Spring 2003. However, the difference persists for Fall 2003 (p = .001).

A lack of uniform grading across instructors makes a direct comparison of grade distribution between design and control students very difficult. This lack of comparability was compounded further while Math 150 had not yet been converted entirely to Web-based instruction. From Fall 2002 through Fall 2003, students were able to switch sections easily. Now that no alternative exists to Web-based instruction in the course, it will be easier to establish whether there is any difference in DFW rate between design students and the historical record of control students. The drop rate in the design sections has been falling over the duration of the course redesign implementation, from 22.4% in Fall 2002, to 20.1% in Spring 2003, and to 13.1% in Fall 2003. In Spring 2004, when full

[1] Throughout *** denotes p<0.001, ** denotes p<0.01, * denotes p<0.05, and else the effect is not significant.

College	Agriculture	Design	Education	Engineering	Family and Consumer Sciences	Business	Liberal Arts and Sciences
F2002 C	71	18	23	5	20	327	101
F2002 D	18	8	3	2	4	72	17
S2003 C	42	11	14	4	17	161	65
S2003 D	12	7	2	2	10	69	20
F2003 C	97	19	21	2	32	428	96
F2003 D	42	14	14	2	15	169	57
S2004 D	44	20	34	3	39	317	120

Table 3: Breakdown into each college of enrollment numbers for each semester for control (C) and design (D) groups. The Business College is the largest stakeholder.

Exam	1	2	3	4	Final
Topics	Review of Algebra, Functions, and Graphing	Basic Linear Algebra	Linear Programming	Probability and Statistics	Comprehensive

Table 4: Subjects covered on each exam.

implementation of Web-based instruction was first executed, the drop rate was elevated to 17.3%. Supplemental Instruction (peer instruction) programs and increased lab time are being incorporated to further reduce the DFW rate.

In Spring 2004, two design sections with different faculty were offered. Of interest is whether students in the class of the main instructor (with vested interest and previous experience in the Web-based course) have different learning outcomes from those in the section with a faculty new to the redesigned course. These two sections are compared with each other and loosely with earlier control sections. Performance on the exams was comparable in the two sections, despite Instructor A's section having a 0.1470* higher cumulative grade-point average and a 1.17 higher high school rank. There was no significant difference between the two sections on all of the content except linear algebra. For linear algebra, Instructor B's section performed slightly better 1.9%*. However, when controlling for high school mathematics experience, high school rank, and ACT math scores, as above, there is no significant difference between the sections on any content. Therefore, the design section effect is not isolated to a particular instructor.

There was some initial concern that gender differences in familiarity and comfort with the Web-based technology or desire for personal interaction might lead to differences in learning within the design sections. The effect of gender on learning the Math 150 material was not significant in nearly every case. Males and females did not score significantly differently on any of the exams in Fall 2002 ($p = .185$, .824, .992, and .451, respectively). Males slightly outperformed females on Exam 2 in Spring 2003 ($p = .041$) for both the design and control sections, but did not score differently on the other three exams in that semester ($p = .229$, .416, and .119, respectively). Also, there were no significant differences in the Fall 2003 ($p = .471$, .232, .855, .507, and .606, respectively) or Spring 2004 ($p = .235$, .374, .959, .896, and .411, respectively). The interaction of treatment group and gender was not significant for any semester; this means that there is no significant interaction between gender and outcomes for either the design or control students.

5.2 Impact on Students

The implementation of Web-based instruction of Discrete Mathematics impacted the students from much of the university who will take this course as a degree requirement. The initial impetus for this change involved saving money and faculty time. Through the redesign of the course, stakeholders were consulted and the added objectives of improving student learning and experience were incorporated into the process.

5.2.1 Improved learning. Students in the design sections (Web-based Math 150) performed no worse, and usually performed better, than did control group (classroom-based) students. These results are based on student scores on comparable exams in Fall 2002, Spring 2003, and Fall 2003.

In a straight comparison, the design sections did significantly better than the control sections on 11 out of 13 tests, with comparable results on the remaining 2 tests. After adjusting for high school mathematics experience (algebra, geometry, and trigonometry), high school rank, and ACT scores in algebra/geometry, elementary algebra, geometry/trigonometry, and general mathematics, the difference is less pronounced, but the design sections still performed significantly better than did the control sections on a majority of the exams.

5.2.2 Improved retention. So far, both the drop rate and the percentage of D and F grades are higher in the design section than in the control section. We attribute the higher drop rate to the fact that at the time of measuring these results Math 150 had not yet been converted entirely to Web-based instruction. Many students prefer classroom-based sections, and would switch sections when space in classroom sections opened up. Since Spring 2004, all sections are Web-based, and we expect the drop rate to decline. There was a slight rise in the drop rate in Spring 2004, although it has not quite risen to the levels observed during implementation. The percentage of D, F, or drop students (DFW rate) design section for Spring 2004 was 35.9%, compared to 37.6% in Fall 2002, 37.0% in Spring 2003, and 31.4% in Fall 2003.

The higher rate of Ds and Fs in design sections than control sections is due partly to more lenient grading on the part of the control instructors (higher final grades despite lower exam scores, see Table 5). We also have observed that the grade distribution in the design sections is more polarized than in the control sections: there are more As, but also more Fs. Still, grading in the design sections is more monotone in comprehensive learning and only students who didn't take the final exam received an F in the design section. In all three semesters where control and design sections were run concurrently, the percentage of D and F grades was higher in the design than the control section(15.2%, 16.9%, and 15.5% for design as compared to 12.0%, 11.2%, and 4.9% for control). The students who keep up with the assignments tend to learn more and perform better in the redesigned course; the students who usually get by through cramming for a few exams don't do so well. We have tried a variety of techniques to motivate those students, but have not discovered the right approach yet.

Supplemental Instruction (SI) has been implemented to improve student support and retention. For Spring 2004, of 575 students who were enrolled after the first period, 111 attended at least one voluntary SI session. Only 8 (7.2%) of the SI participants withdrew from the class; a large reduction from the 93 (20%) of non-participants. Similarly, there is a significant difference ($p < .05$) in the DFW rate: 27% for SI participants and 45% for non-participants. Finally, there is a significant difference ($p < .05$) in the mean final grade points: 2.64 for SI participants and 2.41 for non-participants.

5.2.3 Impact on future learning.

"Downstream" analysis of student performance (grade-point average, retention, and graduation) thus far has involved only a handful of students. The vast majority of the students who took the Math 150 course during Fall 2002 through Fall 2003 have not yet populated the targeted downstream courses in Statistics and Business. Of the 2,776 students in the four semesters of Math 150 analyzed here, 1,647 have been enrolled in follow-up classes (not distinguishing multiple enrollment by the same student). Through Spring 2004, 239 students had taken Stat 101 (Principles of Statistics, covering basic statistics for a very general audience, assuming 1.5 years of high school algebra), 8 had taken Stat 104 (Introduction to Statistics, covering basic statistics for students majoring in the agricultural and biological sciences, and also assuming 1.5 years of high school algebra), 63 had taken Stat 201 (Applied Regression Analysis for Business, covering simple and multiple linear regression and quality control topics, for which 101 or 104 is a prerequisite), 603 had taken Stat 226 (Introduction to Business Statistics I, covering basic statistics for students majoring in business, for which Math 150 or a semester of basic calculus is a prerequisite), 285 had taken Stat 227 (Introduction to Business Statistics, an earlier version of 226 which also covered 201 content, requiring Math 150 or a semester of basic calculus), and 449 had taken POM (Production and Operations Management) 320 (introduction and analysis of the basic concepts in production/operations management, including applied forecasting, aggregate planning, scheduling, shop floor control, total quality management, inventory management, facility layout, and project management, and requiring Stat 226 or 227). Among these groups, only 220 students had enrolled originally in the design section of Math 150, so comparisons of the two groups are questionable at best.

Grade	A	A-	B+	B	B-	C+	C	C-	D+	D	D-	F
Final C	81	74	69	69	63	57	49	39	33	41	38	51
Final D	90	83	84	80	62	71	57	53	NA	43	NA	0

Table 5: Average Fall 2002 Final Exam scores (out of 100) by grade received for control and (C) design (D) groups. Note that (for all but one grade) the design students scored better than the control students receiving the same letter grade. This trend is continued through other exams.

Using all students who enrolled in a downstream class, the drop rates in downstream classes are 2.7% for design students and 4.6% for control students, but this difference could be affected by the self-selection of students into the follow-up courses. Many students from both groups have taken the Business Statistics course, formerly 227 and now 226. We compared performance in downstream grade points while controlling for the grade points received in Math 150. There is no significant difference in the downstream performance of design and control Math 150 students in Stat 226 ($p = .547$). There is a significant increase in downstream performance of design Math 150 students in Stat 227 ($p = .042$). This may be explained by the difference in the two Statistics courses. Stat 227 includes weekly computer labs and therefore is more computer-intensive than is Stat 226; and Math 150 design students may have benefited from their greater exposure to computer applications.

5.3 Impact on Cost Savings

In the original proposal, it was estimated that the course redesign would lower instructional costs from $129 to $75 per student. A number of changes in course organization were made during the experimental period, but the budgetary effects of these changes almost canceled each other out. We successfully implemented a version of the course with an instructional cost of $77 per student.

The original proposed budget included a computer support person, but in practice it became apparent that this position was not needed. However, there was a need for more mathematical help and supervision; in response, the number of faculty and TA hours was increased.

The traditional course used 12 faculty members and 15 teaching assistants to deliver the course to 1,800 students annually; the redesigned course requires only 3 faculty members and 9 teaching assistants. The savings of almost $94,000 per year will be used to keep hardware and software updated, and to reduce class sizes in other areas.

6. Lessons Learned

The process of redesigning and implementing a web-based Discrete Mathematics course has provided lessons on cost saving, mathematics pedagogy, and web implementation.

6.1 Pedagogical Improvement Techniques

6.1.1 Online Assignments. In the experience of most college mathematics instructors, student learning is directly related to the amount of time students spend working problems. Homework is assigned in most courses, but usually the instructor is not able to grade more than a small part of it, and students don't take it seriously. In the redesigned Math 150 course, frequent homework assignments (usually three per week) take the place of the lectures and form an important part of the course and of the students' final grade. Computer grading of all exercises ensures that every assignment gets counted, and gives the students immediate feedback.

6.1.2 Improved Communication. Even though the redesigned course has no lecture meetings, WebCT's built-in communication tools (bulletin boards and email) make sure that students are always aware of upcoming deadlines and other special announcements, as well as their current standing in the course. The online bulletin board lets all students see responses to questions by other students. In some cases students resolve each others' questions. Weekly computer labs with mandatory attendance help students stay in communication with TAs.

We also facilitated the formation of study groups. Students arranged the meetings themselves, but the instructor helped them find each other, and WebCT tools let the study groups keep in contact.

6.1.3 Additional Material: Algebra Review and Excel. Advisors in the Business College felt that many students did not have a sufficient background in basic mathematical skills even after completing Math 150 (Discrete Mathematics) and Math 151 (Business Calculus). They also wanted the students to learn more problem-solving skills. In response, we incorporated a review of basic algebra and precalculus material into Math 150, and added Excel-based projects to the course.

6.2 Cost Savings Techniques

6.2.1 Online delivery and online testing. Traditionally, this course has been taught with a total of 12 instructors and 15 teaching assistants for the year. The redesigned format required only 3 instructors and 12 TAs. These savings are directly attributable to online delivery and online testing.

Since the instructor doesn't have to meet the students in the classroom and does not need to design several exams per term, each instructor can handle between 500 and 600 students. Experience with other online courses has taught us that this is about the limit for one person. The teaching assistants don't have to grade exams any more, so they can be assigned more hours to interact with the students in the computer lab or during office hours.

6.3 Implementation Issues

6.3.1 Creation of exams. The creation of question banks for homework assignments and exams took up considerably more time than expected. All the assignments are administered using MapleTA (formerly called EDU), a program specifically created for administering mathematical questions with write-out solutions. The syntax for creating MapleTA's algorithmic questions is a bit peculiar, error messages are often meaningless or misleading, and documentation is sparse. (In an algorithmic question, the computer generates different numbers for each student.)

However, the final result was well worth it. We now have question banks for homework assignments and exams that can be reused, improved, and expanded term after term.

6.3.2 Technical issues. We were also struggling with some other technical issues. Every new release of MapleTA fixes some bugs and introduces new ones. While these have caused slight concerns to the students and faculty, all have been accommodated.

An early headache was the transfer of scores from MapleTA to WebCT. Initial attempts to simplify this cut the process down to less than 10 minutes, but it still required some action on the instructor's part. Perl scripts have now been developed to fully automate the process.

6.3.3 Lack of computer labs. At the time the course redesign was begun, the College of Liberal Arts and Sciences was planning to create a centralized computer laboratory. These plans did not succeed at the time, so initially it was not possible to implement the course on the planned scale. This problem now has been resolved. The full course was converted to Web-based delivery for Spring 2004 and beyond.

6.3.4 Keeping students engaged. We discovered that online course delivery polarizes student grades. The students who complete most of the assigned work typically get As and Bs, and the students who don't get Ds and Fs. There are relatively few C grades. Personalized emails to the students lagging behind have had only moderate success.

In Fall 2003, we implemented two further changes to address this issue. One of them is mandatory attendance at computer lab sessions, which count for a small part of the grade. The other is that we forward the names of failing students to the advisors in their college. We hope that the students will pay more attention to their advisors than to their instructors.

References

Chickering, A.W., & Gamson, Z.F. (1987). Seven principles for good practice in undergraduate education. AAHE Bulletin 39(7), 3-7.

Huba, M.E., & Freed, J.E. (2000). Learner-centered assessment on college campuses: Shifting the focus from teaching to learning. Allyn and Bacon, Boston, MA.

The Institute for Higher Education Policy. (2000). Quality on the line: Benchmarks for success in internet-based distance education. Washington, DC.

Ott, L., Longnecker, M., & Ott, R.L. (1988). An Introduction to Statistical Methods and Data Analysis. PWS-Kent, Boston.

WebCT: www.webct.com

MapleTA: www.maplesoft.com/products/mapleta/

Barnett, R.A., Ziegler, M.R., and Byleen, K.E. (2005). Finite Mathematics for Business, Economics, Life and Social Sciences, 9th Edition, Prentice-Hall College Division.

Tanzy Love graduated from Iowa State University in 2005, receiving her Ph.D. in Statistics. Her areas of research while a graduate student included Bioinformatics and Education. She is currently a Visiting Assistant Professor in the Department of Statistics at Carnegie Mellon University in Pennsylvania. Here, she continues her previous work and has become involved in mixture modeling and social network modeling.

Fritz Keinert received his Ph.D. in Mathematics from Oregon State University in 1985. After a three-year postdoc at the University of Utah in Salt Lake City, he moved to Iowa State University in Ames, where he is now an Associate Professor in Mathematics. His research interests include various fields of applied mathematics: integral equations, computer tomography, and wavelet theory. For the past six years he has been involved in teaching and developing web-based courses. The biggest such project is described in this paper.

Mack Shelley is University Professor of Statistics and of Educational Leadership and Policy Studies, and Director of the Research Institute for Studies in Education, at Iowa State University. His research interests include math and science education, student outcomes, and multivariate statistical methods.