Assessment of a Course Redesign: Introductory Computer Programming Using Online Modules

Nira Herrmann, Jeffrey L. Popyack, Bruce Char, Paul Zoski
Departments of Mathematics and Computer Science
Drexel University
Philadelphia, PA 19104
215-895-2668/2669
Nira.Herrmann@Drexel.edu, {jpopyack,bchar}@cs.Drexel.edu, pzoski@mcs.Drexel.edu

ABSTRACT
We assess the effectiveness of an extensive redesign of the first Computer Programming course offered to computer science and computer engineering majors. Our goals were to improve student learning while reducing costs by making use of substantial Web-based course material and course management tools, including multi-level online modules that individualize instruction and enable students to self-schedule learning each week. DFW rates and costs were significantly reduced by the redesign.

Categories and Subject Descriptors
K.3.1 [**Computers & Education**]: Computer Uses in Education - Collaborative learning, K.3.2 [**Computers & Education**]: Computer and Information Science Education - Computer science education, Information systems education

General Terms
Management, Economics, Design, Languages, Performance, Measurement

Keywords
CS1, Assessment, Pedagogy, Cooperative Learning, Course Management Systems, Online Course Work, Hybrid Courses

1. INTRODUCTION
1.1 Course Redesign
The course redesign is described in detail in [1]. Here, we briefly summarize the goals for the redesign and the nature of the changes made. The redesign was prompted by problems faced by the department, including (1) a computer science faculty whose modest growth had not kept pace with enrollment growth; (2) incoming students whose widely divergent computing experience and skills could not be properly accommodated by the large-lecture format of the traditional course, and (3) a high rate of non-passing grades: D grades, withdrawals (W) and failures (F), collectively referred to as DWF, from 25-50 percent, depending on the term and audience for the course.

The goals of the redesign were: 1) to provide students with an enhanced individualized learning experience that reduced the number of DWF grades without overburdening a limited faculty; and 2) to reduce costs. The solution has involved a major change in the method of course delivery, including increased use of online materials, and extensive use of electronic course management tools, facilitated by the availability of a campus-wide wireless network and the requirement that all undergraduates have their own computer.

Figure 1 ([3]) briefly summarizes the major structural differences between the traditional and redesigned courses.

Traditional Course	Redesigned Course

• 2 traditional lecture hours + 1 lab hour per week
• Individual assignments only
• Standard lab
• Some online material (instructor created)
	• 1 modified lecture hour and a half + 2 lab hours per week
	• Individual & group projects
	• Group-work lab
	• Substantial online support, plus
	  o Chat & discussion
	  o Online submission of assignments
	  o Online return of graded assignments

Figure 1: Traditional versus Redesigned Course Structure

In the redesigned course, the lecture time is used to orient students to upcoming topics and the online materials available to them as well as to answer questions rather than provide traditional in-class lectures since the lecture materials are available online. The lab sessions are organized around group projects that include multiple stop points where the instructors certify the results before students move on to the next section, insuring that students understand the essential aspects of each lab assignment.

The redesigned course makes extensive use of Web-based material, presented through a course management system (WebCT). A specialized software program, Labrador [1], was developed to assist in retrieving and returning documents from/to WebCT, processing the documents to prepare them for grading or submission to plagiarism detection software, and facilitating development of Web-based material. Electronically submitted student work is graded using tablet PCs, which allow handwritten annotations at the same level of detail and specificity used in grading hardcopy assignments [5].

Having all student work online makes it easier to look over, to know what was or was not turned in, and when work was turned in, as well as to assess students' mastery of it. Electronic submission of student work cuts down substantially on lost work, particularly in large classes. It also makes it much easier to route assignments to the appropriate teaching assistant for grading since everything is done electronically (using the software described in [2]). Returning graded assignments to students electronically prevents losses and eliminates theft of graded student work by students looking to cheat. Thus a major source of wasted time in the traditional course, keeping track of student work and getting it graded in a timely manner, is eliminated.

Additional software tools have been developed to assist in creating quizzes and uploading them to WebCT (e.g., [2]) and to strip student identifiers from Chat sessions so that useful discussions can be distributed to all students. Teaching assistants hold virtual office hours through the WebCT chat feature, particularly late on the nights before assignments are due (10:00pm-midnight).

The syllabus, presented in Figure 2 (from Figure 2 of [3]), covers the CS 1 curriculum for C++ for a ten-week quarter system term:

Week	Topics Covered
1	Course Introduction
2	**Module 1** -- Introduction to C++ First Program, Style, Comments, Variables, Simple I/O
3	**Module 2** -- Numeric Types Basic Arithmetic, Integer Division, cmath library
4	**Module 3** -- C++ Strings string library, char indexing, string methods
5	**Module 4** -- Using Objects Introduction to OOP, Classes, File I/O
6	**Module 5** -- Conditionals if, if ... else, if ... else if conditionals
7	**Module 6** -- Advanced Conditionals and, or, not, nested conditionals
8	**Module 7** -- Introduction to Functions Prototypes, functions, scope, definition, pass by value
9	**Module 8** -- Advanced Functions Pass by reference, const parameters, side effects, simple recursion
10	**Module 9** -- Loops while, do ... while, for loops, nested loops, sentinel controlled loops, EOF controlled loops, Comparing Floating Point Numbers
11	Final Examination

Figure 2: Syllabus for CS 1

A dedicated computer laboratory has been built to facilitate group work, containing five clusters, each with five wireless-networked laptop computers and a projector that can be switched from one computer to another. Group assignments are downloaded from a central server using the wireless network. Each group can project its shared work onto the white board "wallpaper" that covers all of the walls and annotate the projected screen image or write notes to the side as they work through the assignment. More recently, the room has been equipped with tablet PCs, which allow electronic pen-based annotation of assignments in the same way assignments are graded.

1.2 Implementation of Redesigned Course

The redesign was first implemented in a pilot course taught in the Winter Term of 2001-02, concurrently with the traditional sections of the course. Students were told the department was experimenting with a new form of course delivery emphasizing hands-on experiences in the lab instead of formal lectures.

The weekly lecture hour was used to orient students to the next module, but traditional lecture materials were available online rather than in class. In all other ways, the two courses were similar, including the topics covered. The courses made use of identical assignments and examinations, which were graded together, without regard to which class the students were taking. Students were invited to register for the experimental pilot section and were a self-selected group. Starting in the Spring Term of 2001-2002, only the redesigned version of the course was offered and this continued into the Fall, Winter, and Spring Terms of 2003-2003. All sections of the traditional, pilot and redesigned courses were taught by project faculty over the two years of development.

Computer Science (CS) majors generally take this course in the Winter Term of their freshman year, following a general introduction to the field of Computer Science in the Fall Term. Computer Engineering (CE) majors primarily take the course in their third year, either in the Fall or Spring Term. A few students from other majors, including various Engineering (Eng) disciplines, Information Science (IS), and Digital Media (DM), also enroll in this course. Figure 3 presents the percentage breakdown of students by major across the different terms the traditional, pilot, and redesigned courses were offered.

Course Status	Major	Fall 01-02	Winter 01-02	Spring 01-02	Summer 01-02	Fall 02-03	Winter 02-03	Spring 02-03	Total (#)
Traditional	CE	15%	5%						21
	CS	35%	71%						167
	Eng	17%	8%						27
	IS	6%	1%						7
	Other	26%	15%						47
Subtotal (#)		65	204						269
Pilot	CS		100%						34
Subtotal (#)			34						34
Redesign	CE			30%	40%	36%	3%	41%	88
	CS			33%	25%	30%	77%	22%	219
	Eng			10%	5%	16%	4%	11%	34
	IS			18%	15%	2%	2%	13%	36
	Other			9%	15%	16%	14%	13%	56
Subtotal (#)				121	20	44	194	54	433
Total (#)		65	238	121	20	44	194	54	736

Figure 3: Percent of Students in Each Major by Term Taking the Traditional, Pilot, or Redesigned Courses

Pre- and post-tests have been given to students in the traditional and redesigned courses to assess changes in student learning. Similar midterms were also given; however, the final examination for the redesigned courses in 2002-03 was adjusted to be more demanding of students based on their heightened performance on the midterm.

1.3 Student Entry Information

Before comparing student performance in the traditional, pilot, and redesigned courses, it is important to ascertain that the student populations across the different courses are similar. Figures 4, 5, and 6 show that the three groups are similar with respect to ethnic group, gender breakdown, and Total SAT scores (obtained by adding the SAT mathematics and SAT verbal scores):

Ethnic Description	Traditional	Pilot	Redesign	Total (#)
African American/ Black Non-His	9%	6%	9%	66
Asian or Pacific Islander	27%	21%	21%	170
Native American or Alaskan	1%	0%	0%	4
Hispanic	3%	0%	2%	16
Unknown	12%	15%	9%	76
White Non Hispanic	48%	59%	59%	404
Total #	269	34	433	736

Figure 4: Percent of Students in Each Ethnic Group Taking the Traditional, Pilot, or Redesigned Courses

Gender	Traditional	Pilot	Redesign	Total (#)
Female	15%	18%	13%	101
Male	85%	82%	87%	632
Total #	268	34	431	733

Figure 5: Percent of Students by Gender in the Traditional, Pilot, or Redesigned Courses

	Traditional	Pilot	Redesign
Average of Total SAT Scores	1,169	1,191	1,186
Maximum of Total SAT Scores	1,450	1,570	1,520
Minimum of Total SAT Scores	790	970	630
Standard Deviation of Total SAR Scores	123	124	137
Average of SAT-Math Scores	611	620	620
Total # with SAT Reported	221	33	371

Figure 6: Summary of Total and Math SAT Scores for Students in the Traditional, Pilot, or Redesigned Courses

In the remaining sections, we present results on student learning, faculty and student responses to the redesign, cost savings, successes and problem areas.

2. MEASURES OF STUDENT LEARNING

2.1 Pre-Test/Post-Test Results

The pre-test and post-test were identical tests to detect changes in student learning and understanding of the course material. The tests were graded by looking at the total number of questions answered correctly and by assigning differential points to each problem based on its level of difficulty, as determined by the faculty teaching the course. These tests were administered during the Winter Terms of 2002 and 2003.

The pre-test and post-test were not specific language tests but were designed to ascertain students' understanding of the function of various programming constructs, such as conditionals, loops, functions and arrays. On average, students in each class showed improvement on the post-test compared to the pre-test. The greatest improvement occurred among students in the pilot version of the course, followed by the redesigned courses, and then the traditional versions of the course.

2.2 Grade and DFW Results

Figure 7 presents the grade distribution for the traditional and redesigned courses taught during the 2001-02 or 2002-03 terms, with the pilot and redesign groups combined. In addition, the number of students who received a D or F or who withdrew (W) from the course is given (DFW row). A specific goal of the project was to reduce the rate of DFWs.

	#		%	
Final Grade	**Traditional**	**Redesign**	**Traditional**	**Redesign**
A	39	109	14%	22%
B	60	101	22%	20%
C	37	85	14%	17%
CR	1		0%	0%
D	41	60	15%	12%
F	60	77	22%	15%
INC		1	0%	0%
W	31	67	12%	13%
Total	269	501	100%	100%
DWF	132	205	49%	41%

Figure 7: Grade Distribution for Traditional and Redesigned Courses, Combining the Pilot and Redesign Sections and Combining Over all Terms in 2001-02 and 2002-03

Eliminating the special cases of the two students who received Credit but no specific grade (CR) or who received an Incomplete (INC), respectively, a chi square test for homogeneity of the two groups yielded a statistically significant difference ($p=0.013$). Thus, the distribution of grades in the Redesign Group is not the same as that in the Traditional Group across the two years of this project (2001-02 and 2002-03). In particular, there is an excess of failing students (F grades) in the Traditional group while the Redesign Group had additional top performers (A grades).

Several regression models with the course grade as the dependent variable were run. Independent random variables were the SAT score, gender (scored 1 if the student is female, 0 if the student is male) and type of course (scored 1 if the student took a redesigned or pilot course and 0 if the student took a traditional course). In all of the models, the SAT Mathematics score and taking a redesigned course had a statistically significant impact on increasing the student's grade in the class ($p < .001$). Thus, the improvement in grades due to taking the redesign course is present even after correcting for variability in SAT scores among students in the three course types. However, the r-square coefficient, which measures the goodness of fit of the model, did not exceed 0.1881 in any of the models, indicating that these simple models explain only a small portion of the variability in course grades.

3. FACULTY PERCEPTIONS

As part of the redesign project, the faculty met regularly to develop course materials, discuss problem areas, and work together on implementation issues. In addition, focus groups of the participating faculty were held every six months so the faculty could look at their efforts from a more long-range perspective and assess their progress in meeting the project goals. The project faculty had considerable experience teaching the traditional course in previous years as well as during the pilot phase when both the redesigned and traditional courses were presented. As the redesign progressed, the faculty felt that students with good study habits, those they describe as "serious students", did better in the redesigned course than more passive students who expected the faculty to provide all of the information needed for the course. The more active students were perceived as taking a more mature approach to their course work by taking personal responsibility to learn the material.

The faculty noted that the students participating in the redesigned courses were more enthusiastic and alert during class time than students in the traditional courses and appeared to be learning more. Mixing students with previous programming experience with those who had little such experience to create the active work groups provided the less experienced students with greater support in overcoming the initial difficulties with learning to program. The more experienced students could quickly answer questions and demonstrate the use of the computer and/or software tools to the less experienced in their group, preventing them from falling so far behind in the initial stages that they could not catch up. This was a notable departure from the traditional course. The classroom dynamic improved as a result of the group work since the students developed a sense of community earlier in the term than in the traditional course and made good friends in their major much sooner, particularly the entering freshmen.

The online environment supported through WebCT provided new opportunities for mentoring students, using the chat and threaded discussion features as well as email. Virtual office hours allowed students to interact with faculty and teaching assistants even late at night, especially before an assignment is due. Students could participate in or observe group chat sessions or request a private chat with the instructor/teaching assistant. Because all assignments were submitted online and stored in the WebCT course repository, documents were simultaneously available to both student and instructor, facilitating online interactions. Thus, the redesign has resulted in a shift in faculty activity from delivering content in a lecture format to interacting more extensively with students both in class and online.

The hybrid delivery system of the redesigned course, comprising both extensive online materials and in-class time, involves considerably more work for faculty than the traditional course, both in terms of start-up skills needed (e.g., learning the intricacies of the course management system, developing and updating support software, reworking course materials into modules, and adapting to a different style of course delivery) and in delivering the course (e.g., extensive online interactions with students, preparing new electronic course materials and transferring them to the course management system, anticipating technology failures and having mechanisms for dealing with them in a real-time class environment).

There has been a growth in email, chat and threaded discussion as the online component of the course has become more firmly established. Instructors feel that if they do not keep up with all of these exchanges, they can lose touch with what the students are thinking. This is particularly important because the instructors do not see the students in lecture as often as in the traditional course. As a result, they have to rely on other mechanisms to learn what the students are thinking about the course. Students may also feel abandoned when the faculty does not participate in the threaded discussions, particularly if the discussion involves problems the students are having with the course.

Initially, faculty were not convinced that the new format provided sufficient face time with students: while the students had more opportunities to interact and meet each other, the faculty felt more removed from the social aspects of the learning process. Faculty also had to master how and when to intervene in group work situations, how to motivate students to solve difficult problems without giving away the answers, and how to make sure students stayed on task.

4. STUDENT PERCEPTIONS

Students' perceptions were obtained through class meetings to discuss the course, end of term evaluations, and comments made to the instructors and teaching assistants as the term progressed. When first exposed to the redesigned course, students also expressed concern that the one hour large group/lecture session per week did not provide enough time for faculty-student interactions. They requested that the number of in-class hours be increased to provide more face-to-face time with the faculty, even if that would result in more in-class hours overall. Surprisingly, they tended to be extremely conservative about changes in course delivery and in the demands that the active learning environment opened for them as learning opportunities, preferring the lecture format even when it did not meet their needs.

We have partially accommodated this request by adding a half hour to the weekly lecture session each week. This seems to be satisfying the needs of both the students and the faculty for this type of interaction without departing in a major way from the goal of a more interactive learning environment. The extra in-class time affords opportunities for large group activities (such as "pair and share" [4]) to increase student understanding of the material.

At a focus group session, some students stated that the faculty were not really doing work for the course because they were not giving lectures. Since the extensive behind-the-scenes work is not readily visible to the student, this impression was not totally groundless and indicated a couple of problems we had to deal with: first, making sure the students were aware of the thought and effort faculty were devoting to the course; and second, making sure the students felt that the faculty were interested in them by increasing faculty and teaching assistant interactions with students, both online and live. Putting too much online had the effect that students felt abandoned by the faculty rather than encouraged to be active learners.

5. COST SAVINGS

The cost savings were analyzed using the Course Planning Tool available at no cost from the Center for Academic Transformation Web site (http://www.center.rpi.edu/PewGrant/Tool.html). This analysis reveals a substantial savings, over 20% overall, in the cost of delivering the introductory programming courses. The savings accrue from several sources: the high level of re-use of course material, changes in the level of faculty needed to teach the courses, and the reduction in course administration tasks.

Once the course materials were organized into online modules, re-use became simplified and accessible. Assignments and tests from previous terms were used as study guides in subsequent terms while lecture and enrichment materials were re-used directly, reducing faculty preparation time. The course modules have also stabilized the core course content across instructors with the result that less senior faculty can provide quality instruction that meets departmental standards and goals for the course. The use of the active learning labs has further shifted the staffing needs from senior faculty to multiple teaching assistants working with part-time undergraduate and graduate students who can provide peer-tutoring during class as students work through their lab assignments.

Automating routine paper-handling activities, such as the submission, grading and return of assignments, quizzes and exams, has produced a substantial time savings for all personnel involved in these courses. As a result, the number of hours needed to present the course is reduced sufficiently that faculty and students can take on responsibility for a greater number of course sections to maintain the same workload. This has resulted in salary savings associated with the course redesign.

This project was started to find ways of handling ever-increasing enrollments, and the current structure has the capacity to take on additional students with minimal additional resources, so some of the potential cost savings have been unrealized by the recent downturn in enrollment in Computer Science and related majors.

6. CONCLUSIONS

Redesigning courses to adopt a new learning paradigm or environment is very time consuming, even when substantial course materials already exist. Both faculty and students need encouragement from the department leadership to sustain their efforts during the transition. As the faculty and students experience success with the new paradigm, the changes become self-reinforcing. For example, as students accommodated to the more interactive classroom and extensive online course support, they demanded similar online components in their other courses.

Redesigning a course at this level requires considerable faculty time. Faculty must be rewarded for providing this type of effort and the department has to encourage other faculty to learn the new paradigm and continue to support it. With the extensive use of online materials and tools, this involves establishing a mechanism for training new instructors and teaching assistants. For them to embrace the changes, not only must the changes be perceived as useful in increasing learning outcomes, but the instructors must feel that their extra effort is acknowledged in meaningful ways. The course redesign described here has improved student learning and created a more positive, interactive environment in both the computer lab and larger "lecture" meetings. It has also accomplished the goal of providing an enriched learning environment without straining faculty resources by making use of extensive online course materials and software tools for efficient course administration.

7. FUTURE WORK

We plan to continue developing course materials and software tools to improve course delivery and student learning and to address student and faculty concerns about maintaining interactions with each other: we need to explore whether faculty and students really need more formal lecture time to interact or are simply used to them and uncomfortable with change. We also plan to extend this approach to other courses in the programming sequence and in other areas, particularly in mathematics where we have close links and where the demand for courses is equally high.

A complex issue that needs greater investigation is determining what students in different majors need to learn and how to extend the modules to fit these different needs. At the moment, we are offering two versions of the redesigned course: a two-term, fast-moving course for well-prepared students and a three-term, "stretched" version that covers the same information at a slower pace, giving under-prepared students more time to master the material. For students who want to take upper level Computer Science courses, this type of approach insures that even under-prepared students acquire sufficient skills for those courses. On the other hand, a substantial number of students taking introductory programming courses do not intend to pursue the more technical aspects of Computer Science, so we are working on re-organizing the material in the modules to clearly specify the different knowledge levels appropriate to each major as discussed in [3].

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