BENCHMARKING THE QUEEN'S UNIVERSITY MECHANICAL AND MATERIALS ENGINEERING CURRICULUM WITH THE CDIO SYLLABUS

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Abstract
The application of the previously used CDIO benchmarking process to the core, option and elective programs in Mechanical and Materials Engineering at Queen's University in Canada is discussed. The results have been used to assess how well the Queen's University curricula perform in the various CDIO syllabus areas. The results have also been compared with the results obtained in an alumni survey. The benchmarking of the curriculum was based on the use of a course-by-course assessment carried out with the instructor in each course in the program using the Introduce (I), Teach (T) or Utilize (U) procedure applied to the various CDIO topic areas to generate an ITU Index value for each of these topic areas. It was found that Mechanical and Materials Engineering at Queen's meets or excels in all categories of the CDIO syllabus that were benchmarked with the exception of the following areas: *4.2 Enterprise and Business Context, 4.6 Operating, 2.3 System Thinking, 2.5 Professional Skills and Attitudes*, and *4.1 External and Societal Context*. However, the extent of these shortcomings varied between streams and options.

Keywords: Benchmarking, CDIO Curriculum, ITU Index, Alumina Survey

Introduction
The present paper describes the application of the previously used CDIO benchmarking process [1] to the core, option and elective programs in Mechanical and Materials Engineering at Queen's University in Canada. The results have been used to assess how well the Queen's University curricula perform in the various CDIO Syllabus areas [2]. The results have also been compared with the results obtained in an alumina survey. The procedure used was based on that described in Ref. [1] and was based on the use of a course-by-course assessment carried out with the instructor in each course using the Introduce (I), Teach (T) or Utilize (U) procedure applied to the various CDIO topic areas to generate an ITU Index value for each of these topic areas. The syllabus areas considered are:

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
- 2.1 ENGINEERING REASONING AND PROBLEM SOLVING 4
- 2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY
- 2.3 SYSTEM THINKING

2.4 PERSONAL SKILLS AND ATTITUDES
2.5 PROFESSIONAL SKILLS AND ATTITUDES

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK
3.2 COMMUNICATION

4 CONCEIVING, DESIGNING. IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT

4.1 EXTERNAL AND SOCIETAL CONTEXT
4.2 ENTERPRISE AND BUSINESS CONTEXT
4.3 CONCEIVING AND ENGINEERING SYSTEMS
4.4 DESIGNING
4.5 IMPLEMENTING
4.6 OPERATING

There are thus 13 CDIO syllabus areas at the second level (i.e., the X.X level) that are included in the benchmarking survey. It will be noted that area *3.3, COMMUNICATIONS IN FOREIGN LANGUAGES*, was not included because it is not required by the Canadian Engineering Accreditation Board (CEAB), the body that undertakes the accreditation of university engineering Programs in Canada.

The Queen's University Mechanical Engineering Program consists of two core options (the General Option and the Materials Option) plus a fairly large number of elective courses which are grouped into various areas although the students in the General Option can, in fact, take a mixture of elective courses from the various areas. The benchmarking was done both for the core portion of the curriculum and for the core plus electives curricula. The results of this benchmarking have been compared to see if the results are significantly dependent on the option and on the elective courses chosen.

The ITU index generated using the procedure outlined above has been compared to a *Resource Level* value defined by a survey of alumni [3]. This survey involved allocating 100 points over thirteen different sections of the CDIO syllabus. The Resource Level for each of the CDIO curriculum areas being considered is shown in Table 1.

Table 1: Resource Level for Queen's University (n=15)

Section	2.1	2.2	2.3	2.4	2.5	3.1	3.2	4.1	4.2	4.3	4.4	4.5	4.6
Resource Level(n=15)	12.72	6.57	11.2	8.77	7.58	6.99	9.92	5.03	6.23	7.63	6.62	5.22	5.53

It is interesting to note that the largest spreads in the Resource Level values so obtained were in the areas *2.3 System Thinking* and *4.6 Operating* while the lowest spreads were in the areas *2.2 Experimentation and Knowledge Discovery* and *2.4 Personal Skills and Attitudes*. This needs to be taken into account in assessing the implications of the comparison between the ITU and Resource Level values although it may partly arise from differences in the interpretation of the terms *System Thinking* and *Operating*.

Benchmarking Protocol

For each of 13 COIO topic areas at the second (X.X) level considered, faculty members were asked if they currently Introduced, Taught, and/or Utilized the topic in each of the courses for which they were responsible. The definitions of Introduce, Teach and Utilize described in Ref. [1] were provided to the faculty members. Each definition contains six elements: intent, relationship to learning objectives, time, relationship to assignments, relationship to assessment, and examples. The definitions of Introduce, Teach and Utilize, as the terms are used in the benchmarking study, together with examples that attempt to clarify these definitions that were given to the faculty members were as follows:

Introduce

Touch on, or briefly expose, the students to this topic.
No specific learning objective of knowledge retention is linked to this topic.
Typically, less than one hour of dedicated lecture/discussion/laboratory time is spent on this topic.
No assignments/exercises/projects/homework are specifically linked to this topic.
This topic would probably not be assessed on a test or other evaluation instrument.

Examples of *Introduce:*

1. At the beginning of class, an example is given of the operation of an engineering system (4.6) to motivate an aspect of the design. However, no explicit discussion of the design or analysis of operation is presented.
2. An ethical problem or dilemma (2.5) is presented to the students that sets the context of an example or lecture. However, no explicit treatment of ethics or its role in modern engineering practice is presented.

Teach

Really try to get students to learn new material.
The learning objective is to advance at least one cognitive level (e.g. no exposure to knowledge, knowledge to comprehension, comprehension to application).
Typically, one or more hours of dedicated lecture/discussion/laboratory time are spent on this topic.
Assignments/exercises/projects/homework are specifically linked to this topic.
This topic would probably be assessed on a test or other evaluation instrument.

Examples of *Teach:*

1. The process and methodology of product design (4.4) are explicitly presented to students through lectures and presentations, and then practiced by the students in a graded project or assignment.
2. Several workshops are presented on working in teams and group dynamics (3.1), and a coach works with students on improving teamwork throughout the semester's team project. The students' teamwork skills are assessed along with their project results.

Utilize

Assumes students already have some proficiency in this topic.

No specific learning objective is linked to this topic, but the student will use knowledge of this topic to reach other learning objectives.
No time explicitly allotted to teaching this topic. Assignments/exercises/projects/homework are not designed to explicitly teach this topic.
Tests or other evaluation instruments are not designed to explicitly assess this topic.

Examples of *Utilize:*

1. When taking a course other than communications, students are expected to use their skills in preparing and giving oral presentations (3.2) that explain their work. However, no explicit instruction in oral presentation skills is given.
2. When working in a laboratory session, students are expected to use their experimentation skills (2.2). However, no explicit instruction on techniques of experimentation is given.

The results of the interviews with each Faculty member were documented using the same table as that described in Ref. [1]. The results for each core course for which an ITU analysis was undertaken are given in the Appendix.

Using the results obtained in this way, an *ITU Index* [1] was generated where the ITU index was defined as:

$$ITU\,Index = \frac{0.1\sum_{i=1}^{N} I + \sum_{i=1}^{N} T + 0.3\sum_{i=1}^{N} U}{(N/10)} \qquad (1)$$

where N is the number of benchmarked courses. This equation weights Introduce (I) at 10% and Utilize (U) at 30% relative to Teach (T).

Despite the provision of the above definitions of the I, T, and U areas and of the examples of their meaning, it appears that there remained very significant differences between faculty members in the interpretation of the terms Introduce, Utilize, and Teach. This means that there is a relatively large effective “uncertainty” in the ITU values obtained. This also appeared to be differences in how faculty members interpreted the meaning of some of the terms used to describe the CDIO curriculum areas, this being particularly true of the terms *4.1 External and Societal Context, 4.3 Conceiving and Engineering Systems*, and *4.6 Operating*.

Mechanical Engineering Program at Queen’s University

The program in Mechanical Engineering at Queen’s University in Canada has the following basic features:

1. A common first year taken by all engineering students. This program is the responsibility of the Faculty not of any department. Students do not decide which program (Chemical Engineering, Civil Engineering, Electrical Engineering, Computer Engineering, Engineering Chemistry, Engineering Physics, Geological Engineering, Mathematics and Engineering, Mechanical Engineering, Mining Engineering) they want to go into until near the end of their common first year and at the moment they are guaranteed admission to their program of choice provided they have performed at a satisfactory level in the common first year.

2. The Mechanical Engineering program has, at the moment, two options - the General Option and the Materials Option.
3. The Program contains a Core program taken by all students in the program plus a number of elective courses. There is only a relatively small difference between the core programs in the two options. In the Materials Option, the elective courses are essentially prescribed but in the General option the students can select from a wide range of courses. To assist the students in selecting their elective courses, groupings of these elective courses into various areas or streams are provided, these at the moment being:
    - Aerospace Engineering
    - Biomechanical Engineering
    - Manufacturing and Design Engineering
    - Mechatronics Engineering
    - Thermodynamics and Fluids Mechanics Engineering

   However it must be stressed that students do not have to limit their elective course selection to one of these streams, most students, in fact, taking a mixture of elective courses from these various streams.

The benchmarking has been carried out for the core program, for the core plus elective courses in the Materials option and for the core plus the elective courses in each of the elective streams which were listed above. However, it must again be stressed that very few students in the General Option restrict their choice of elective courses to those in a single stream. The results of this benchmarking have been compared to see if the results are significantly dependent on the option and on the elective course area chosen.

Results

The results for the two core programs are shown in Figs. 1 and 2.

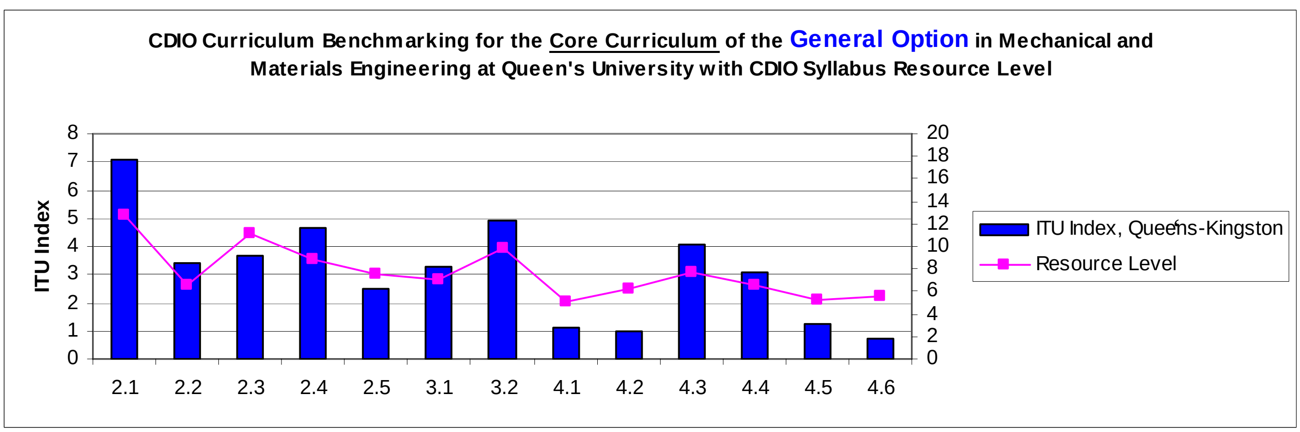

Figure 1: Benchmarking of General Option core curriculum courses.

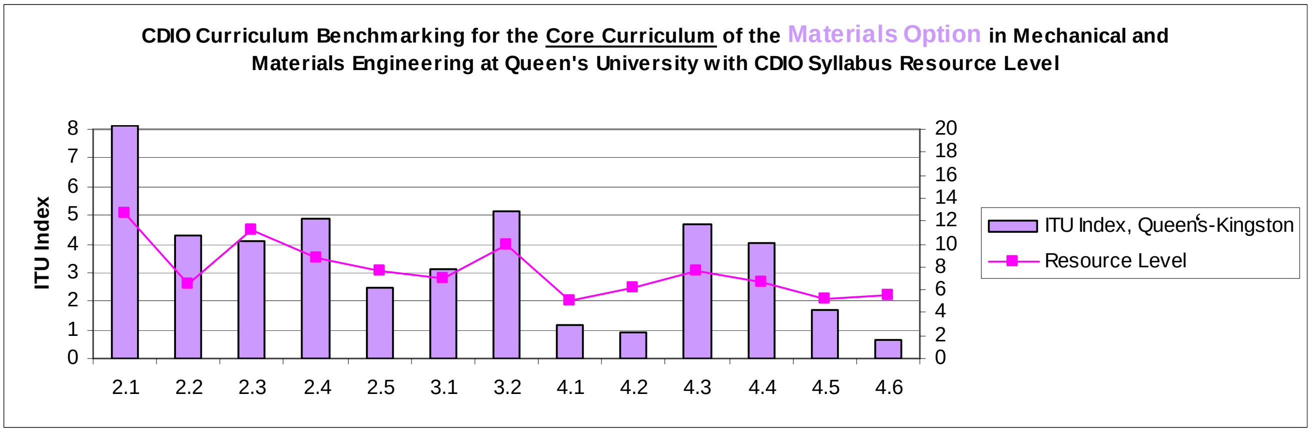

Figure 2: Benchmarking of the Materials Option core curriculum courses.

It will be seen from these figures that both options meet expectations or significantly surpass them in the following syllabus sections: *2.1 Engineering Reasoning and Problem Solving*, *2.2 Experimentation and Knowledge Discovery*, *2.4 Personal Skills and Attitudes*, *3.1 Teamwork*, *3.2 Communications*, *4.3 Conceiving and Engineering Systems*, *and 4.4 Designing.* It will also be seen from these figures that in both options there is room for improvement in the following areas: *2.3 System Thinking*, *2.5 Professional Skills and Attitudes*, *4.1 External and Societal Context*, *4.2 Enterprise and Business Context*, *4.5 Implementing*, and *4.6 Operating*, the biggest deficiencies being in areas *4.1, 4.2, and 4.6.* It should also be noted that in syllabus section *2.1 Engineering Reasoning and Problem Solving* the ITU index very significantly exceeds the Resource Level value. This could be taken as indicating that excessive attention is being devoted to this area.

The results for the full program, i.e., for the core courses plus the elective courses, will be considered next. In the case of the General Option, results will be given for each of the five elective streams listed above although, as previously noted, most students take a mixture of courses from these streams. Results for the full programs in each of the five elective streams are shown in Figs. 3, 4, 5, 6, and 7.

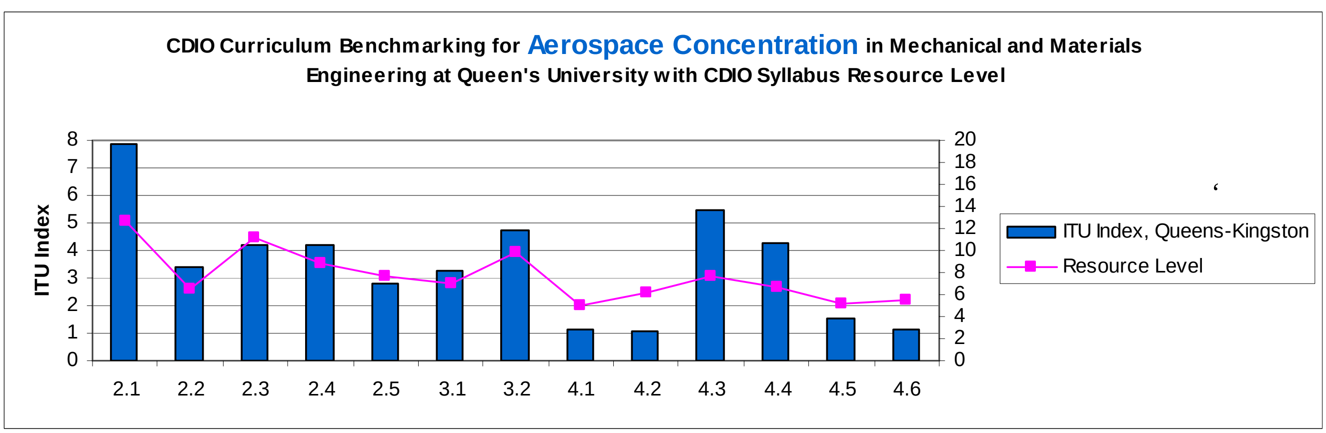

Figure 3: Benchmarking of the Core plus Aerospace elective stream in the General Option. 36 courses are included.

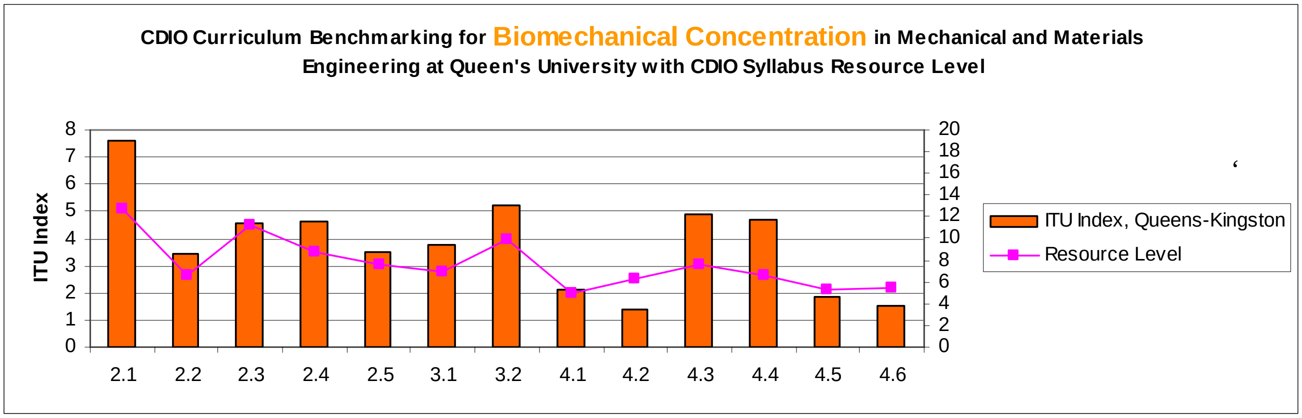

Figure 4: Benchmarking of the Core plus Biomechanical elective stream in the General Option. 36 courses are included.

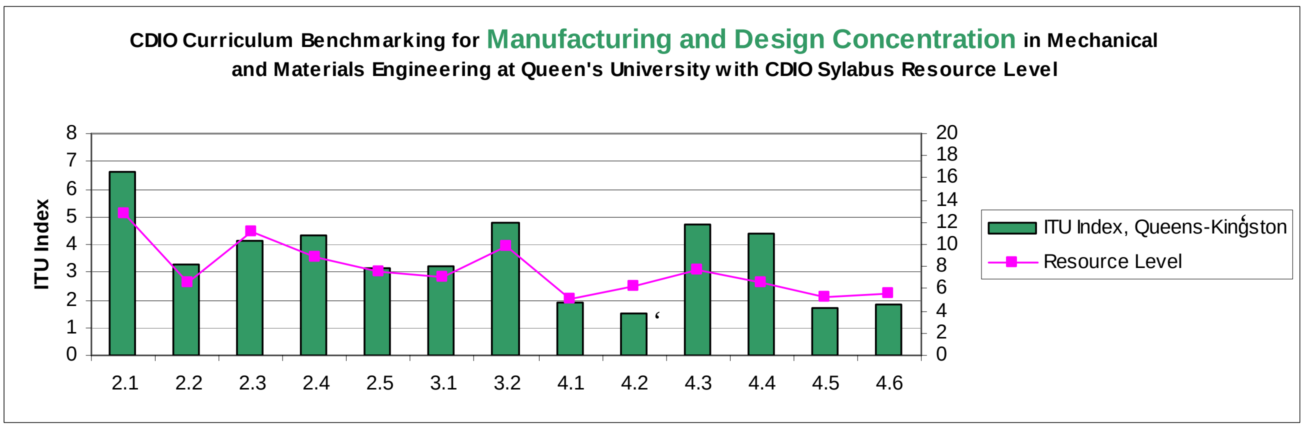

Figure 5: Benchmarking of the Core plus Manufacturing and Design elective stream in the General Option. 36 courses are included.

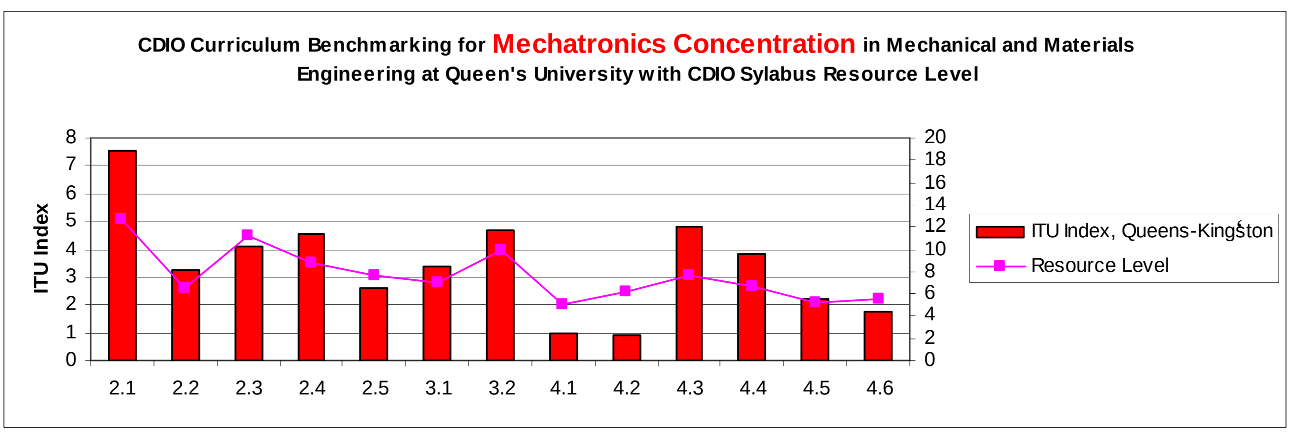

Figure 6: Benchmarking of the Core plus Mechatronics elective stream in the General Option. 35 courses are included.

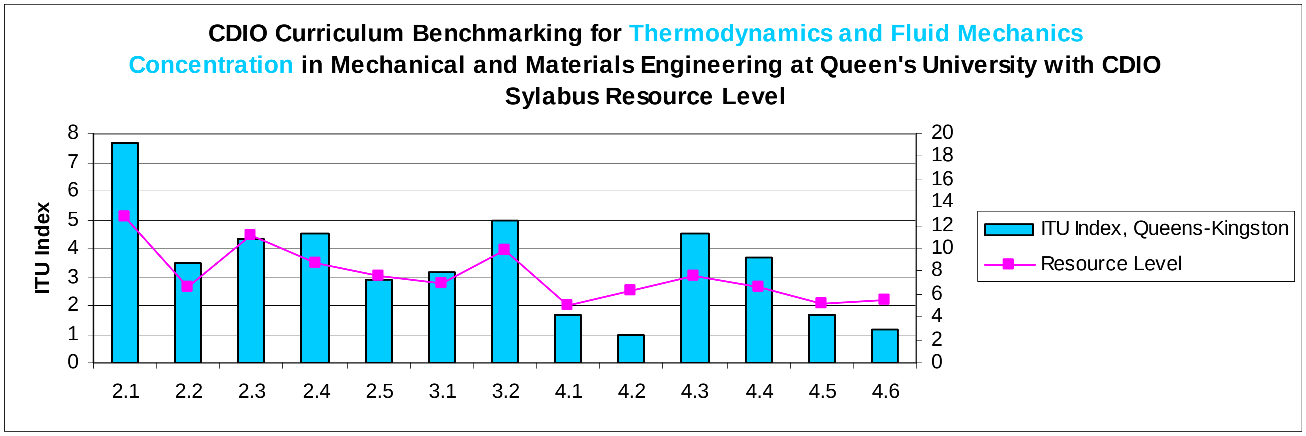

Figure 7: Benchmarking of the Core plus Thermodynamics and Fluid Mechanics elective stream in the General Option. 36 courses are included.

Consideration of the results shown in Figs. 3 to 7 shows that the aerospace stream has significant differences between the ITU values and the Resource Level values in areas *4.1 External and Societal Context*, *4.2 Enterprise and Business Context*, *4.5 Implementing*, and *4.6 Operating* and minor differences in areas *2.3 System Thinking*, and *2.5 Professional Skills and Attitudes*, that the Biomechanical stream shows the closest overall fit between ITU values and the resource level values only showing a significant deficiency in three areas: *4.2 Enterprise and Business Context*, *4.5 Implementing*, and *4.6 Operating*, that the Manufacturing and Design stream is only significantly deficient in area *4.2 Enterprise and Business Context* and shows minor deficiencies in areas *2.3 System Thinking, 4.5 Implementing, and 4.6 Operating*, that the Mechatronics stream is strongly deficient in areas *4.1 External and Societal Context* and *4.2 Enterprise and Business Context* and has minor deficiencies in areas *2.3 System Thinking, 2.5 Professional Skills and Attitudes, and 4.6 Operating*, and that in the Thermodynamics and Fluid Mechanics stream the ITU index fell short of the resource level by a significant margin in areas *4.2 Enterprise and Business Context*, and *4.6 Operating* and fell slightly below in areas *2.3 System Thinking, 2.5 Professional Skills and Attitudes*, *4.5 Implementing*, and *4.1 External and Societal Context.*

The results of the benchmarking of all courses in the Materials Option are shown in Fig. 8.

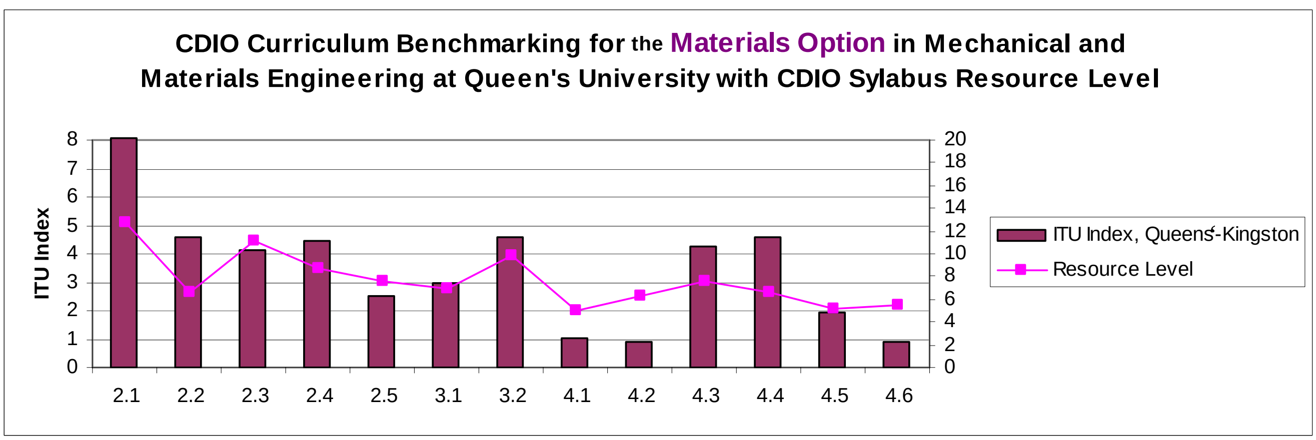

Figure 8: Benchmarking of the Materials Option. 38 courses are included.

It will be seen that in the Materials Option the ITU value is significantly below the resource level in areas *4.1 External and Societal Context, 4.2 Enterprise and Business Context,* and *4.6 Operating* and that there are minor differences in areas *2.3 System Thinking, 2.5 Professional Skills and Attitudes,* and *4.5 Implementing.*

Considering all the results shown in the above Figures indicates that the program at Queen's University in Canada shows the biggest differences between resource level and that ITU value in areas *4.1 External and Societal Context, 4.2 Enterprise and Business Context,* and *4.6 Operating.* These areas therefore need to receive the most attention in future curriculum planning.

It should be noted that errors in the benchmarking process could have resulted from inconsistencies in the interpretation of the questions asked to professors. In addition, the benchmarked elective streams are only recommended course selections for a particular area of focus and students are able to select courses at their discretion and may not choose to follow one of the pre-selected streams. This could potentially mean that the student selects a collection of elective courses that would give ITU values that either significantly exceeded the Resource Level values in some areas or that fell significantly below the Resource Level values in some areas. These differences could be somewhat greater than indicated by the benchmarking that was undertaken but is unlikely to seriously alter the overall conclusions.

It should also be noted that the results of the benchmarking of the Queen's University programs gives results that are not in any basic way dissimilar to those obtained in the benchmarking of the programs at four Swedish universities and at MIT [3], e.g., they all showed significantly lower ITU values than the Resource Level values in CDIO syllabus area 4.2. This similarity between the outcomes at the six schools is basically to be expected because the programs have many similar features [4].

Conclusions

The results of the benchmarking indicate that both options and all the elective areas offered by the Department of Mechanical and Materials Engineering at Queen's University show good basic agreement between the ITU values and the Resource Level values in all areas except *4.1 External and Societal Context, 4.2 Enterprise and Business Context* and *4.6 Operating.* In addition, some streams showed deficiencies in the areas *2.3 System Thinking, 2.5 Professional Skills and Attitudes, 4.1 External and Societal Context,* and *4.5 Designing.* The exact degree of the deficiency varied between streams and options. In one of the options and in some of the elective streams, the ITU value for *2.1 Engineering Reasoning and Problem Solving* was significantly higher than the Resource Level value possibility indicating that too much attention is given to this area.

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APPENDIX

Results of ITU Analysis of Core Courses

The following courses that are part of the core program in either the general option or the Materials Option were considered.

APSC100 Practical Engineering Modules	APSC161 Basic Engineering Graphics
APSC190 Professional Engineering Skills	MECH212 Design Techniques
MECH213 Manufacturing Methods	MECH215 Instrumentation and Measurement
MECH228 Kinematics and Dynamics	MECH230 Thermodynamics I
MECH241 Fluid Mechanics I	MECH270 Materials Science and Engineering
MECH290 Technical Communications	MECH271 Materials Science and Engineering (No Lab.)
MATH225 Ordinary Differential Equations	MATH272 Application of Numerical Methods
CIVL220 Statics and Solid Mechanics	ELEC210 Introductory Electric Circuits and Machines
MECH302 Technical Communication	MECH321 Solid Mechanics II
MECH323 Machine Design	MECH328 Dynamics and Vibration
MECH330 Applied Thermodynamics II	MECH341 Fluid Mechanics II
MECH346 Heat Transfer	MECH350 Automatic Controls
MECH398/99 Mechanical Engineering Lab. I/II	MECH370 Principles of Materials Processing
MECH371 Fracture Mechs. and Dislocation Theory	STAT367 Engineering Data Analysis
PHYS333 Electronics for Scientists and Engineers	COMM244 Project Management and Economics
MECH460 Team Project - Conceive and Design	

The results of the ITU surveys of these courses are shown in the following table.

CDIO Syllabus Area

	Course	2.1	2.2	2.3	2.4	2.5	3.1	3.2	4.1	4.2	4.3	4.4	4.5	4.6
Year 1	APSC100*	ITU	ITU	IU	IU	I	ITU	ITU			ITU	U	IU	U
	APSC161*	I				I		TU			I	TU	TU	
	APSC190*	ITU	ITU	ITU	ITU	ITU	ITU	ITU	ITU	I	ITU	I		
Year 2	MECH212	U	U	U	U	YU	U	TU	I	T	ITU	ITU	ITU	U
	MECH213	I	I	I	I	I	I	I	I	I	I		I	
	MECH215	I	T	U	T	U	T	T	U	U	T	U		
	MECH228	TU	TU	TU	U			TU			IU	I		
	MECH230	TU		U	U									
	MECH241	TU		I					I		I	I		I
	MECH270	T	T	T	U		U	U						
	MECH290	I	I		IT	T	IT	ITU				IT		
	MECH271**	T	I	I	I	I	I					I		
	MATH225*	ITU	IT		I						IT	I		
	MATH272*	ITU	IT		ITU		I	TU			IT	ITU	ITU	
	CIVL220*	U	I	I	I	I		I	I			I		
	ELEC210*	TU	TU				U				I			
Year 3	MECH302	I	I		IT	T		ITU						
	MECH321	T		IT	TU			U			TU	TU		
	MECH323	TU		TU	TU		TU	U		U	TU	TU		
	MECH328	TU			U									
	MECH330	TU		I	TU	U			I		I			
	MECH341	TU			I	I			I		I	T		
	MECH346	U		T	U		I	I			T			
	MECH350	U		T	U									
	MECH398/9	U	U		U	U	TU	TU			U		U	U
	MECH370**		U	TU	U	I	U	U				TU		
	MECH371**	TU	T	T	I	U	I	U	U		T	T	U	
	STAT367*	T	T	U	U			U						
	PHYS333*	U	U					U						
Year 4	COMM244*	TU			T		U		T	T	T			T
	MECH460	U		U	U	T	U	U			U	U		

* Non Mechanical Engineering Course ** Materials Option Course

Bibliographical Information

Patrick H. Oosthuizen is a professor in the Department of Mechanical and Materials Engineering at Queen's University. He teaches in the areas of aerospace engineering, compressible flow and heat transfer. His primary research interests are in the areas of Convective Heat Transfer and its applications in Energy Systems. He has received several awards for his research and for his teaching. He has published more than 550 technical and educational papers and textbooks on Compressible Fluid Flow and on Convective Heat Transfer Analysis.

Urs P. Wyss is a professor and Head in the Department of Mechanical and Materials Engineering at Queen's University. His current scholarly interests focus on the human musculoskeletal system with particular interest in the design of artificial joints, the analysis of gait and other movements, and the design of aids for individuals with a disability. Present research projects include: kinematics and kinetics during activities of daily living (ADL) in different cultures (hip, knee and ankle); design of mechanical devices for individuals with a disability; and design of an artificial knee joint.

Nathalie Kubrick was the first CDIO student representative at Queen's University, Canada. She attended several CDIO meetings and helped organize the 1st CDIO conference. After graduating from the Department of Mechanical and Materials Engineering at Queen's University, she accepted a position with a Canadian industrial company.

Dane Smith is, and has been for several years, a CDIO student representative at Queen's University, Canada and has been involved with the implementation of the CDIO based program at Queen's University. He has attended a number of CDIO meetings, both regional and international. He is in his final year of studies in the Department of Mechanical and Materials Engineering, Queen's University Canada.

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