CASE STUDY: APPLICATION OF TEAM-BASED LEARNING TO A MECHANICAL ENGINEERING DESIGN COURSE TRADITIONALLY TAUGHT IN LECTURE FORMAT

H.F. Machiel Van der Loos, Peter M. Ostafichuk
Department of Mechanical Engineering, University of British Columbia

ABSTRACT

The teaching of a third-year university course in design elements – e.g., gears, belts, bolts, bearings – has traditionally been taught in lecture format. In response to student feedback from the previous year, this course was redesigned using a team-based learning approach. Following the redesigned one-semester course in 2008, results include increased in-class discussion, peer-learning and attendance, as well as improved course effectiveness based on student evaluations. In addition, delivering design knowledge that is applicable to other core third-year courses and arranging for a better mesh with other curriculum components have improved design instruction in the department overall.

Keywords: Team-based learning, design engineering education

1 INTRODUCTION

Lecture-based teaching is a powerful means of one-to-many communication used in formal learning environments across all disciplines, especially for instruction of theory and higher-level concepts. Lectures, focused on knowledge acquisition, are often complemented by one-on-few settings (tutorials, for example) for skill acquisition in the particular domain. Settings with fewer students promote dialog, discussion, identification and resolution of learning blocks and development of working knowledge, steps that are impractical in lectures. The team-based learning (TBL) approach brings the mechanism of effective discussion among all students into lectures, resulting in some of the same advantages of tutorials but in the seemingly incompatible venue of a lecture hall. To improve knowledge acquisition and student-teacher communication in courses traditionally taught in lecture format, the Department of Mechanical Engineering at the University of British Columbia (UBC) has increasingly been using the TBL approach in its core curriculum. The TBL approach was first introduced for courses in medicine and business by Larry Michaelson [6,7], and has expanded from those domains to others, such as education and engineering.

In this paper, the **Background** Section describes the UBC Mechanical Engineering Department learning environment; the **Aims** Section outlines the problem being addressed and the goals we sought in changing from lecture to TBL format. The **Approach** Section describes team-based learning and how it was specifically applied to one course, "Mechanical Design-1," MECH 325, which teaches derivation and design knowledge of the most common machine elements. In the **Challenge** Section, the didactic, logistical, human dynamic and procedural issues we faced in implementing TBL are profiled. The **Successes** Section provides data on outcomes, and the **Future Improvements** Section explains changes we intend to implement for the upcoming year's MECH 325 course in organization, materials, procedures and tools.

2 BACKGROUND

The Department of Mechanical Engineering at UBC graduates approximately 120 Bachelor of Applied Science (BASc) students annually through a tightly-coordinated curriculum of courses in the second, third and fourth undergraduate years. There are three specializations, Mechatronics, Thermofluids and Biomedical Engineering, in addition to the general mechanical engineering category. Each year, all students must take a core set of courses, complemented by courses in the three specializations. Mechanical Engineering courses are also taught as services courses for other departments, such as

Engineering Physics and Integrated Engineering, which increases core course enrolment by approximately 25%. Courses comprising the core set have traditionally been taught in lecture classes of 150 students or two sections of 70-80 students by one or two instructors and an appropriate number of teaching assistants. Lecture courses typically have two 90-minute lectures augmented by two tutorial sessions per week. Bi-weekly assignments, a midterm and a final exam are used for student assessment. Anonymous evaluation of teaching by students is mandatory for all courses and is used for feedback to improve future course offerings, as well as for instructor performance assessments in all departments.

Over recent years, instructors in the Department of Mechanical Engineering, and, indeed, other departments in the Faculty of Applied Science at UBC, have increasing been embracing TBL [6] to replace lecture-style teaching for the core courses. Instructors prepare new material during the summer months; in some cases, Teaching and Learning Enhancement Fund (TLEF) grants have been used by faculty to assist in preparing new material for TBL courses.

The Mechanical Design-1 course (MECH 325) covers the topics listed in Table 1. This third-year course has always been a core component of the Department, with incremental changes over time. In 2005, a TLEF grant was used by a former instructor to perform an extensive reorganization of the course materials into ten modules, including computer-based presentation slides, tutorial hand-outs and monthly assignments, taught in conventional lecture style. These materials were used with success (based on student survey results) for two years by the original instructor. In 2007, due to a rotation of faculty, the same presentation materials were used, with minor adaptation, by two other instructors. In that year, class size had increased by 50% over the previous year to 160 students due to external factors, and the 250-person lecture hall was ill-suited to student participation in-class. Students, having been exposed to several TBL classes in their second-year curriculum and responding positively to that format [5], provided a low "overall effectiveness" rating for the instructors in this lecture-based course in the post-semester anonymous survey.

Table 1. Subjects in the third-year core course MECH 325: Mechanical Design-1.

In 2007, the material was taught in ten modules of 1-3 lectures each. In 2008, the curriculum was divided into five 2-week modules and sequenced to mesh with other core courses. In each year, the course was taught in two 90-minute lectures and two tutorials per week for 12 weeks, with one midterm and one final exam.

2007	2008
Threaded components and power screws	1. Gears and power screws
Fasteners and non-permanent joints	
Welded joints	2. Flexible drives and bearings
Springs	
Shafts and attachment mechanisms	3. Shafts and shaft accessories
Flexible mechanical elements	
Bearings	4. Energy storage, transmission and dissipation
Fluid power	
Gears and gear trains	5. Fastening and joining
Brakes and clutches	

3 AIMS

In response to the clear need to improve MECH 325, the lead instructor (second author) was selected based on his extensive experience with the TBL approach, notably in second-year mechanical engineering courses. After review of the 2007 experience in MECH 325, the following primary course goals were set for the 2008 class:

1. Decrease the amount of material presented to improve retention of core knowledge, especially reducing the focus on derivations and increasing the design relevance of the material
2. Divide the class into two 80-student sections, each taught by one instructor in smaller lecture halls than in the previous year to increase in-class communication

3. Provide tools for on-line and anonymous student feedback on class and team effectiveness, with periodic review and response by instructors
4. Reorganize the course into five two-week modules with clear start and end points, and with one open-ended assignment each
5. Reorder the material to mesh better with other core third-year courses.

4 APPROACH

The means of addressing the aims are discussed below:

1. Reduce the amount of material presented: The slides from the previous year were dense and included first-principles derivations. In an explicit effort to focus more on design, class time was devoted not to derivation but to the design process for the constituent technologies. For example, the mathematical derivation of the involute tooth profile used on gears was not provided, except as a means to transfer rotational power at a constant angular velocity ratio. On the other hand, significant attention was devoted to the understanding of transverse, axial and normal pitch of gear teeth and their roles in calculating the kinematics and transmitted loads between gears, which is highly relevant to the specification and dimensioning of other components such as shafts and bearings.
2. Divide the class into two 80-student sections: Space is a critical factor in successful teaching. The choice of classroom for the 2007 course (not under departmental control) was twice as deep as it was wide, and had a 250-person maximum capacity. With an average of 50% attendance, each lecture had approximately 80 students (one quarter room capacity), most of whom sat in the back half of the steeply-sloped auditorium. This situation, exacerbated by the room's reverberating acoustics, made interactive communication with the class as a whole impractical. Replies to questions solicited of the students were always answered by those in the first five rows. In 2008, the two smaller sections resulted in allocation of smaller lecture halls, with six rows of 15 seats. Eye contact with those in the back row was possible, and interaction was not limited to those sitting in the front. The smaller classes and the focus on in-class communication allowed instructors to get to know many students by name. This was facilitated by the decision to have each section be taught by one instructor (the two authors), who coordinated all teaching materials to equalize as much as possible the experience of the two sections.
3. Provide tools for student feedback: The University provides an on-line website for each course via VISTA [1], allowing instructors to select from a range of course support communication and materials-delivery functions to implement. Five evenly-spaced surveys, one per learning module, were assigned and mandatory. This measure highly motivated students to provide anonymous feedback to instructors on-line. The two instructors read and discussed the remarks. If the same comment was made by several students, a response was developed and communicated to each of the sections in class. For example, a change was made in the process of leading the tutorials after the second module so that teaching assistants (TAs) spent more time answering questions than solving problems on the board. Students preferred to have more time for team-based problem solving followed by TA explanation when they got stuck.
4. Reorganize the course into five two-week modules: Since the TBL approach works well in courses that can be divided into learning modules, MECH 325 was reorganized from ten technology-specific sections to five function-specific modules, each with a theme (refer to Table 1). Each module started with a RAP (readiness assessment process) quiz and ended with an open-ended assignment. In previous years, the didactic goal of the assignment component was to span mechanism classes (for example, combine shafts, gears and bearings into one problem). These previous assignments, done individually by the students, had one correct answer, which facilitated grading but did not provide an opportunity to develop design knowledge decision-making skills. In 2008, assignments were developed for each module to allow students to solve a particular functional problem in different ways. For example, in the "Flexible Mechanical Elements" module, a drivetrain for a hypothetical jelly-bean polishing machine could be designed with a flat belt, V-belt or chain drive (Figure 1). Students had to decide which was most appropriate based on the problem statement. When assignments were handed in, key parameters, such as weight and component cost, were collated by team number

into a 2-D graph and projected in class to show which design was most efficient. While this did not contribute directly to the assignment grade, it spawned lively discussions on trade-offs, compromises and cost issues during the written (and graded) assignment evaluations done by the students of each others' project posters.

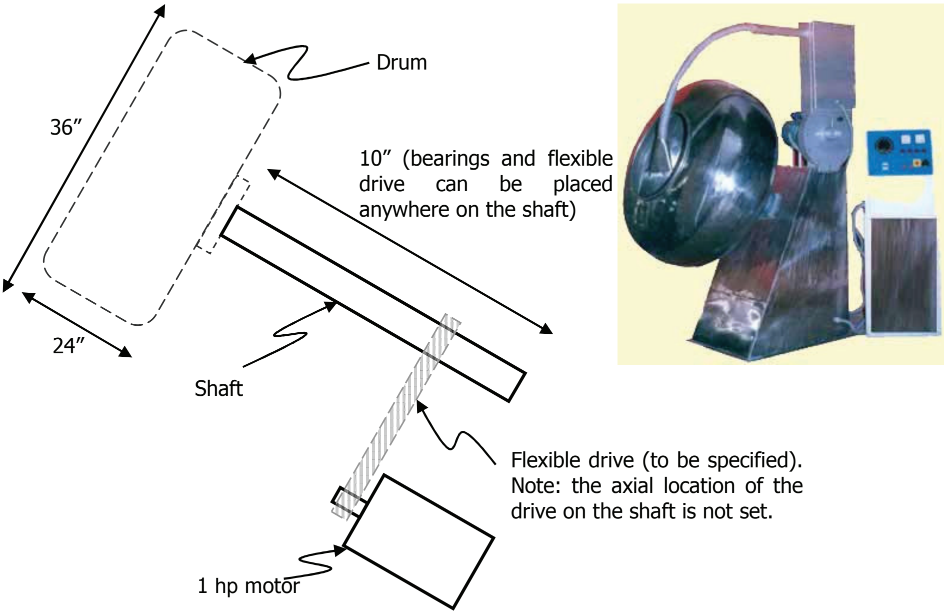

Figure 1. Hypothetical Polishing Machine Schematic from the "Flexible Mechanical Elements" Assignment. The actual machine is shown on the right. [The dimensions in this assignment were given in Imperial units, as were approximately half of the problems and assignments, to reflect the variety in North American engineering practice.]

5. Reorder the material to mesh with other core third-year courses. The other design-related core courses in the third-year curriculum are 1) co-requisite Mechanical Design-2 (MECH 326), which covers static and fatigue failure, finite element analysis and mechanisms such as linkages and cams, and 2) a design project course (MECH 328), which introduces students to design analysis tools, such as Pugh charts, weighted decision matrices (WDMs) and failure modes and effects analysis (FMEA), in the context of a report-generating design project. It was decided to present functional transmission elements such as gears and belts early in the MECH 325 course to provide students with knowledge they would need early in their project, and to cover assembly elements such as welds and bolts later, since these would be needed in a later stage in the design project. In MECH 326, fatigue failure was taught just before it was needed in MECH 325, since it dominates shaft and shaft accessory design because of the prevalence of stress concentrations in determining dimensioning and safety factors.

More generally, the TBL approach was adopted primarily to increase in-class communication between instructor and students and improve learning effectiveness. In terms of the cognitive domain of Bloom's Taxonomy (see, for example, [4]), the TBL approach shifts development of low-level abilities (such as recalling, naming, and listing) to readings done outside of class, while class time is used for the development of higher-level abilities (such as analyzing, judging, and evaluating). The following list represents the most salient aspects of the TBL approach that were adopted for the MECH 325 course:

- The class was divided into teams of 5-9 students. Teams were selected by the instructors to maximize diversity of expertise and experience in each team (see [2, 6, 8]). Students sat in the lecture by team to facilitate in-class discussion during team activities without moving from their seats.
- At the start of each two-week module, a multiple-choice readiness assessment process (RAP) quiz was administered, first individually (20 min) and then by team (10 min), on the required readings for the whole module. This step incentivized students to come to class prepared, since (a) the quiz was part of their final grade, (b) their team grade suffered if they were not individually prepared, and (c) they would have more difficulty understanding the material presented in class and in tutorial without the readings. Individual RAP quiz grades had a mean of 67%. Immediately following the individual tests, each team completed the same quiz using an "Immediate Feedback Assessment Technique" (IF-AT) scratch-off card [4]. This process required the members of teams to discuss and debate the questions and agree upon the answers. The team grades had a mean of 91% over teams and modules.
- In-class team exercises were given during each lecture to develop a clearer understanding of particular concepts considered key by the instructors. For example, four dimensioned drivetrains of different types (helical, worm, hypoid and planetary) were shown on-screen with given input speed and direction of rotation of the pinion. Student teams were asked to derive the output direction of rotation and speed. After five minutes, an informal simultaneous-answering scheme was typically used (e.g., "Raise your hand if you think the output speed is clockwise, or raise a sheet of paper if counter-clockwise … Now!") as a starting point for a discussion of the exercises and how to improve concept learning strategies.
- Team-based design assignments were given for each module. There were three graded components: a 5-page report, a 2-page poster for in-class, gallery-style presentation, and a team-based evaluation of all the other teams' posters. The evaluations allowed students to assess the completeness and presentation of other teams critically, and provide insights on possible improvements for their poster for the next module. Incremental improvements of content were evident during the course, both in the assessments and in the posters.

In summary, the changes made in this course provided significantly more peer-based learning in teams in class, in tutorial and for assignments, more student-instructor communication in-class and on-line and better integration of the core third-year curriculum courses.

5 CHALLENGES

5.1 Design process commonality across technologies

The primary challenge faced by the MECH 325 students was the integration of a wide spectrum of technologies (e.g., shafts, gears, bearings, brakes, welds) that lend themselves to the same type of analysis and design process but that are all different in specifics. All design processes start with operating conditions (for example, power or speed), involve calculation of loads, and require choice of material, component sizing and stress calculation to verify if the resulting safety factor is adequate for the application. However, bearings, for example, are sized using a very different procedure from gears or shafts: each technology is grounded in specific work practice derived from one hundred years of industrial experience informed by theoretical derivation and empirical results. Our goal has been to provide students with usable design knowledge and an appreciation of its source, without lengthy derivations that would go largely unused. To achieve this didactic goal, the two primary mechanisms were the distillation of the previous year's slides to focus on design knowledge and the implementation of open-ended assignments to develop critical design thinking.

5.2 Team-based and individual grades

Due to differences in enrolment in the different tutorial sections, the sizes of teams varied between 5 and 9 students. There was widespread dissatisfaction with group size expressed by students in teams of seven to nine students. The concerns, increasing through the first half of the semester, related to difficulties in arranging meeting times to work on assignments, difficulties communicating and sharing information with a large number of team members and difficulty fairly dividing work between all team members. Although it was impractical at that point to redo the team structure entirely, since TBL grading is partly individual and partly team-based, the instructors addressed the students' concerns by allowing the biweekly assignments to be handed in by half-teams of each of the original larger teams, and applying a transparent and clearly-understood grading scheme. This relieved the dominant issues of coordination and contribution and was a tractable solution from a grading point of view.

5.3 Role of module-specific assignments

The assignments in each module were an important constituent of the TBL approach in that all teams worked on the same problem, but there was no single "right" answer. Through the peer-assessment of posters, students saw how other teams approached and solved the same problem, and they evaluated the strengths and weaknesses of the other designs. Considerable thought went into the design of each assignment given their open-ended nature; the scenarios had to be sufficiently open to allow for innovation but sufficiently constrained to remain within the focus of each particular module. In addition, the marking scheme could no longer be based on correct/incorrect answers but rather on more qualitative aspects, such as innovativeness, appropriateness and completeness of stress calculations. As a result, grading was a considerably more time- and effort-consuming process.

5.4 Role of the readiness assessment process quiz

The readiness assessment process (RAP) quizzes were taken by students after the reading assignment, typically 20-30 pages of the textbook, Shigley's Mechanical Engineering Design [3], and before any formal presentation of the material. Each RAP quiz consisted of 15 multiple-choice questions. Gauging the level of knowledge achieved from the readings proved to be a challenge. After each RAP quiz, in-class discussion of problematic topics often resulted in at least one question being removed due to question design or ambiguity. See Section 6.4 for an example of such cases.

5.5 Preparation of material for tutorials

Each tutorial was a series of approximately four increasingly difficult design problems for students to complete during two 90-minute sessions moderated by a TA. Through the course, instructions to the TAs were made increasingly detailed so that the TAs could become more effective in answering questions without spending many hours preparing their sessions. While tutorials started largely as TA-led solutions being presented, they were converted, based on student feedback, to solutions of simple problems by TAs followed by student teams working through solutions of more advanced questions, with TAs available for providing hints and answers. This required more work to prepare the TAs, but resulted in students who worked more independently in teams on their solutions.

5.6 Exam design challenges

With the complete refocus of the course, the instructors had certain expectations of the students on midterm and final exams, based on observed performance on the RAP quizzes, assignments and in-class discussions. The midterm and final exam were therefore completely redesigned from last year's versions. The midterm, while not considered too difficult, was made considerably too long, and no students finished within the allotted 90-minute class time. The final exam was consequently better designed and provided the expected range and distribution of grades.

6 SUCCESSES

The success of the redesign of MECH 325 was evident, anecdotally, in the attitudes of the students in-class, in the communication between instructors and students in and out of class and in the context of the other third-year courses. The encouragement to provide feedback using various media allowed students who might not otherwise have voiced their concerns to contribute to the incremental improvements adopted over the semester. Approximately 75% contributed substantive feedback comments over the duration of the course, while less than 10% did so the previous year, providing their comments only on the required post hoc course evaluation.

6.1 UBC standard survey

At UBC, students in each course are given a survey in each semester during the last week of class, i.e., before the final exam. Instructors are absent from the classroom while these anonymous surveys are being completed. They are compiled by each Faculty and returned to the department and instructors approximately one month after the semester ends. An extract relating to the course is provided in Table 2. It shows a significant reduction in perceived workload and complexity of material from 2007 to 2008, suggesting that the TBL approach resulted in a lower workload during the semester and better familiarity with the material at the end of the course. The other two questions, relating to professional relevance and interest of the material, were statistically unchanged from one year to the next, suggesting that this core course was indeed perceived as being a necessary constituent of the curriculum in both years.

6.2 MECH 325 exit survey

In addition to the standard survey, a post-course on-line, anonymous survey was given to students approximately one month after they completed their final exam. Among other things, the survey asked students to evaluate the effectiveness of five aspects of TBL in the course:

- readings give an introduction to the course material
- RAP quizzes motivate students to do the readings and give feedback on the understanding of the readings
- classes reinforce and enhance understanding of course material
- tutorials help students to be able to perform requisite detailed calculations
- assignments help students to be able to size and select components in open-ended scenarios

Table 2. Results from Student Satisfaction Ratings from the 2007 and 2008 MECH 325 Course. The ratings ranged from 5=strongly agree to 1=strongly disagree. The first two questions, "Does the course require a heavy workload? and "Does the course contain more advanced material than your other courses?", showed reductions in rating that were statistically significant from 2007 to 2008 at the 95% confidence level (in bold).

	Heavy workload	Advanced material	Relevance to professional needs	Interesting material
2007: n=95				
Mean	**4.38**	**4.05**	4.31	3.79
Variance	**0.98**	**1.12**	1.17	1.55
2008: n=103				
Mean	**4.13**	**3.60**	4.47	3.93

Variance	**0.66**	**0.63**	0.45	0.73
p-value	**0.05**	**0.001**	0.24	0.37

The questions and responses are shown in Table 3. With approximately 60% positive response or better, students either mildly or strongly agreed that all five TBL aspects of the course were effective towards the intended objectives above.

Table 3. Results from Exit Survey for 2008 MECH 325 Course. Five questions relating to the processes and objectives of TBL were asked. The ratings ranged from 5=strongly agree to 1=strongly disagree. The aggregate responses indicate that most students found each aspect of the TBL process to be effective towards its intended objectives.

	Number of Responses at Each Rating						
Question	**1**	**2**	**3**	**4**	**5**	**Mean**	**% Agree**
The reading assignments were effective in giving me an introduction to the mechanical components studied in MECH 325	4	7	4	20	7	3.5	64%
The RAP quizzes were effective in encouraging me to do the readings and giving me feedback as to whether or not I understood the readings	6	9	1	17	9	3.3	62%
The classes were effective in reinforcing and enhancing my understanding of the mechanical components studied in the course	1	6	8	14	13	3.8	64%
The tutorials were effective in helping me be able to perform the detailed calculations and analysis associated with each mechanical component	2	3	6	13	18	4.0	74%
The assignments were effective in helping me be able to select and size mechanical components	3	6	9	19	5	3.4	57%

6.3 Lecture attendance and the effect of RAP quizzes

The average attendance in class improved from 2007 to 2008 from an estimated 50% to 80% of enrolled students. The use of RAP quizzes, which form 15% of the student's grade collectively, also made class attendance compelling. We believe that our intent to present material in class that formed a bridge from the textbook material to actual design knowledge was an important contribution to student attendance.

The logistics of class scheduling for all third-year MECH students coincidentally placed two of the four weekly tutorial sessions earlier in the day than the relevant lectures on the same topic. Since students could not switch tutorial sessions due to other conflicts, half of the students were exposed to material in tutorial before the lecture. This turned out to be less of a problem than feared since the RAP quiz necessitated completion of the reading material beforehand. The tutorials all started with simple exercises, which the RAP reading somewhat prepared the students to handle. Had this been a non-TBL lecture class, we would have anticipated more student disconnectedness in tutorial since they would not have been required to complete the textbook readings beforehand.

6.4 Communication and responsiveness

At numerous points in the course, the two instructors reiterated that improvement in the course was possible mainly through student feedback and that there were numerous means to effect change. In addition to the peer reviews and anonymous surveys mentioned, after each RAP quiz there was a post hoc discussion of the questions students had most difficulty answering, based on the near-instant response using a card scanning device in class to tally grades. After the instructor went over the reasoning of the most problematic 3 or 4 questions, and after elucidation of any other questions brought up by the class, the students were encouraged to challenge the validity of the multiple-choice questions and answers if they deemed them inaccurate or misleading. Two examples of appealed questions are provided in Figure 2.

5. Marin factors k_a through k_f (not to be confused with K_f and K_{fs}) are used to:

a) take into account geometric factors in calculating endurance strength
b) take into account operational factors in calculating shaft bending stress
c) increase the estimated bending stress due to notches and stress concentrations
d) take into account differences in endurance strength between rotating and oscillating shafts
e) take into account operational factors in calculating endurance strength

6. Marin factors are:

a) always less than or equal to 1
b) always greater than 1
c) greater than 1 for hardened steel
d) derived from extensive finite element analysis of different shafts
e) analytically determined from first principles

Figure 2: RAP Quiz 3: Shafts: These are questions 5 and 6 (of 15). The "correct" answers are shaded: 5e and 6b. In question (5), students challenged that answer 5a was as valid as 5e since k_b is the size factor, and 'size' should be considered a geometric parameter. Our intent in (5) was to contrast Marin factors, which mostly focus on operational parameters and steel strength, with the stress-concentration factors K_f and K_{fs}, which focus on shape (geometry) in calculating actual stress. In (6), the intent was to focus on the main effect of the Marin factors, which is to reduce the estimate of strength of a real steel component in relation to results from a standard room-temperature tensile fatigue test. While all factors are normally less than 1, we had neglected to note that the temperature factor k_d shows a minor but demonstrable 2.4% increase in resistance at 200°C over a test done at 20°C (for which $k_d = 1$), so $0.567 < k_d < 1.024$ [3, p. 282] over the range of temperatures tested.

In all but one of the modules, this led to the removal of one or two questions on the basis of wording or interpretation. This empowerment was made possible by the prior studying of the required textbook [3] readings (approximately 20-30 pages for each module). The in-class discussion led to the elimination of both questions in the case presented in Figure 2, and, more importantly, to a clearer understanding by the entire class of the true *intent* of the two types of factors.

7 FUTURE IMPROVEMENTS AND CONCLUSIONS

During the year, the instructors have been collecting notes on all developed materials, and incremental changes will be made on all: presentations, assignments, RAP quizzes, exams, tutorials and tutorial TA guides. The challenges described above provide additional areas of intended improvements.

One area of specific improvement will be the development of more in-class exercises. This past year, each lecture had one or two exercises. More exercises, and more varied team activities, will be designed for next year to improve in-class communication and team cohesiveness. The nominal team size next year will be restricted to 5-6 students, as dictated by enrolment.

In conclusion, the team-based learning approach notably improved student morale over the previous year, provided more useful design knowledge to students that they could immediately use in other courses, improved student-instructor communication and improved critical design thinking skills of third-year mechanical engineering students.

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Contact:

H.F. Machiel Van der Loos
University of British Columbia
Department of Mechanical Engineering
2054-6250 Applied Science Lane
Vancouver, BC V6T 1Z4
Canada
Phone: 604-827-4479
Fax: 604-822-2403
E-mail: vdl@mech.ubc.ca
URL: http://www.mech.ubc.ca/facultystaff/vanderloos.html

H.F. Machiel Van der Loos, PhD, is Adjunct Professor in the Department of Mechanical Engineering at the University of British Columbia, teaching design courses and pursuing research in the CARIS Lab on personal and rehabilitation robotics. He received his Diplôme d'Ingénieur from the Ecole Polytechnique Fédérale in Lausanne, Switzerland in 1978 and his PhD from Stanford University in 1992. He was a Principal Investigator at the VA Palo Alto Rehabilitation R&D Center in California from 1992 to 2007. As Consulting Associate Professor at Stanford University from 2004 to 2007, he was member of the faculty team for ME310, the industry-sponsored, graduate design course in the Department of Mechanical Engineering.

Peter M. Ostafichuk, PhD, is a Senior Instructor in the Department of Mechanical Engineering at the University of British Columbia. He co-developed and coordinates the award-winning, integrated Mech 2 program for second year mechanical engineering students. Dr. Ostafichuk received a B.A.Sc. in engineering physics in 1997 and a Ph.D. in mechanical engineering in 2004, both from the University of British Columbia.