JUST COMPUTER-AIDED INSTRUCTION IS NOT ENOUGH

COMBINING WEBWORK WITH IN-CLASS INTERACTIVE SESSIONS INCREASES ACHIEVEMENT AND PERSEVERANCE OF SOCIAL SCIENCE CALCULUS STUDENTS

INTRODUCTION

In the late 1500's Clavius introduced Mathematics to university studies and ever since, instructors have struggled with how to teach/learn Mathematics (Smolarski, 2002). Complaints about Mathematics instruction are not a new phenomenon. The Bulletin of the American Mathematical Society in 1900 (October 1900, pp. 14-24) states, "The fundamental principles of Calculus must be taught in a manner wholly different from that set forth in the textbooks" (Ewing, 1996). One hundred years later, while student success and understanding ebb, we still debate how to teach Calculus.

Teaching Mathematics in science programs at the post-secondary level has been abundantly studied over the past decades (*e.g.*, Springer, Stanne and Donovan, 1999) while teaching Mathematics in so-called service courses has received much less attention. This is unfortunate because students' lack of success and perseverance at college-level Mathematics can seriously jeopardize their career plans in the Social Sciences. Successful completion of a course in Differential Calculus is a condition of admission into business programs at any Quebec university. Although a college-level course in Mathematics is not a prerequisite for admission to a variety of other Social Science programs (*e.g.*, Sociology, Psychology, Economics), mathematical knowledge is necessary for success in subsequent compulsory statistics courses.

Current trends in the CEGEP system indicate a declining enrolment of Social Science students in Calculus courses. This is illustrated at Vanier College by a drop in the percentage of Social Science students taking Calculus I from 74% of the 1994 cohort to 55% of the 2001 cohort. Similar trends are observed across the CEGEP network (*Profil Scolaire des Étudiants par Programme*, SRAM, 2005). Summary statistics from the registrar of Vanier College indicate that this problem of Social Science students' low enrolment in Calculus courses persists; it decreased significantly from 39.4% in 2004 to 31.2% in 2006 (Pearson P2 (2,3322)=16.516, p < .001). This continuing decline cannot be attributed to student performance because average grades in high school Mathematics courses remained constant over that period. Alarmingly, in these three cohorts, 10.3% of students graduating with distinction (an average grade of 75.12) from the highest level Mathematics courses at both Secondary IV and V decided not to pursue CEGEP Mathematics courses. Further, although women formed the majority in two of the three cohorts, nevertheless in all three cohorts fewer women than men enrolled in Mathematics courses.

Failure rates in Social Science Calculus courses hover around 40%, compounding the problem of low enrolment. Too many CEGEP Social Science program graduates are ill-prepared for their chosen program of university studies and this has consequences that are bound to harm any society aiming to succeed in the intense economic competition of the twenty-first century.

The purpose of this study was to determine whether Social Science students' success and perseverance in Calculus courses could be improved, thereby reversing current trends. To this end, three instructional strategies were examined in Calculus classes and we report below on the outcomes of this experiment in terms of students' academic performance (grades and knowledge of Calculus), their persistence in Mathematics courses, and then on the implications of this research for the CEGEP network.

> *[...] students' lack of success and perseverance at college-level Mathematics can seriously jeopardize their career plans in the Social Sciences.*

THEORETICAL PERSPECTIVE

Currently, in a typical CEGEP Mathematics learning environment, the teacher presents a new concept and then assigns problems that students can only solve if they have understood the concept. Although most CEGEP instructors assign weekly homework, for reasons of workload they can rarely collect and correct homework. That is, teachers ask students, largely on their own: to do problems, to monitor their own success and to self-correct their understanding until concepts are mastered. From the perspective of socio-cognitive theory (Bandura, 1997), this type of internal feedback loop works well only for highly self-efficacious students possessing appropriate self-regulatory strategies (Zimmermann & Pons-Martinez, 1990). It is unlikely that such educational practices promote effective learning for any other group of students. When ineffective learning processes are followed by summative assessment, the combination delivers an educational one-two punch: it diminishes self-efficacy beliefs and effort expended in completing assignments and it also promotes adoption of less adaptive achievement goals. All of this further lowers achievement.

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However, many instructors observing poor student performance may draw a different conclusion; namely that, lacking the incentive of marks, students are not motivated and just won't do homework. High failure rates result and neither teachers nor students see how to change. The missing key component in this common scenario is effective feedback to/from students from/to teachers during learning (Crouch and Mazur, 2001; Buttler and Winne, 1995). Unfortunately, college instructors have no teaching assistants to correct weekly student homework assignments and their workloads prohibit weekly homework correction.

With the advent of computer technology, Mathematics instructors began searching for ways to provide feedback *via* the computer and in 1997, a freely available and award-winning online assessment tool called WeBWorK was developed (Gage, *et al.*, 2002). WeBWorK has features that make it a valuable tool for Mathematics educators:

- Students access problem sets from any computer that has an Internet connection and they are provided with instantaneous feedback (correct/incorrect answer);
- The system can deliver assignments, quizzes, exams, diagnostic tests, or be a tool in class;
- Students can collaborate, but not copy solutions, because each student is assigned problems with randomized parameters;
- Instructors set limits on the number of tries allowed;
- Instructors set the due date for each assignment (which can be altered for the whole class or for individual students, even while students are working on it);
- Statistical data concerning the progress both of individual students (*e.g.*, history of attempts for each problem) and of the whole class are automatically generated by WeBWorK and are available in real time for the instructor (allowing for "just in time teaching" where the instructor can use information generated by WeBWorK to focus his or her instruction);
- Evaluation routines allow for problems for which the expected answers are: numbers, functions, symbolic expressions, arrays of yes/no statements, multiple choice questions;
- While students use calculator syntax to enter symbolic expressions, a preview screen allows them to see the expression in typeset mathematical notation;
- A large collection of ready-to-use problem sets for many Mathematics courses is available in the WeBWorK database (problem sets were assembled by a large number of Mathematics educators, they were tested on thousands of students and new problems are constantly generated and discussed and shared within the WeBWorK user community);
- Instructors adopting the system can modify existing problems, write new ones patterned on existing ones and, with programming expertise, add their own answer evaluator routines.

The WeBWorK system is robust and used by many institutions in U.S. and Canada. This makes it safe for teachers/institutions to invest time and energy on further development. WeBWorK allows teachers to assign a large number of practice problems without the heavy grading burden otherwise required to generate constant feedback to students. Weibel and Hirsch (2002) and Gage, Pizer and Roth (2002) report on the impact of using WeBWorK in Calculus I classes. They found that using WeBWorK to deliver homework problems significantly improved the academic achievement of those students who in the end actually did the homework. Weibel and Hirsch (2002) also report student comments that WeBWorK's instant feedback helped them to monitor their own learning progress.

In view of the above studies, we hypothesized that an implementation of WeBWorK, combined with in-class interactive sessions similar to "interactive engagement" as defined by Hake, would promote students' success and perseverance in Calculus just as "interactive engagement" does in physics (Hake, 1998). The objective of this quasi-experimental study was to contrast students' performance and persistence in three settings: traditional lectures with paper-based assignments added on (C1); traditional lectures with WeBWorK assignments (C2); and traditional lectures with in-class interactive sessions designed to provide teacher and peer support for students working on WeBWorK assignments (C3).



METHODOLOGY

PARTICIPANTS

Participants were Social Science students enrolled in the Calculus I course in the fall term in 2006. There were 354 students (42.1% women and 57.9% men) who agreed to participate. Eight instructors who were teaching nine intact classes of Calculus I also agreed to participate. The nine classes were assigned to three experimental conditions of three classes each on the basis of the instructors' preference for the instructional design to be used in each condition. Thus, 118 student participants (38.1% women, 61.9% men) were enrolled in experimental condition 1 (C1); 114 students (38.6% women, 61.4% men) were enrolled in C2; and 122 students (49.2% women, 50.8% men) were enrolled in C3.

VARIABLES

Student high school performance was assessed using their grades in Mathematics courses taken in Secondary IV (Algebra) and Secondary V (Functions). Quebec high school students choose one of three different levels of Mathematics courses. Consultations with expert high school teachers revealed that the content of the lowest level courses (416 and/or 514) is substantially reduced in comparison to the higher level courses. The content of the second level courses (426 and/or 526) is essentially the same as the content of the highest level courses (436 and/or 536) and the difference lies primarily in the difficulty of the problems that students are expected to solve. To account for these different levels, we used an algorithm developed in previous research (Rosenfield *et al.*, 2005) to reduce grades obtained in the lowest level course by a factor of 0.7 and to increase grades obtained in the highest level course by a factor of 1.1. In this manner the scale of student performance is stretched such that it ranged from 0 to 110. Then a variable, High_School_Math_Performance, was computed as the average performance in Secondary IV and Secondary V.

Students' academic performance at the CEGEP level was assessed by their final grade (Final_Grade) in the Calculus course. Students' knowledge of Calculus was also assessed independently from their instructors' grading practices. Over the course of the semester instructors included a set of 17 problems in the three term tests and students' answers were photocopied by the researchers. In addition, researchers photocopied students' solutions to the common final exam (10 problems). Coding schemas were developed for all 27 problems and two independent coders coded all the student solutions. The inter-coder reliability was assessed to be in excess of 92%. Grades for each student were then computed based on the coding. In addition, all students completed ten assignments that were scored (percentage of correct answers) either by WeBWorK (conditions C2 or C3) or by an independent coder (C1). A common evaluation schema (20% assignment grade and 80% term tests and final examination) was used to compute a variable (Final_Score) that assesses students' knowledge of Calculus independently of instructors' grading. In addition, we computed the percentage of correctly-solved problems on assignments (Assignment) and the frequency of submission of assignments (Frequency). Perseverance (Perseverance) was assessed using students' academic records with 1 indicating that a student took only Calculus I, and 2 indicating that a student enrolled in Calculus II the following semester. Students may also enrol in Calculus II and/or Linear Algebra in their third or fourth semester of collegial studies.

To improve assessment of perseverance we accounted for the possibility of taking math courses later by computing the probability of perseverance (Probability_Perseverance) in Mathematics. Logistic regression was performed with Perseverance as outcome and two continuous predictors (Final_Grade, High_School_Math_Performance). Results indicated that the full model against constant-only model was statistically reliable Π2 (2,318) = 168.146, $p < .001$ with Nagelkerke R square equal to .548. The classification table reveals that the model satisfactorily classifies participants since it correctly predicts 77.8% of non-persisters and 80.6% of persisters. The probability of classification was saved as the variable Probability_Perseverance and used in subsequent analysis. In addition, we also assessed students' perceptions of learning environment and the instructors who created those environments using a scale developed by Rosenfield *et al.*, (2005). The General Linear Model (GLM), linear regression, logistic regression and crosstabs were all used in the analysis of data.

> *[...] instructors expressed concerns that many students did not really work on assignments, but instead copied solutions from more diligent peers.*

PROCEDURE

Participating instructors met with the researchers before the course began and agreed to a common textbook and set of ten problem assignments. Hoping to increase Social Science students' motivation to study Mathematics by increasing its relevancy, instructors agreed to use Social Science applications more frequently than in past years. Thus, most assigned problems refer to situations encountered in either business or Sociology. Instructors also

agreed to give three term tests containing some common questions, to set a comprehensive common final examination and to use a common evaluation schema.

The three instructors in condition C1 lectured in class and assigned paper versions of problem sets. Corrected assignments were returned to students one week after submission. The two instructors in condition C2 also lectured in class; but assignments were WeBWorK based with an unlimited number of tries. Students in condition C2 obtained instantaneous feedback (correct/incorrect) and were encouraged to try again when their solution was incorrect or to seek help from peers or teachers.

Condition C3 differed from C2 solely in that the three instructors engaged students to work on WeBWorK-based problems for approximately one hour per week (20% of class time) in a computer lab. During these in-class interactive sessions students were encouraged to seek help from the instructor or their peers while working either alone or in groups.

RESULTS

We assessed the equivalence of students' skills prior to enrolment in a Calculus course using the GLM with High_School_Math_Performance as a dependent variable and experimental condition as a fixed factor. The results showed no significant differences in high school grades between the three experimental conditions (F(2,285)= 1.438, p=.242). Further, the GLM showed that students' perceptions of the learning environment did not significantly differ (F (2,243)=2.682, p=.070, Partial 0^2=.022).

Table 1 shows the results of the GLM with Final_Grade, Final_Score, Assignment, Frequency and Probability_Perseverance as dependent variables and the three conditions as a fixed factor. F-statistics, significance and partial 0^2 are values obtained in univariate tests.

TABLE 1

	C1 MEAN (SD)	C2 MEAN (SD)	C3 MEAN (SD)	F (2,286)	Sig.	Partial 0^2
Final_Grade (instructors)	58.5(25.0)	60.1(23.1)	67.4(22.5)	6.945	=.001	.046
Final_Score (independent coders)	47.4(22.3)	43.9(20.6)	58.2(21.3)	11.478	<.001	.074
Assignment	61.5(17.7)	59.5(25.0)	78.5(19.9)	24.407	<.001	.146
Frequency	8.37(1.90)	8.39(2.13)	9.38(1.46)	9.467	<.001	.062
Probability_Perseverance	.460(.325)	.414(.288)	.633(.298)	6.281	=.002	.042

Table 1 shows that C3 students significantly outperformed C1 and C2 students on all measures. They were more likely to have higher final grades (Final_Grade), to have greater knowledge of Calculus (Final_Score), to have a higher percentage of correctly-solved assigned problems (Assignment), to submit assignments more frequently (Frequency) and to have a higher probability of enrolling in subsequent Mathematics courses (Probability_Perseverance). At the same time, the GLM with Final_Grade, Final_Score, Assignment, Frequency and Probability_Perseverance as dependent variables and the two conditions C1 and C2 as a fixed factor, showed no significant differences on any of the dependent variables.

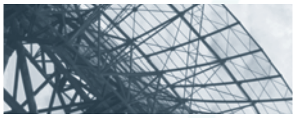
Assuming that the final grade (Final_Grade) as computed by instructors should be related to assessment of knowledge of Calculus (Final_Score) as computed by independent coders, we computed linear regression coefficients for each of the conditions. The regression equations are shown in Table 2 below.

TABLE 2

	Final_Grade=B (SD)*Final_Score+CONSTANT (SD)	t	Sig.
C1	Final_Grade=1.068(.033)*Final_Score+7.758(1.744)	31.906	<.001
C2	Final_Grade=1.054(.031)*Final_Score+13.516(1.528)	34.283	<.001
C3	Final_Grade=1.006(.030)*Final_Score+8.477(1.841)	33.492	<.001

Note that the slope parameter is nearly 1 in all conditions, thereby indicating that instructors and independent coders were remarkably consistent in assessing students' performance. However, the constant coefficient varied across conditions. Condition C2, with the lowest mean on Final_Score also had the highest constant value. It appears that C2 instructors increased grades more than instructors in either condition C1 or C3. Failure rates also differed significantly across the three conditions (Pearson Chi-square = .022). In condition C1, 43.2% failed while only 36.0% of C2 students failed and 26.2% of C3 students failed.

Post-experiment interviews with instructors generated some interesting observations. With the exception of one instructor, who retired the next year, and another, who



plans to retire shortly, all instructors now use WeBWorK in all of their courses. In addition, as a result of this experiment, all instructors said that they plan to use the C3 instructional strategy. C1 instructors expressed concerns that many students did not really work on assignments, but instead copied solutions from more diligent peers. C1 and C2 instructors reported that students rarely sought help outside of class. On the other hand, C3 instructors reported a deluge of e-mails sent by students asking questions about assignments. One such instructor discouraged e-mails, but invited students to discuss their questions with him face-to-face either during computer lab classes or in his office. It appears that C3 students were seeking help outside of the classroom more actively than C1 and C2 students and this despite the fact that C3 students already had extra instructor and peer support during their weekly in-class interactive sessions.

DISCUSSION

Since there were no significant differences in prior academic performance in Mathematics between students in the three conditions, and since prior performance is usually the most reliable predictor of future performance, it is reasonable to attribute post-results to the differences among the three conditions. In this quasi-experimental study we attempted to avoid pitfalls found in many studies of the effectiveness of Computer-Aided Instruction (CAI), namely a failure to control instructional design differences between control and experimental conditions (Jenks and Springer, 2002). Since in this study all instructors used the same text, assignments sets and evaluation schema of students' performance, we conclude that the mode of delivery of assignments (paper *vs.* WeBWorK), and consequent promptness of feedback (one week later *vs.* instantaneous with submission) were the only features of instructional design distinguishing conditions C1 and C2. There were no significant differences in performance or perseverance of students in the more traditional C1 and the WeBWorK C2. This result contradicts some meta-analyses of studies of the effectiveness of CAI which report CAI as being more effective (*e.g.*, Christmann and Badgett, 1997). On the other hand, the result supports the thesis that the positive impact of CAI reported by many studies disappears when there is control for instructional design (Jenks and Springer, 2002).

Table 1 shows that C3 students outperformed C1 and C2 students on every measure. Aside from the mode of delivery of assignments and delivery of feedback, the C3 instructional design included weekly one-hour long in-class interactive sessions. It is particularly important that students in condition C3 were significantly more likely to pursue Mathematics in future. Although the effect size is small, .042, we may speculate that if high school and CEGEP teachers were to use this instructional strategy, then the trend of declining enrolment of Social Science students in Calculus classes at CEGEP might be reversed. C3 students' knowledge of Calculus was superior to that of their C1 and C2 peers. Similarly, the effect size was small (.074); but a close to 14% difference between mean Final_Scores is likely to have a very significant impact on failure rates in Calculus. These results support the conclusion of Lowe (2001) that CAI is not a panacea, but rather a tool that can enhance an effective instructional strategy.

Finally, as anticipated when viewing the final grades, failure rates in C3 were significantly lower than C1 or C2. Actually, failure rates in C2 were also lower than those in C1. However this difference between conditions C1 and C2 may be an artefact of the tendency of C2 instructors to boost final grades. Also we note that failure rates in C1 do not differ from those reported in the network of colleges. It appears that instructors' effort to situate problems in contexts relevant to budding social scientists, and assigning paper-based marker-corrected homework did not by themselves do much to improve learning or motivation to succeed.

> *[...] the mode of delivery of assignments [...] and consequent promptness of feedback [...] were the only features of instructional design distinguishing conditions C1 and C2.*

We note that virtually all instructors in this experiment were sufficiently impressed with the C3 instructional design that they now employ it in their classes. This result alone is extraordinary because recommendations flowing from educational research usually have little impact on teaching in sciences and Mathematics (Handelsman, Ebert-May, Beichner, Bruns, Chang, De-Haan, Gentile, Lauffer, Stewart, Tilgham and Wood, 2004). Although this design requires schools to have a sufficient number of computer labs with Internet connections, this may not be much of an impediment to implementation because many schools and colleges now have such classrooms.

We also noted an unexpected result. When we studied the relationship between Final_Grades and Final_Scores, we observed that although students' knowledge of Calculus was significantly lower in C2, the instructors compensated by significantly increasing "the fudge factor" (our interpretation of the

Constant in the regression equations). Instructors were surprised when shown this result and claimed that they had not consciously raised marks. Perhaps it is not coincidental that the largest boost of final grades happened in the weakest classes. This may also be related to a phenomenon commonly referred to as "grade inflation". If this result can be replicated, it may explain why average grades rise despite instructors complaining that, if anything, increasingly their students seem less well-prepared.

Although there were no significant differences in students' perceptions of the learning environment across the three conditions, during post-experiment interviews, the instructors reported different student behaviours. All C3 instructors brought up the fact that students frequently e-mailed them questions about assignments. On the other hand, instructors in C1 and C2 did not recall any increase in help-seeking behaviour by their students.

A main C1 concern was that many students copied assignment solutions. The results show that C3 students performed the best on assignments, although the effect size was still modest, .146, and they submitted assignments significantly more frequently, where again the effect size is small, .062. It seems that the C3 learning environment promoted increased effort to complete assignments correctly and that may explain why C3 students outperformed their peers.

It appears that C1 and C2 learning environments did not promote student effort to the extent that the C3 learning environment did. One reason why the C3 instructional design worked better might be because it included instructional support for students, something that Lowe and Holton (2005) consider to be essential for successful implementation of CAI. Much as Weibel and Hirsch (2002) observed, having markers, or even having a computer system to instantly correct assignments, do not by themselves seem to improve learning.

LIMITATIONS

The results of this study suggest that interactive sessions may enhance the impact of WeBWorK on student learning. However, in this study we cannot disentangle the differential impact of WeBWorK and of interactive sessions, since we did not conduct a full 2x2 design. Furthermore, no data collected can explain precisely how the learning environment in C3 promoted students' learning. We speculate that it allowed students to ask questions that they would otherwise be too intimidated to ask. It is also possible that they felt more supported by their instructor, or that there was a heavier emphasis on the importance of doing assignments in C3 by virtue of spending class time on them. The interactive sessions also provided an environment where collaboration with peers was easily initiated and frequently employed by students. More research is needed to clarify the exact mechanisms involved. We are also not reporting here on students' motivational characteristics because this is the subject of another paper (Dedic, Rosenfield and Ivanov, 2008) in which we also explore gender differences, both in terms of achievement and perseverance.

CONCLUSION

The results of this study indicate that we can reverse the downward trend in enrolment and diminish failure rates in Mathematics courses at the CEGEP level if we promote implementation of instructional designs similar to C3 both in CEGEP and in secondary schools. When combined with in-class interactive sessions, this form of CAI substantially improves student learning and the likelihood of continuing with Mathematics studies. While delivering and grading assignments *via* a computer is an efficient alternative to employing human markers, this research shows that providing feedback *via* WeBWorK alone is not enough to improve students' achievement and perseverance or to promote their effort. Finally, as indicated by the results of this experiment, Mathematics instructors, virtually all of whom firmly believe in the old maxim "practice makes perfect", may be eager to implement a C3 design across the network of colleges. As a consequence we would anticipate increases in enrolment in Mathematics and lower failure rates in Calculus, thereby allowing more Social Science students across the CEGEP network to successfully meet their career goals. This strategy entails a small start-up cost in terms of equipment, and a small operating cost for technical support for instructors. On the other hand, the human cost, and the cost to society, is likely to be much larger if we do not solve the problem.

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