Optional Activities as a Way to Improve Student Engagement and Academic Achievement in a Large Engineering Class

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***Abstract* - Engineering programs across North America have been experiencing drops in enrolment and high attrition rates. While there are many reasons for this situation, there is evidence that students do not engage with the content and that instructional strategies are not addressing their learning needs. Yet a large body of research exists, showing that active, collaborative learning engages, motivates and empowers students and improves their learning. The literature review also indicates that students are more engaged and better results are achieved when instructors widen their range of instructional strategies, providing support for various learning styles among their students. There is no doubt that as class sizes continue to grow, the goal of keeping the students meaningfully engaged and motivated can be challenging. However, the author's experiences in teaching large cohorts of engineering students show that a considerable improvement in student engagement and more importantly, in academic achievement, can be attained despite the large class size. In this paper, the author presents results of a two-year study that identified positive correlations between the students' engagement in a variety of optional activities designed to support a wide range of learning styles, and their academic performance as well as their satisfaction.**

Index Terms – Active Learning, Learning Styles, Felder Model, Student Engagement.

BACKGROUND

Student engagement can strongly affect academic achievement. Self-regulation (learning strategies) and motivation lead to improved academic achievement, and while ultimately students are responsible for their own learning, the learning strategies they choose, as well as their motivation, can be influenced by the choice of instructional strategies employed by an instructor. Many studies, including seminar work by Chickering and Gamson [1] show that encouraging active and collaborative learning is a cornerstone of "best practices" in teaching, that it motivates and empowers students, promotes communication and evaluation skills, and ultimately results in better academic achievement. Another example is a study of over 2,000 British students, where "good teaching", flexibility in ways to complete course requirements, and a choice of learning methods to accomplish these tasks, clear goals and standards and real-life relevance was found to foster deeper learning [2]. In engineering education, the work of Felder, an engineering professor at North Carolina State University and a pre-eminent North American educator, also shows that choosing strategies that encourage active, collaborative learning has a measurable effect on student performance [3].

Self-efficacy (personal beliefs about one's capability to learn and perform actions at designated levels), is identified as one of factors that contribute to cognitive engagement [4]. It can be influenced if multiple opportunities for students to succeed are provided. Incentives such as frequent graded activities increase the drive to perform, which contributes to increased motivation and are found to improve self-regulation (for example, planning), which in turn improves motivation and achievement [4]. Small group work that allows for active, collaborative, experiential learning also improves self-motivation, engagement and ultimately, achievement, and can be implemented even within the constraints of teaching large classes [5]. Examples in the literature also show that student engagement, and ultimately achievement, can be improved by multimedia and online resources, if combined with active, collaborative learning [6]-[7].

Student engagement also can be linked to their learning styles. A model developed by Felder, particularly relevant to engineering education, identifies characteristics of the learners according to four categories: Active - Reflective, Sensing - Intuitive, Visual - Verbal and Sequential – Global [8]-[10]. According to Felder, there is a mismatch between the learning styles of engineering students, who are overwhelmingly Active, Sensing and Visual learners, and traditional instruction methods still prevalent in engineering departments. Felder suggests that students are less likely to become disengaged when a wider range of teaching strategies is used, which better support their different learning styles and proposes "taking an engineering approach to learning styles, regarding them as useful heuristics for understanding students and designing effective instruction" [10].

Improving quality of undergraduate education steadily gains prominence across the whole North American university system. The US-based National Survey of Student Engagement [11] that includes many Canadian universities is one example of efforts made to assess educational experiences of undergraduates. Academic teachers, particularly in engineering, tend to justify not straying from a conventional lecture format, which these days often becomes a proverbial "death by PowerPoint". Here are some often repeated reasons: growing class sizes, the time required to set up and maintain meaningful in-class and online experiences for the students, as well as claims that while courses where students are actively involved may be more entertaining, there is no clear evidence that such activities result in better learning.

When class sizes continue to grow, the goal of keeping the students meaningfully engaged and motivated can indeed be challenging. Similarly, setting up active, collaborative experiences and capitalizing on the potential that new technologies have to support learning, requires reflection on learning objectives, some understanding of learning theories and often a considerable effort. However, the author's experiences in teaching large cohorts of engineering students show that with careful planning and preparation this can be gradually achieved. Over the years, the author has incorporated practical experiments, multimedia and online support into her teaching [12]-[15], and developed multiple ways to engage students in large class lectures [16]. She also conducted research showing that such engagement resulted not only in increased student satisfaction but also in better learning. Her previous research focused on student engagement and supporting their learning styles through the use of interactive multimedia, online tools and group activities [17]-[20], as well as on the validation of the Felder model of learning styles [10], [21]. In this paper, the author presents results of her more recent (2005-06) study that identified positive correlations between the students' engagement in a variety of optional, but graded, in-class, take-home and online activities, and their academic performance and satisfaction.

CONTEXT OF THE STUDY

The study took place in a third year engineering course in Control with a large class lecture for 160 to 180 students. Students enrolled in the course also worked on lab projects involving real-time control experiments and simulation software, and had access to the course website developed by the author. Online course management system provided a secure access to communication tools (email and discussion board) and grades, to course notes, review materials, a bank of previous exams and tests, various online multimedia (HTML tutorials, PDF documents, video clips, links to online Control systems resources and interactive Java applets) and a set of tutorials with streamed video of real-life control systems, animations and interactive feedback quizzes developed not just to support this particular course, but also freely available online to any interested instructor [14]-[15].

Three hours of class time were divided into shorter segments alternating lecturing with individual or small group activities, followed by segments utilizing multimedia and computer simulations, videotaped real-life control applications, interactive Java applets, or an invited guest talk, a topical presentation by students from another senior level controls course taught by the author, etc. Each class ended with a segment that allowed the students to reflect on the content as well as on the learning process, and to provide the instructor with a formative feedback. The feedback was analyzed and provided the starting point for the following lecture. While many of these activities were organized *ad hoc*, some were a part of an optional activities strategy analyzed in this paper. Besides marks for the compulsory course components (i.e. tests, exam, assignments and lab projects), students also received points for the optional activities, announced ahead of time, which counted towards the 10% "course participation" mark in course evaluation. Importantly, once that quota for that mark was reached, the points accumulated towards a small bonus mark. As an engagement and motivation tool, all student work completed during these activities was graded, as suggested in [4].

Assigning bonus marks in a course usually meets with resistance on the part of instructors, who typically argue that bonus marks, often achieved as a result of collaboration, boost grades for otherwise failing students. They also claim that students usually stop participating in bonus activities once they reach the allowed maximum score. The author remains convinced that students would not participate in the optional activities had they not perceive them as meaningful and helpful in their learning, as opposed to simply being motivated by a prospect of an easy grade boost. However, to encourage individual accountability and ownership of one's learning, a student would only receive the bonus if he/she achieved a passing grade in the individual course tests (i.e. formally supervised mid-term and final exams).

Additional graded activities were designed to support as well as challenge various learning styles, the latter notion adopted from Felder's notions that students need to develop cognitive flexibility in order to function effectively in their professional lives [8]. Thus they included individual and group tasks; tasks completed entirely in class while others started in class and were finished online; timed in-class quizzes and take-home activities. Assessment of the impact of these voluntary activities on the student engagement and subsequently, on their academic achievement, is the subject of the study reported in this paper.

DESCRIPTION OF ACTIVITIES

Roughly 70% of the activities related to the content of the course while the remaining 30% involved tasks designed to set the proper tone for collaboration and honesty ("netiquette" and "academic integrity" online quizzes), assist with the development of learning strategies, judgment and reflective skills (learning style assessment, self- and peer-assessments, evaluations of guest speakers and senior student presentations), improving class morale and providing the instructor with formative feedback ("one minute papers" "start-stop-continue", exit survey), and promoting problem-solving skills and collaboration (games, puzzles, etc). Figure 1 shows the number and type of activities involved.

In-class activities included: discussions, "think-pair-share", individual and paired quizzes, class polling using color-coded cards (a low-tech version of instant class feedback provided by the recent "clicker" technology), role-playing skits, and competitions. Online activities included using an online learning style questionnaire [22], independent research, group and individual contributions to online discussions of various aspects of control systems, emailing the instructor an "Introduce-Yourself" essay about the student's goals for the course, his/her interests, etc., and emailing a report on History of Control Systems, with proper references and bibliography. Take-home activities involved problem-solving assignments, solving textbook questions and small computer simulations.

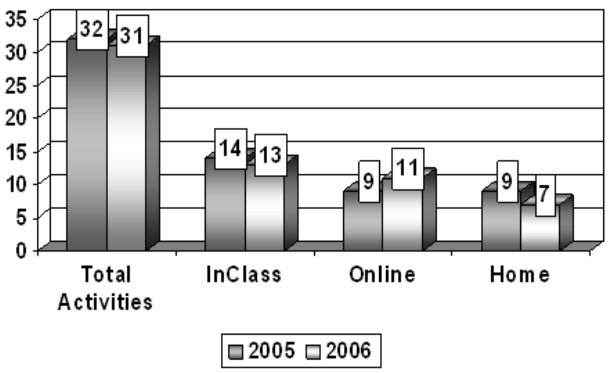

FIGURE 1
NUMBER AND TYPE OF OPTIONAL ACTIVITIES

To keep students involved in the activities throughout the semester, there was no specific cut-off point that would ensure a full bonus; instead, the median value of the total class activity score, which constantly increased based on how many activities all students participated in, was used as a sort of a "moving target". This way, all those who qualified and had scores above the median, received the full bonus, and those who qualified but had scores below the median, received a "sliding scale" portion of the bonus.

STUDY METHODS

The study took place during two offerings of the course, in 2005 and 2006. It was taught as a single large lecture class, with the enrolment of N = 173, and N = 170, respectively. The study protocol was reviewed and approved by the Ryerson Ethics Board. Student participation in the study was voluntary and the students were not exposed to any risks or reprisals for refusal to participate in the study. In 2005 the participation was solicited by a third party through email, with 55.4% consent rate. In 2006, the consent forms were distributed by the third party during class, with the instructor absent, and the consent rate was 68.3%. The author did not have access to the participants' list until three months after each course ended. Only data on course activities of those who consented to participate is included in this paper. Optional activities were available to all students. There were no additional tasks involved for the students participating in the study, beyond the regular course load and all optional activities were available to all students. The study participants consented to have their course grades accessed for correlation analysis.

Two specific hypotheses were tested. The author hypothesized that participation in optional activities would improve students' academic achievement on course tests. Based on the previous research [17]-[19], the author also hypothesized that the lower-achieving students would improve relatively more due to a wider support for various learning styles.

RESULTS AND DISCUSSION

As shown in Figure 1, the total number of activities was large enough to remove the need on the students' part to participate in every single activity; scoring approximately 40% of all available points qualified a student for a full bonus mark. With TAs performing only contractually required grading of project reports and assignments, it also made the marking load less punishing on the author. Still, as Figure 2 shows, average participation rates in the activities were between 40% and 75%, with in-class activities enjoying the highest participation, followed by take-home and online activities. A visible general increase in participation in 2006 is probably attributable to a better organization in the second year of the study.

Of the in-class activities, the highest participation rates were recorded for "paired quizzes" (94% and 84% for 2005 and 2006, respectively), where the students were allowed to talk through the solutions to quiz questions with a partner. Paired quiz has an advantage of not only providing the students with a confidence boost, but can also be administered in a large, theatre-style lecture hall with minimum supervision, as students are too busy to consult with their partner to engage in "rubber-necking". Other high participation activities included "Start-Stop-Continue" surveys (88% and 86%, respectively), exit survey (86% and 97%, respectively) and evaluating presentations of senior-level students (85% and 84%, respectively). The latter, an example of peer-teaching activity, served a dual purpose, as it also provided a substitution for a required class presentation for a group of students in a senior level elective course.

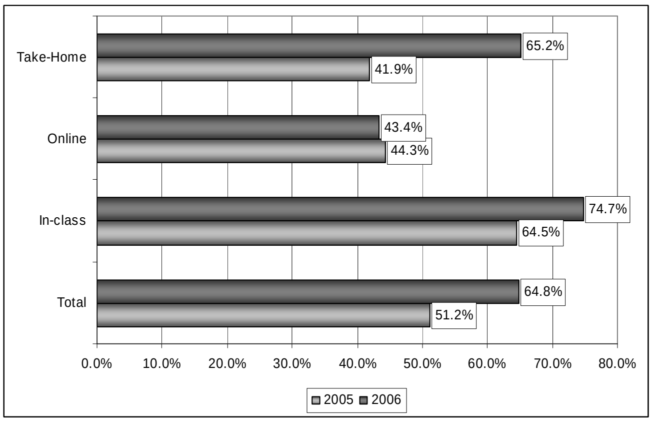

FIGURE 2
PARTICIPATION RATES

Of the graded online activities, the highest participation rates were recorded for the learning style activity (57% and 79% for 2005 and 2006, respectively), where the students had to complete an online learning style questionnaire [22] and then post on the course bulletin board their results, together with a personal reflection on how that matched their intuitive assessment. Another popular online activity (72% and 70%, respectively) involved following an in-class small-group discussion of various controller schemes with an online research on that topic, and a group-organized posting of the findings on the bulletin board. In keeping with an idea of supporting a wide range of learning styles, individual students could also add their own comments to all postings in a threaded discussion forum.

In general, both the quantity and quality of online communications increased, including those not directly connected to the online activities. Simply, more students were contacting the instructor online. Access to the instructor during "face-to-face" counselling hours is less viable in classes with large enrolments, with further limitations of conflicting student and instructor schedules. It has also been commonly observed that some students don't feel comfortable talking to the instructor in person and that "virtual" counselling hours help the instructor reach students who otherwise would remain silent. However, while it is assumed that nowadays students are comfortable with online technology, some are still reluctant to use it to contact the instructor. Having several organized activities involving email and bulletin board presence helped lower these inhibitions. Figure 3 shows an increase in the percentage of students using these tools and in the number of contacts per person, as compared to the course in 2002, where no optional graded activities were used.

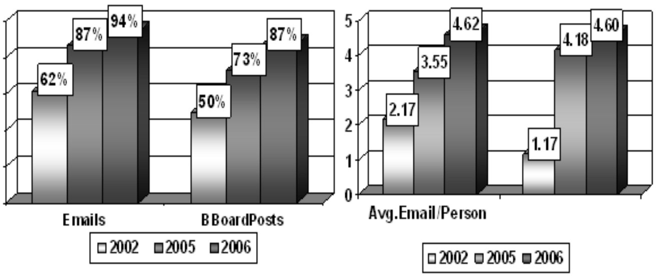

FIGURE 3
COMPARISON OF ONLINE COMMUNICATIONS

Take-home activities included several problem sets based on the textbook, with one randomly selected problem to be marked, and three more complex analysis and design problems where some computer simulations were required. The students had a choice of completing these either individually or in pairs. In 2005, participation rates in the nine take-home activities peaked at the beginning and the end of the semester (83% and 61% respectively), dipping significantly in the middle weeks around 30%. In 2006, their number was reduced to six, and the participation rates remained steady through the course, between 50% and 75%.

The popularity of group activities, whether in-class (paired quizzes), online (controller postings) or take-home (problem sets), is consistent with the fact that the majority of engineering students are Active and Sensing learners who thrive on involvement and collaboration [8]-[10]. This was also true of the students enrolled in the course, where the split along the Active-Reflective modality was 62% to 58%, and along the Sensing-Intuitive modality was 67% to 33%. Indeed, the proportion of students who chose to pair up with a peer to complete the optional activities roughly matched that last distribution.

Exit surveys were conducted anonymously, so as not to inhibit the students' responses - in order for the students to receive activity credit for these surveys, one student representative collected stubs with their names and student numbers, while another collected the actual survey responses, and handing them separately to the instructor. Figure 4 shows that when asked about their satisfaction with the course on a scale from 0 (not at all) to 5 (very much), 83% and 92% (in 2005 and 2006, respectively) of survey participants responded with a 4 or a 5. Figure 5 shows an even higher satisfaction with the course instructor, with 93% and 95% (in 2005 and 2006, respectively) of survey participants choosing either a 4 or a 5.

On the scale of 0 (not at all), 1 (useful) and 2 (very useful), 40% of the respondents rated the activities at very useful, with another 51% rating them as useful. In the open-ended section of the survey, the elements of the course design most often mentioned as helpful, motivating and engaging were voluntary activities in general, or specific examples of those (72% of respondents), different aspects of the website (57% of respondents), and the use of multimedia in class (42% of respondents). The most often-mentioned voluntary activities were take-home problem sets (46%), paired quizzes (53%), "brain-twisters" and games (59%), feedback surveys (47%), on-line controller activity (31%), an online academic integrity quiz (33%), and emailed "Introduce-Yourself" essays (28%).

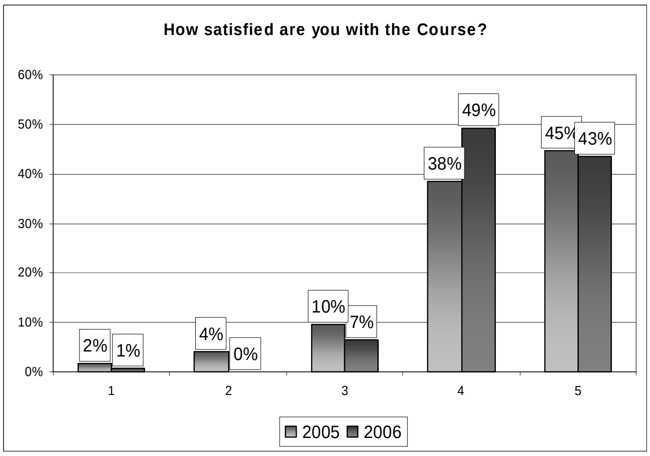

FIGURE 4
COURSE SATISFACTION – EXIT SURVEY

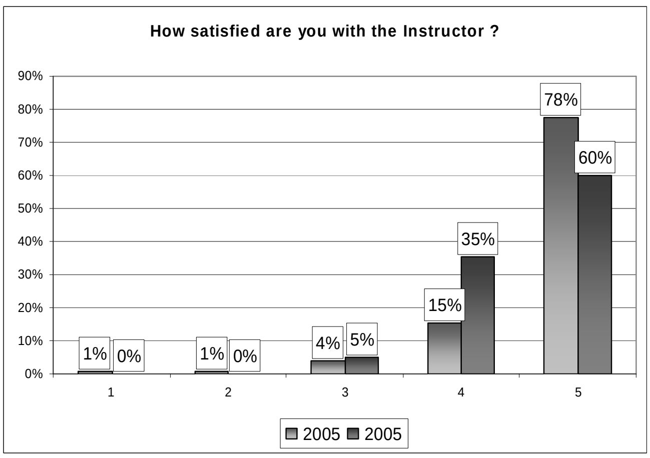

FIGURE 5
INSTRUCTOR SATISFACTION – EXIT SURVEY

The overall course design also seemed to have a general positive effect on attendance rates. While attendance rates are not measured, anecdotal rates for the institution are around 50%, and often significantly lower in engineering courses, especially in weeks just before mid-terms and final examinations. However, the attendance in the course remained steady above 75% throughout the semester even when no graded activities were taking place, and sometimes reached over 90% on days of planned activities. In the exit survey, 71% of the students self-reported having attended more than 30 out of the total 39 hours of lectures, with further 22% having attended between 20 and 29 hours. The author contributes high attendance to a high level of student engagement and satisfaction with the course as a result of the mix of instructional strategies designed to support active learning (informal group work in class) and visualization (multimedia and computer simulations).

To test the first hypothesis put forth by the author, individual students' participation in the optional activities was correlated with their scores. Table I shows statistically significant correlations found between the midterm and final exam scores and the total number of optional activities.

TABLE I
PEARSON CORRELATION BETWEEN NUMBER OF ACTIVITIES AND SCORES

	Midterm Score (out of 100%)	Final Exam Score (out of 100%)	Final Course Score (out of 100%) – without Bonus
Total No. of activities	r = 0.217** p = 0.002 N = 207	r = 0.231** p = 0.001 N = 207	r = 0.408** p = 0.0001 N = 207
No. of in-class activities	r = 0.072 p = 0.302 N = 207	r = 0.089 p = 0.203 N = 207	r = 0.242** p = 0.0001 N = 207
No. of take-home activities	r = 0.201** p = 0.004 N = 207	r = 0.258** p = 0.0001 N = 207	r = 0.362** p = 0.0001 N = 207
No. of online activities	r = 0.153* p = 0.028 N = 207	r = 0.098 p = 0.167 N = 207	r = 0.242** p = 0.0001 N = 207

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

To test the second hypothesis, namely that the lower-achieving students would improve relatively more, previous academic standing of the students had to be factored in. Due to institution policies on privacy the author could not access student Grade Point Averages, the most obvious indicator of whether a student should be consider under- or over-achieving, with respect to his/her median GPA. Instead, a "baseline quiz" was used. The quiz, conducted in the first week of classes, tested review material from a pre-requisite Signals and Systems course. Based on its results, in the data analysis the participating cohort was split into two groups, referred to as "previously below the median" or PBM, and "previously above the median", or PAM.

Correlations between the midterm, final exam and course scores and the total number of optional activities were comparably strong and statistically significant in both cohorts and there were no statistically significant differences between the PAM and PBM cohorts in the average numbers of, or scores in, the activities: one way analysis of variance (ANOVA) tests were (F = 3.335, p = 0.69, df = 1, 207) and (F = 3.439, p = 0.065, df = 1, 2007), respectively. Next, differences in the mean scores on the course tests for PAM and PBM cohorts were computed. Compared with the difference in the mean scores on the baseline quiz (approx. 21 point difference), they were significantly reduced (approx. 10 points for mid-term 9 for final and 6 points for the course grade), suggesting larger relative gains in achievement for the PBM (i.e. lower-achieving) cohort. Since score differences are meaningless unless standard deviation is considered, meta-analytic studies use Effect Size, defined as the difference between the mean score of two groups, divided by the standard deviation (1).

$$ES = \frac{Mean_{\exp} - Mean_{contr}}{std_{avg}} \quad (1)$$

Figure 6 shows ES for differences between the PAM and PBM cohorts, computed for the baseline quiz and for the course tests. While Effect Sizes for the course tests are still statistically significant (in the literature on meta-analytic approach, an Effect Size above 0.4 is considered statistically significant [23]-[26]), they are reduced by more than half, when compared with the Effect Size for the baseline quiz.

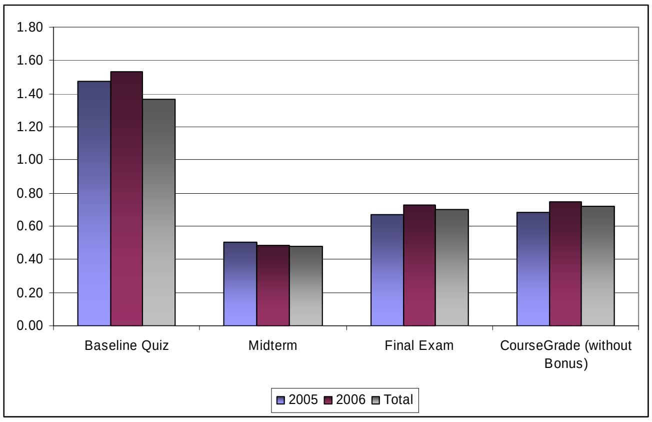

FIGURE 6
AVERAGE GAP IN EFFECT SIZE BETWEEN PAM AND PBM SCORES

SUMMARY AND CONCLUSIONS

The results of the exit survey showing high degree of satisfaction with the course and the instructor, and the popularity of course activities are consistent with the increased engagement and satisfaction observed in the author's previous research [17]-[20], and are aligned with the theoretical framework of active, collaborative learning theories [1]-[8].

The study found statistically significant correlation between participation in optional activities and the academic achievement on individual tests in the course (Table I), with Pearson's coefficient reaching r = 0.408 (statistically significant at 0.01 level, two-tailed, p = 0.001, N = 207) for the correlation between the number of activities and the final course score. A significant reduction in the difference between the mean values of the course test scores for the PAM and PBM cohorts was also found, as compared with the gap between the means of the baseline quiz for these cohorts, suggesting that the academic performance of lower-achieving students improved relative to their higher-performing peers. In effect, they were "catching-up" academically. Thus both hypotheses were confirmed. These findings are also consistent with the author's previous research where the relatively larger gains in academic performance of the students who performed below-the-median prior to the course were also observed [17]-[19].

While the focus of the previous study was on using the multimedia and web support, both the previous and current work show that all students benefit from a wider range of instructional strategies that better support their learning styles, and that such support seems to be particularly beneficial for lower-achieving students.

This observation is consistent with the theoretical framework, particularly with the Felder Learning Model. While Active, Sensing and Visual learner are a majority among both higher- and lower-achieving students, the higher-achieving students typically have better learning strategies (e.g. as time management) and other coping mechanisms and thus are not as affected by a mismatch between the passive, highly theoretical and verbal-oriented style of lectures and their own learning preferences. The lower-achievers who tend to rely on their natural learning styles are thus more likely to struggle in a course where such mismatch exists, but do better where their learning styles are supported; as a result they are more motivated and engaged with the course, which helps them to improve their learning strategies, and ultimately perform better academically.

Figure 7 provides an attempt to illustrate learning gains in the course as a result of increased student engagement and motivation stemming from various instructional strategies introduced over the years to better support the student learning styles. Such longitudinal comparisons are not unreasonable in this case since, while over the past decade the course has been typically team-taught by the author with another professor, the author has been the principal course instructor, developer and coordinator. In fact, in 2002, 2003 and 2005 the author was its sole instructor. In 2001, 2004 and 2006, even though two instructors were involved, the course was taught in a single class format, i.e. with both instructors present in class during the lecture, and alternating in taking the major responsibilities of its delivery. Thus, at any given time all students were exposed to the same instructor(s), both instructors followed the same routine of class activities, and all extra activities were available to all students. As well, considering the author's significant involvement in the course as a constant throughout, individual instructor traits are assumed not to have been a significant factor in such comparisons.

Grading criteria in the course have also remained virtually constant over the past decade, with similar percentages of the final grade assigned to the final exam (35-40%) and to lab project work (25-30%), with the remainder assigned to mid-term tests and quizzes. The author, as the course coordinator, had strived to maintain control and uniformity of the difficulty level of the tests and examinations. The author thus argues that it is possible to make meaningful longitudinal comparisons of student academic performance in the course.

The first trace in Figure 7 corresponds to the grade distribution in the course when it was taught using conventional "chalk & talk" lectures with minimal student involvement in class, though the lab projects have always placed emphasis on students' hands-on experiences with real-life control systems and on peer collaboration (1996-1998).

The second trace represents a shift in grade means that occurred after the gradual introduction of multimedia and computer simulations, and an increasing emphasis on active learning in the classroom, as well as on web support outside of it. The last trace corresponds to the two years of the current study (2005-2006), with a specific focus on the optional activities in the course. While the further changes are not as dramatic as when the multimedia and web support were introduced, the grade distribution shift towards higher grades continued.

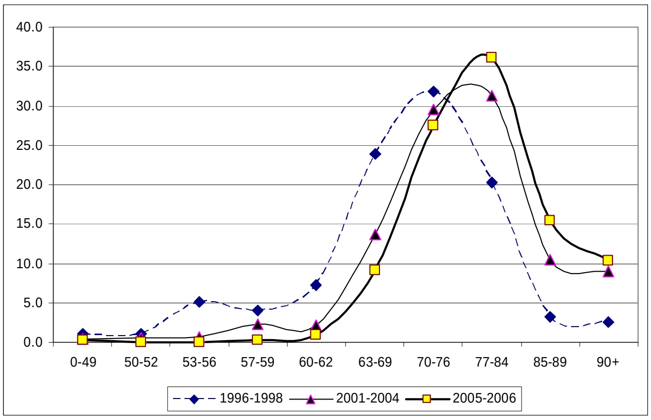

FIGURE 7
GRADE DISTRIBUTION OVER TIME

While this particular study has been confined to a single course, the author believes that the results can be generalised to other settings and courses. Preparation and delivery logistics of such additional activity program are somewhat time-consuming and thus not recommended for first-time instructors who may be struggling with the course delivery and thus easily overwhelmed by the additional commitment required throughout the delivery of a course. However, any reasonably experienced instructor prepared to invest some extra time to set up such activities should see his/her students benefiting from this approach. In fact, anecdotal evidence from a course taught by another Ryerson engineering instructor who decided to adopt this approach is beginning to accumulate in its support.

In summary, the analysis of results self-reported by students in the course exit surveys show that the goal of motivating and engaging them has been achieved. The study also provides further evidence in support of instructional strategies that engage students that is consistent with the existing body of literature on the benefits of active and collaborative learning. It clearly shows that not only student satisfaction with the course increases, but that engagement and academic achievement are strongly correlated.

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