
Analysis of Mech 2: An Award-Winning Second-Year Mechanical Engineering Curriculum

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Prior to 2004, Mechanical Engineering students at the University of British Columbia (UBC) took 15 disparate courses during the second year. The resulting artificial separation between related material in these courses caused many students to compartmentalize information along course lines, and made it difficult for instructors to collaborate on the delivery of complementary content and draw connections between subjects.

In 2004, the UBC Mechanical Engineering Department replaced its entire Second Year undergraduate curriculum with a new program called "Mech 2". The primary innovation of Mech 2 was to rearrange the content of the previous Second Year courses into an integrated curriculum. Students take only one course at a time and teaching is done by a committed team of 14 instructors collaborating from five departments and two faculties. Instructors teaching related topics cooperate to ensure optimal timing of the material and to emphasize and reinforce natural connections between subjects. The courses in Mech 2 also involve many different coordinated learning activities such as classes, tutorials, labs, design projects, presentations, and field trips. The last three activities were instated particularly to increase the "hands-on" and professional training that students receive.

Program surveys have shown students prefer Mech 2 to a conventional curriculum (70% positive response) and they perceive Mech 2 as being more effective at integrating diverse subject matter (90% positive response). A statistical analysis of student performance shows that students who have taken Mech 2 have higher averages, and fail fewer courses, than students from the conventional program.

1. Introduction

Before implementation of Mech 2 in September 2004, the Department of Mechanical Engineering at the University of British Columbia (UBC) had a fairly conventional second year curriculum. Specifically, the second year consisted of 15 separate courses in solid mechanics, rigid body dynamics, basic electrical circuits, ordinary differential equations, multi-variable calculus, thermodynamics, fluid mechanics, engineering design, materials science, technical communications, and machining. The engineering science portion of this curriculum was consistent with other programs across Canada, both in terms of the subject matter covered and the division of topics into specific courses (see Table 1). This compartmentalization of information is organizationally convenient, but it was believed to inhibit students' deeper understanding of the material. Owing to bureaucratic and logistical challenges, not only were students taking many courses simultaneously, but the timing of the course offerings was almost completely uncoordinated. For example, students might have been taught linear differential equations either long before (or worse, long after) it would be required to understand single degree of freedom vibrations.

Table 1. Core subject offerings at different major Canadian universities. A “✓” in the table indicates that a single distinct course covers the subject; a blank entry indicates that the subject is not explicitly covered in the curriculum.

Subject \ University	Solids	Dyn	Elec	Diff Eq	Mtrl	Thermo	Fluids	Calc
Alberta	✓	✓	✓	✓	✓	✓	✓	✓
Calgary	✓	✓	✓	✓	✓	✓	✓	
Dalhousie	✓	✓	✓	✓	✓	✓	✓	✓
Manitoba	✓	✓	✓	✓	✓	✓	✓	✓
McGill	✓	✓		✓	✓	✓	✓	✓
Toronto	✓	✓	✓	✓	✓	✓	✓	✓
Queen's	✓	✓	✓	✓	✓	✓	✓	
Western	✓	✓		✓	✓	✓	✓	✓
Waterloo	✓	✓		✓	✓	✓	✓	✓
UBC	————— MECH 221 —————				————— MECH 222 —————			

Legend: Solids=Solid Mechanics; Dyn=Dynamics; Elec=Electric Circuits; Diff Eq=Differential Equations; Mtrl=Materials Science; Thermo=Thermodynamics; Fluids=Fluid Mechanics; Calc=Multi-variable Calculus

The primary innovation of Mech 2 was to rearrange and revise the second year content into an integrated curriculum where all the material is coordinated to bring related topics together in a systematic and orderly sequence. A consequent innovation of Mech 2 was to reduce (from seven to one) the number of courses students take concurrently. As shown in Table 1, the eight core engineering science subjects are delivered through two courses (MECH 221 and 222), taken consecutively. This integration of material is consistent with the primary recommendation of Schneider and Shoenberg (1998).

Currently, Mech 2 is taught to approximately 120 students by a team of 14 instructors from five departments and two faculties. Through the program, students also work closely with six technicians and are supported by over 50 teaching assistants.

2. Objectives, Desired Learning Outcomes, and Benefits of the program

The goal of Mech 2 is to give students a clear and unified understanding of fundamental mechanical engineering concepts and practices. The program is inter-disciplinary in nature, combining mathematics, physics, engineering science, engineering design and technical communication into a single learning context. The new curriculum emphasizes interactive learning, including multi-modal dialogue and “hands-on” training. Personal interactions between students, instructors and teaching assistants are enhanced compared with traditional engineering instruction styles. Mech 2 is designed to respond to the rapidly evolving and interdisciplinary nature of the Mechanical Engineering profession.

The desired learning outcomes for students completing the Mech 2 program are to:

- be able to apply fundamental principles of Mechanical Engineering to real-world, multifaceted engineering problems.
- be able to communicate engineering concepts and designs to other engineers and to non-technical stakeholders.

- work effectively in both membership and leadership roles in a team.
- have developed lifelong learning skills.

Along with achieving our key objectives, this program has had a number of ancillary benefits, including:

- increasing personal contacts between faculty and students, through reduction of large format lecture time, and increase in small group activities mentored by faculty.
- producing a higher level of faculty satisfaction with the way we “teach”, directly related to measurably better outcomes for our students.
- increasing the cohesiveness of the faculty as a unit.

Finally, one of the most useful activities implemented within the Mech 2 program are weekly instructor meetings and the yearly program retreat/review sessions. By maintaining close communications between the teaching team and through student surveys and discussion boards, instructors have the agility to respond quickly to learning issues that develop within the class. Comprehensive student surveys are done throughout the year and evaluated and addressed such that the Mech 2 program is one that continues to improve, winning the ASME Curriculum Innovation Award in 2006, the UBC Alfred Scow Award for student development and learning in 2007, and the STLHE Alan Blizzard Award for collaboration in teaching in higher education in 2008.

3. Implementation

Mech 2 was largely inspired by Science One (<http://www.scienceone.ubc.ca/home/>), a team-taught first-year undergraduate science program at UBC in which biology, chemistry, mathematics and physics are presented in a unified, integrated format. A hands-on emphasis flows through all Mech 2 courses, in part following the successful design-based practicum focus in the engineering program at Harvey Mudd (Bright & Philips, 1999, Dym et al., 2005). The design portion of Mech 2 was also partially inspired by the problem based learning (PBL) approach that characterises all education at the University of Aalborg (Kjersdam & Enemark, 1994) and the Project Integrated Program (PIP) in the Electrical and Computer Engineering Department at UBC (Lawrence et al., 2006)

Mech 2 is delivered through four main courses presented sequentially

- MECH 220 Engineering Skills Practicum
- MECH 221 Engineering Science 1
- MECH 222 Engineering Science 2
- MECH 223 Engineering Design

A brief description of each of the Mech 2 courses follows below. For further information, the reader is referred to Ostafichuk et al. (2006) and Hodgson, Ostafichuk, and Sibley (2005).

3.1. Engineering Practicum (MECH 220)

MECH 220 is a practicum in which students complete four one-week modules in machine shop practice, instrumentation and electronics, CAD, and engineering drawing. The class is divided into four groups of 30, and each group rotates through each module. At the end of the four weeks, students have modelled, documented, fabricated and tested their own fully working, electronically controlled magnetic levitation device.

A primary objective of this course is to develop students’ hands-on skills and self-confidence in a variety of areas important to mechanical engineering. Another objective is to give students exposure to a typical mechanical engineering project in which concepts from disparate

disciplines are integrated during the design process. The course provides some early insight to students who are still unsure of exactly what Mechanical Engineering involves. An unanticipated consequence of such insights is a small attrition (3-5 students) in the first few weeks from the total enrolment in Mech 2. Informal discussions with these students indicated that they had come to realize that their real interests lay in other fields, typically in the Arts, Commerce, or Science (it is rare for a student to wish to transfer to another engineering discipline). While in one sense it is disappointing to lose these students so soon, it seems preferable that they redirect their studies at an early stage when the academic “cost” is low, rather than later or not at all.

During the first year of the program, the practicum course went very well; however, upon entering the following engineering science courses, there was a sudden rise in student anxiety around facing integrated exams covering related material from multiple areas. These issues were mainly addressed in following years by the introduction of an entrance exam and optional review sessions during the practicum course. The exams help students to identify knowledge which they may not have mastered prior to joining the program. The review sessions help to consolidate student knowledge in these areas as well as to introduce ideas about integrating knowledge and taking on a broader, self-responsible approach to learning.

3.2. Engineering Science 1 (MECH 221)

The second course (MECH 221) is ten weeks long and covers material in engineering science including rigid body dynamics, solid mechanics, materials engineering, electrical circuits, and differential equations. The math content is fully integrated into MECH 221 in delivery and assessment, but a separate course (MATH 256) appears on student transcripts for administrative purposes only. Five instructors from four different departments collaborate on the teaching of MECH 221 using a combination of lectures, tutorials, labs, computer labs, field trips, guest speakers, and question-answer sessions (see Figure 1 for a sample schedule of typical week). Twelve lectures per week are the primary contact between students and instructors; students also spend time in small groups with instructors in question-answer sessions. The tutorials, labs, and other events are integrated into the schedule so as to be coordinated with the lecture schedule and delivered in a timely manner. Instructor schedules are not fixed, but rather change from week-to-week to facilitate the flow of the material.

Students receive prompt feedback on their learning through weekly quizzes and online assignments throughout the course. At the end of MECH 221, students write three integrated final exams. At least two subjects appear in each exam, and at least some of the questions combine multiple topics and are jointly written by the instructors involved.

Students are required to pass all subjects of MECH 221 individually as well as collectively. Thus, insufficient achievement in one subject, for example Math, would technically trigger failure in the entire course. To avoid excessive hardship to students with low marks in a minority of subject areas but with a passing average overall, a system of deferred marking was introduced to facilitate the needed remediation. Students in this situation are given a “course in progress” grade on their transcript, which is allowed to remain for up to two following academic terms while they take prescribed remedial courses. On successful completion of these courses, the requirement to pass all elements of MECH 221 is waived and the original average mark is posted. The same system is used for the second Engineering Science course MECH 222. Although administratively burdensome, the “course in progress” marking system is effective in motivating students to make up deficiencies with a positive spirit. On completion of the prescribed remedial courses, individual subject fails are entirely “repaired”, and leave no trace in academic transcripts. This is certainly an attractive outcome from the student viewpoint.

Sample Weekly Timetable (MECH 221/2/3)						
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	
8 00	Tutorial	Lecture	Tutorial	Special event (field trip, quiz, project, or guest lecture)	Tutorial	
8 30					Technical Communications	
9 00	Lab Tutorial	Lecture	Lab Tutorial		Lecture	
9 30						
10 00	Lecture	Lecture	Lecture		Lecture	
10 30						
11 00	Lecture	Tutorial	Lecture		Lecture	
11 30						
12 00						
12 30						
13 00	Lecture	Technical Communications	Lecture		Lecture	
13 30						
14 00	Lab	Tutorial				Computer Lab
14 30						
15 00		Question-Answer Session				
15 30						
16 00			Lab			
16 30						
17 00						
17 30						

Figure 1. Typical weekly schedule for MECH 221, 222, and 223

3.3. Engineering Design (MECH 223)

In the second semester, students begin an engineering design course (MECH 223). The course is divided into two parts: one that occurs at the start of the second term, after MECH 221, and one that occurs at the end of second term, immediately following a second engineering science course, MECH 222 (see below). The first part of MECH 223 combines the practical elements of MECH 220 with the engineering science of MECH 221 and it introduces students to a formal design process. MECH 223 is taught in a fully team-based learning approach (see Michaelson, Knight, & Fink, 2004) which helps foster a cooperative and collaborative environment. Six instructors from three departments work together to deliver the lecture content. Invited experts from industry and class discussions explore issues relating to the societal context of engineering. Similar to MATH 256 above, the technical communications content appears separately on students' transcripts (as APSC 201) for administrative purposes.

The highlight of each part of MECH 223 is an intensive design project, common to the entire class. The projects are supported with lectures on design theory and technical communication, workshops on group dynamics and rapid visualization, and computer labs on CAD and material selection. Each design project concludes with collaborative team formal reports and oral presentations.

In support of the emphasis on teamwork and team-based learning, great care is put into assigning students to their teams. Each team's members are carefully selected by the instructors, as suggested by Feichtner and Davis (1991) to ensure maximum heterogeneity (see Michaelson et al., 2004, and Wright, 1994). In particular, the factors considered in group formation include parameters such as the Myers-Briggs personality type, grades in MECH 220

and MECH 221, communication and language ability, and so on. This heterogeneity ensures that each team benefits from a variety of different perspectives, skills and resources, and that the teams have equal opportunities for success in the projects. To assist students with functioning as a cohesive team, several workshops on group dynamics are included in the course.

MECH 223 concludes with two final examinations on design and one final examination on technical communication.

3.4. Engineering Science 2 (MECH 222)

The fourth course that Mech 2 students see (MECH 222) is an engineering science course on fluid mechanics, thermodynamics, and multi-variable calculus. The course is seven weeks in duration and has an almost identical structure to MECH 221. Three instructors from two departments collaborate in the delivery of MECH 222. As with MECH 221, the math course appears separately on students' transcripts (as MATH 253) but is otherwise fully integrated into MECH 222 in delivery and assessment. Following the end of MECH 222, students continue with the second portion of the MECH 223 design course but this time they complete a project requiring application of content from MECH 222.

4. Impact on Student Learning

Assessment of the effectiveness of Mech 2 in meeting the goals set out in Section 2 was done by examining student performance in other courses (this section) and through student feedback (Section 5). The comprehensive nature of the changes in second year course structure, assessment techniques, instructors, and so on meant that there was no direct means (that is, no direct control group) to compare student performance in Second Year between Mech 2 and the conventional Mechanical Engineering curriculum. Instead, performance in Third Year core Mechanical Engineering courses and one core Fourth Year course was used as a benchmark for comparison of the Second Year programs. The benchmark courses included Third Year engineering design, six subjects in engineering science (vibrations, solid mechanics, applied electronics, heat transfer, thermodynamics, and fluid mechanics) and a Fourth Year course in automatic control (MECH 466). The automatic control course was selected as it was one of the few courses taken by a majority of students at the Fourth Year level. In addition, the performance of Mech 2 students in the technical communications course (APSC 201) was compared to students from other engineering disciplines in the Applied Science Faculty.

In total, four metrics were selected for assessing the effectiveness of Mech 2 in comparison to the previous conventional curriculum:

1. average grades in benchmark courses
2. change from average grade in First Year to average grade in benchmark courses
3. failure rates in benchmark courses
4. average grades and failure rates in the technical communications course

Examination of student grades in Third and Fourth Year courses indicates that Mech 2 students academically outperform students who completed a conventional second year curriculum. Likewise, comparison of student performance in the technical writing course shows that Mech 2 students are significantly more likely to achieve a passing grade than their non-Mech 2 counterparts from the rest of the Applied Science Faculty.

4.1. Average Course Grades

As a result of differences in student timetables due to work experience terms (Co-operative education) and changes to the Third Year curriculum, there was one year when the same core Third Year engineering science courses were taken by some students from the 2004 cohort of Mech 2 and some students from the previous conventional curriculum. A comparison of the average grades in these courses is shown in Table 2 below.

Table 2. Comparison of Third Year course grades for Mech 2 students and students from the previous conventional program

Courses	Conventional		Mech 2		p
	n	Average grade	n	Average grade	
Engineering design courses*	76/6	75.8%/72.0%	4/76	83.8%/80.0%	- / -
Engineering science courses	77	64.7%	81	77.5%	< 0.001
MECH 466 course	100	69.1	23	75.4	0.072

* Due to changes in the Third Year course scheduling, only a small number of Mech 2 and pre-Mech 2 students were in the same engineering design courses at the same time. Results from two separate years are shown for completeness; statistical comparison has been omitted.

The students from the 2004 Mech 2 cohort outperformed the non-Mech 2 students by an average of 12.8% in the engineering science courses and 6.3% in the MECH 466 automatic controls course. The significance shown for the difference in the average engineering science and MECH 466 course grades was determined using a two-tail T-test for the difference in means with normal distribution in grades assumed. One weakness with this analysis is that it does not take into account differences in the innate academic ability of the Mech 2 and non-Mech 2 students. For this reason, a further comparison of performance in the Third Year engineering science courses was made by considering the change in grades from First Year engineering.

4.2. Change in Course Grades from First Year

UBC Engineering students in all disciplines take a common First Year curriculum consisting of engineering science and math courses. In order to more fairly compare the 2004 Mech 2 cohort to the pre-Mech 2 students, the individual grade changes from First Year to the Third Year engineering science benchmark courses was tracked. Students were grouped according to the letter grade associated with their First Year average. Only the engineering science courses were considered in the analysis as it was the only benchmark case with a significant number of students (57 Mech 2, 24 non-Mech 2) who completed First Year at UBC.

For each letter grade group, the mean change from First Year average to Third Year engineering science average was computed. The results in Figure 2 below show that for equivalent First Year performance, Mech 2 students outperform non-Mech 2 students for all First Year grade levels. The average grade change from First to Third year was -3.3% for Mech 2 students and -8.1% for non-Mech 2; in terms of the resulting letter grades, the Mech 2 students saw an average drop of 0.7 letter grades while the non-Mech 2 students dropped by over 1.6 letter grades.

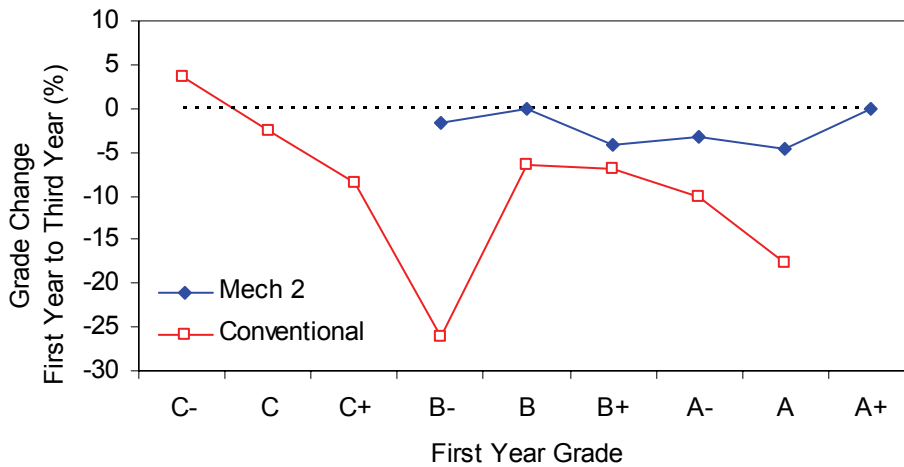


Figure 2. Change of grade from First Year to Third Year comparison for Mech 2 and conventional program

4.3. Course Failure Rates

The analysis above in terms of average course grades and the change in grades from First Year is based on the mixed Mech 2 / non-Mech 2 classes during one year. In order to expand the analysis to a larger group of students, historical data regarding course failure rates from before and after the introduction of Mech 2. “Failure rate” is used to describe the percentage of a class that did not achieve a passing mark in a given course and was required to repeat that course in the future. In the case of mixed Mech 2 / non-Mech 2 classes, the failure rates are defined with respect to the number of students belonging to the same second year curriculum. Course failure rate was used as it was believed to be less sensitive to changes in course structure, assessment methods, instructor, and so on than other metrics such as average course grade.

Historical data drawn over seven years from the benchmark courses was used to compare the Mech 2 cohort (two years of data) to students who passed through the conventional Second Year system (six years of data). The results are shown in Table 3 below and clearly illustrate that the Mech 2 students experience dramatically lower failure rates (more than a four-fold reduction) than their counterparts from the previous curriculum. The standard deviation in failure rates in a given course from year-to-year was quite consistent and ranged from 3.2% to 5.8% for the 69 courses considered with the non-Mech 2 students and 0.5% to 1.9% for the 20 courses with Mech 2 students.

Table 3. Historical failure rate comparison for students from Mech 2 and the conventional program in benchmark courses

Courses	Conventional		Mech 2	
	Number of courses	Average failure rate	Number of courses	Average failure rate
Engineering design courses	19	5.4%	8	1.1%
Engineering science courses	43	8.1%	10	2.3%
All Third Year MECH courses	62	7.3%	18	1.7%
MECH 466 course	7	3.9%	2	0.4%

4.4. Performance in Technical Communications

The APSC 201 technical communications course is taken by all Second Year Engineering students at UBC. The Mech 2 students take a modified form of this course which integrates with the MECH 223 design course. All students from the Faculty, including those in Mech 2, write the same final exam, which they must pass in order to pass the course. A comparison of performance in technical communications of the Mech 2 to non-Mech 2 students is shown in Table 4 below.

Table 4. Comparison of Mech 2 and non-Mech 2 performance in the APSC 201 technical communications course

Year	Non-Mech 2			Mech 2		
	n	Average grade	Average failure rate	n	Average grade	Average failure rate
2004	616	65.7%	14%	97	66.5%	3%
2005	609	62.0%	26%	101	67.6%	17%
2006	604	66.9%	20%	127	70.9%	6%
All years	1829	65.0%	20%	325	68.7%	8.5%

Over all years, the Mech 2 students show a slightly higher average course grade (+3.7%) and a considerably lower failure rate compared to non-Mech 2 students. All engineering students at UBC are required to complete a First Year English course in advance of APSC 201. For students who completed this English requirement at UBC, the approximate average change in grade from First Year English to APSC 201 was -4.9% for non-Mech 2 students and -4.0% for Mech 2 students. This analysis was based on 227 Mech 2 students and a random sample of 400 non-Mech 2 students over the three years. A two-tail T-test for the difference in these mean values gave $p = 0.32$, suggesting that the difference in average course grade is not highly significant. The large reduction in failure rate for the Mech 2 students is believed to be due to the strong team-based focus of the program, where students with weaker language skills benefit from close work and collaboration with stronger team mates. A second feature of Mech 2 believed to contribute to the superior student performance in technical writing is the integration

of technical communication activities with the design projects such that the enthusiasm and engagement generated with the projects extends into the technical communications activities. In contrast, the non-Mech 2 students engage in technical communications activities unrelated to their project work and, in many cases, unrelated to their personal interests.

4.5. Discussion

Although there is compelling evidence that Mech 2 is very effective, it is not clear which attributes are most responsible for the success. For example, it is impossible to distinguish the effect of extra instructional *effort* from the change in instructional *format*. Engineering educators should consider this issue carefully before attempting to emulate Mech 2, because it may not be necessary to retain all aspects of the program to obtain most of the benefits. In our department, for example, it is impractical to organize the Third and Fourth Year curricula into large integrated courses, but we have decided to introduce several Mech 2 features into the upper years.

5. Student Survey Responses

Summative course surveys have been used at the end of each year in Mech 2 to obtain feedback and determine overall student opinion of the program. The online surveys were optional and anonymous and had response rates ranging from 40 to 54%. The surveys included a selection of multiple-choice and open-ended written questions. Quantitative results from two survey questions (effectiveness at removing artificial subject barriers, and preference to a conventional program) are provided below.

5.1. Mech 2 Effectiveness

In the surveys, students were asked “How effective do you feel Mech 2 was in removing artificial barriers between course content?” The responses were based on a four-point scale and are shown in Figure 3 below.

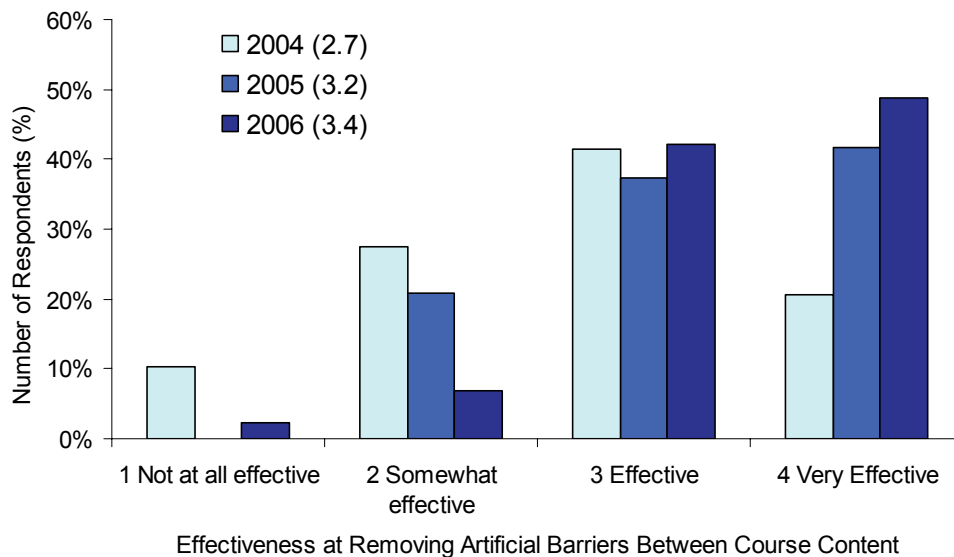


Figure 3. Survey results showing student rating of Mech 2 effectiveness at removing artificial barriers between course subjects

The weighted averages for the 2004 to 2006 sessions were 2.7/4.0, 3.2/4.0, and 3.4/4.0 respectively. The number of students who rated Mech 2 as either effective or very effective in each year from 2004 to 2006 was 62%, 79%, and 91%. The 2005 and 2006 results in particular indicate a strong positive student perception of the effectiveness of the Mech 2 approach. In related survey questions in 2006, Mech 2 was rated as being effective or very effective in developing practical (“hands-on”) skills by 93% of students, and in developing professional skills (such as team-work, time management, and communication) by 98% of students.

5.2. Program Preference

The second key aspect considered from the summative surveys is the student preference for program format. Students were asked “Considering the material that you covered in Mech 2, if that were instead delivered in a conventional program which do you think you would prefer?” and they were given five answer choices ranging from strong preference for a conventional program to strong preference for Mech 2. The survey results are shown in Figure 4 below.

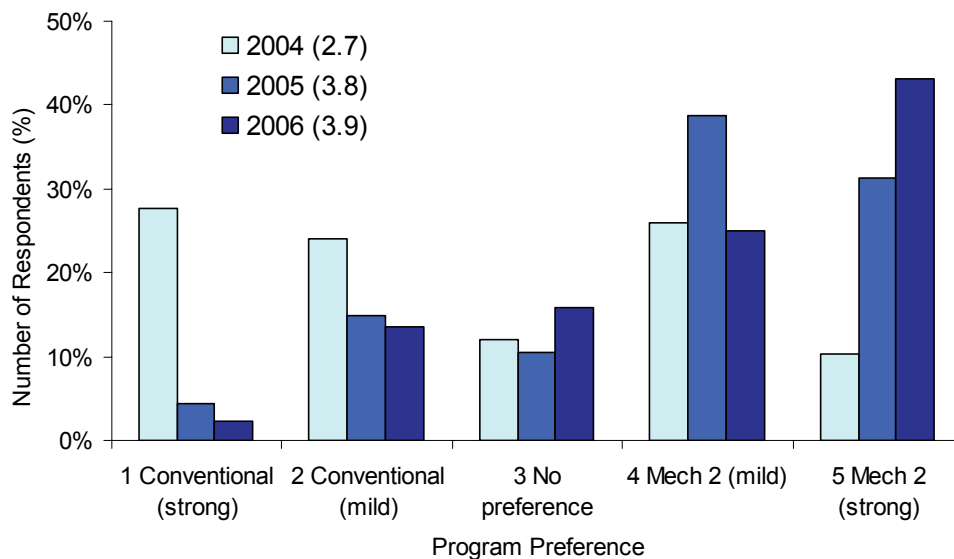


Figure 4. Survey results showing student preference for Mech 2 over a conventional-style program

The program preference trends from the 2004 to 2006 cohorts were similar to the trends in effectiveness rating above. With an average response of 2.7/5.0, the 2004 cohort indicated a slight overall preference for a conventional program (36% of students preferred Mech 2). The 2005 and 2006 cohorts indicated a preference for Mech 2 with scores of 3.8/5.0 and 3.9/5.0 respectively. In total, 70% of the 2005 cohort and 68% of the 2006 cohort preferred Mech 2.

6. Conclusions

Mech 2 combines many traditional courses into a compact group of team-taught, focused courses. This structure was adopted to eliminate artificial barriers between related concepts that might have appeared unconnected in a traditional program. The Mech 2 program has several other special attributes, including a strong sense of community, enhanced student and peer review of teaching methods, and an increased emphasis on “learning by doing”. Broadly

stated, the goal of the program was to provide a more engaging learning environment that would foster better understanding and ability to apply the course material.

Statistical analysis of student grades show that Mech 2 “alumni” are more likely to be successful in Third and Fourth Year courses than students entering the upper-level courses by other routes. The benefits of Mech 2 are significant even for cohorts stratified by First Year UBC grades (that is controlling for incoming student ability and preparation). Of equal importance, student surveys indicate that the students feel engaged with the program, and support our efforts to integrate course concepts in the Mech 2 format. Not only do students report that Mech 2 is effective, but they also show a strong preference for this format over a conventional curriculum.

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