The integrated mechanical engineering curriculum at the Université de Sherbrooke

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Since 1996, the School of Engineering at the Université de Sherbrooke has been offering a totally renovated mechanical engineering curriculum. Starting from scratch, this new curriculum is based on a competency development approach which is aimed at educating engineers beyond knowledge transfer through the development of student know-how and know-how-to-be (i.e., attitudes). This is achieved via four major program thrusts, which are: integrating knowledge, learning in an engineering context, promoting technical and personal achievement and increasing student responsibilities. As salient programmatic features, this curriculum incorporates, among others: design from day 1, a closely integrated sequence of courses within a semester and from one semester to the next, engineering integration semester projects and a large-scale capstone design activity. In addition to presenting a broad overview of this curriculum, the paper focuses on the first semester to illustrate the “mechanics” of making such a wide ranging reform work.

1 Background

The history of the engineering profession has been characterized by numerous changes related to its nature and role, and this has followed closely the global evolution of society. As essential links in the economic and social progress of modern societies, engineers always had to adapt to the current socio-economic context. And at the beginning of the third millennium, the engineering profession is thus probably the one currently subjected to the most profound and rapid changes.

Up to about twenty years ago, engineers were essentially hired for their technical skills. This has changed, however, and engineers have suddenly become multifunctional professionals responsible for achieving the “impossible trilogy” of producing better products more rapidly at lower costs. In addition to analysis skills, engineers now must ideally be designers and innovators, capable of integrating a variety of knowledge bases and rapidly changing technologies; they must also be able to communicate effectively and work in a team environment.

Although these changes in the practice of engineering are well known and documented, engineering education has lagged behind this revolution. In Canada, engineering education has
remained practically unchanged since around 1970, albeit for the piecewise and uncoordinated introduction of a number of new subjects such as computer science into traditional curricula. Due to lack of equipment and support, laboratory work has been eliminated or confined to specialty courses and design has taken the back seat to analysis. The perceived quality of engineering undergraduate programs has shifted from excellence in education to accomplishment in research.

However, since the 1980s, many warnings have been sounded regarding the inadequacy between engineering practice and education, among others by the NSF, the ASEE, American and Canadian accreditation boards, industry and government scientific advisory boards, for example. Under this overwhelming evidence, the Department of Mechanical Engineering at the Université de Sherbrooke has decided to act and embarked, in 1992, on a major revision of its undergraduate curriculum with the goal to educate the best graduating engineers possible within a four-year, 8-semester program. In designing this new curriculum, we found that it was not possible to attain our objectives with any of our existing courses, so a strategic decision was made to build the program from the ground up, starting from scratch. This curriculum was first offered to the class entering in the fall of 1996; thus we have already graduated two classes, in 2000 and 2001.

This paper describes the general features of this curriculum and examines in more detail the inner workings of the first semester. Our curriculum has already been the subject of an ASEE Prism feature article, which gave a broad overview of its content and methods. The pedagogical underpinnings of our approach are quite complex and these have been presented before. The first part of the present paper briefly presents this material and the practical application of these concepts is presented in the second part of the paper, through the detailed description of the first semester.

2 General features of the new curriculum

Our approach to curriculum development was based on a thorough review of the available worldwide literature, to identify the shortcomings of existing programs and to learn from the numerous proposed innovations. From there, we were able to identify the strengths and weaknesses of the various approaches. In parallel, we established a working collaboration with researchers from our Faculty of Education who are specialized in the pedagogy of professional education.

2.1 A competency-based curriculum

The main conclusion of our study of existing program was found to be that graduating engineers had knowledge but were dramatically lacking in know-how. Indeed, most engineering programs are based on the acquisition of knowledge, characterized by technical subject content and objectives. Actually, there is nothing wrong per se about knowledge acquisition in education, but for terminal professional programs such as engineering, students must also demonstrate a certain practical aptitude level upon graduation.

Because of this, we have decided to develop a competency-based engineering program. Although there are many available definitions within the education field, we define a competency as “an
array of cognitive skills (knowledge), of psycho-sensor-motor skills (know-how) and of socio-affective behaviors (attitudes or know-how-to-be) which allow a graduate to perform upon entering the workforce.”

The conversion of knowledge into know-how and attitudes requires four necessary ingredients: putting currently acquired knowledge into the proper practical context, integrating previously or concurrently acquired technical and non-technical knowledge, promoting technical and personal achievement and increasing student responsibilities (Figure 1). Our curriculum is thus articulated around these four components.

**Figure 1** Conversion of knowledge into know-how and attitudes through a competency-based program.

Because this concept had never been applied to engineering education, we had to define the array of competencies that are required for the practice of mechanical engineering. Without going into details, these competencies can be put into four classes: technical competencies (e.g., the mastery of the laws of mechanics), process competencies (e.g., how to design a new product or system), interpersonal competencies (e.g., teamwork and communications) and intrapersonal competencies (e.g., self-learning and professionalism).

2.2 Content

To promote the acquisition of these competencies, we have first modified the content of our old curriculum to incorporate this transformation from knowledge acquisition to the development of the correct know-how and desired attitudes. This was first done by carefully examining the knowledge content, which led to the reduction or elimination of some previous components and the addition of new ones. Then, new emphasis was being applied to process-type activities and these were closely integrated with the knowledge components. The content of the revised curriculum is therefore characterized by:

- A balance between problem-solving methods and techniques provided by the use of mathematics, numerics and experiments. Indeed, we strived to achieve balance in the problem-solving methods and techniques by increasing the room allowed for numerical and experimental methods.
The elimination of superfluous and redundant material, as the close integration of the material throughout the curriculum reduces repetition to a minimum. Also, handbook-type knowledge, such as mechanical element design, was removed from the curriculum.

The addition of new technical content, particularly in the field of mechatronics, which we consider as being an integral part of the new practice of mechanical engineering.

A balance between analysis and synthesis (design), making room to incorporate design activities in every single semester, starting from day 1. In the first five semester, students have to work in teams (typically 4-5) on what we call “integration projects,” in which they have to propose a paper solution to a real engineering problem by using the material presented in the current and past semesters. Next, over the last three semesters, students work on a major team design project, using concurrent engineering methodologies, resulting in a working prototype. This component of our revised curriculum has been described and discussed elsewhere.  

The integration of humanities and the incorporation of socio-economic contextualization. Again, this was done to promote the development of engineering competencies by presenting and applying, throughout the curriculum, material promoting the development of the correct attitudes or “know-how-to-be.” This material includes: teamwork, oral and written communications, creative problem solving, project and time management, ethics and professionalism.

2.3 Programming of curriculum content

Once the content was established, its programming through the eight semesters of the curriculum was achieved by promoting lateral and longitudinal integration of course material. For us, lateral (or vertical) integration is the close integration of the material presented within a semester. To achieve this, the material within a given semester is chosen to be as closely related as possible between the various topics and disciplines. Not only is the material within given semester globally related, but efforts are made to achieve local synchronization through a just-in-time approach. In addition, there are a number of activities (assignments, labs, projects) which are common to the courses of a semester. Rather than having an almost hermetic separation between the courses within a semester as in conventional programs, our students almost get the impression that they are taking a single multidisciplinary course each semester taught by a number of different faculty members.

As well, longitudinal or horizontal integration refers to the integration of material from one term to the next. This is done to achieve a maximum of material reuse and to reduce repetition to a minimum. In this context, students know that they cannot flush their mental circuits once a course or a semester is over. An example of horizontal integration is presented in Figure 2 for the “Laws of Mechanics” technical competency.
Without going into the content details, the courses comprising the revised curriculum are shown in Table 1.

2.4 Delivery

Obviously, there are also a number of improvements that can be made in a curriculum revision through the use of modern teaching methods and tools.

First, because of the close integration of the revised curriculum, to do it correctly you need a cohesive faculty organization. The best way to achieve this is through the establishment of teaching teams, each team having responsibility for a given semester. The team comprises the faculty members teaching each single course of a given semester, and they meet weekly to plan for the upcoming week. Issues discussed have to do with: semester scheduling, integration projects, common assignments, common examples, evaluation activities, etc.; the team is thus responsible for the vertical integration of the material within a semester. As well, the team leader is responsible for ensuring integration with the other teams, i.e., horizontal integration.

As an aside, this obviously requires a new relationship between faculty members, which could be characterized in the past as “single educational entrepreneurs.” In our case this has required some adjustments. For example, most of our mathematics courses used to be taught by the Department of Mathematics in the Faculty of Science. However, since they could or would not participate in our closely integrated curriculum, we decided that the our department would take care of the
Table 1 Revised Mechanical engineering curriculum.

<table>
<thead>
<tr>
<th>First semester:</th>
<th>Second semester:</th>
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<tbody>
<tr>
<td>Newtonian dynamics (4 credits)</td>
<td>Energetics (3)</td>
</tr>
<tr>
<td>Linear algebra (3)</td>
<td>Lagrangian dynamics (2)</td>
</tr>
<tr>
<td>Differential equations and calculus (3)</td>
<td>Multivariable functions (1)</td>
</tr>
<tr>
<td>Computer exploitation (3)</td>
<td>Thermodynamics and characterization of materials (1)</td>
</tr>
<tr>
<td>Introduction to fabrication technology (1)</td>
<td>Mechanical systems and elements (2)</td>
</tr>
<tr>
<td>Introduction to engineering (1)</td>
<td>Technical and computer drafting (2)</td>
</tr>
<tr>
<td></td>
<td>Teamwork and time management (1)</td>
</tr>
<tr>
<td></td>
<td>Technical communications (2)</td>
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<table>
<thead>
<tr>
<th>Third Semester</th>
<th>Fourth semester:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid mechanics (3)</td>
<td>Thermofluids I (2)</td>
</tr>
<tr>
<td>Solid mechanics (3)</td>
<td>Analysis of structures I (2)</td>
</tr>
<tr>
<td>Engineering mathematics I (3)</td>
<td>Engineering mathematics II (3)</td>
</tr>
<tr>
<td>Elements of the experimental method (3)</td>
<td>Mechatronics I (3)</td>
</tr>
<tr>
<td>Mechanical properties of materials (1)</td>
<td>Materials microstructure and selection (3)</td>
</tr>
<tr>
<td>Foreign language (3)</td>
<td>Teamwork and leadership (1)</td>
</tr>
<tr>
<td></td>
<td>Introduction to scientific research (1)</td>
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<th>Fifth semester:</th>
<th>Sixth semester:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermofluids II (3)</td>
<td>Introduction to quality engineering (3)</td>
</tr>
<tr>
<td>Analysis of structures II (2)</td>
<td>Materials reliability (3)</td>
</tr>
<tr>
<td>Mechatronics II (3)</td>
<td>Design project I (3)</td>
</tr>
<tr>
<td>Fabrication processes (3)</td>
<td>Creative problem solving and critical thinking (2)</td>
</tr>
<tr>
<td>Design methodology (3)</td>
<td>Communications in engineering (1)</td>
</tr>
<tr>
<td>Project management (1)</td>
<td>Elective (3)</td>
</tr>
</tbody>
</table>

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<tr>
<th>Seventh semester:</th>
<th>Eighth semester:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechatronics project (3)</td>
<td>Design project III (6)</td>
</tr>
<tr>
<td>Case studies (3)</td>
<td>Health and safety in the workplace (1)</td>
</tr>
<tr>
<td>Design project II (3)</td>
<td>Professionalism (2)</td>
</tr>
<tr>
<td>Engineering economics (3)</td>
<td>Two electives (6)</td>
</tr>
<tr>
<td>Elective (3)</td>
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Also includes four coop work-terms.

Between 4th and 5th semesters, during the students' first work term: Communications in the workplace (1)
Between 5th and 6th semesters, during the students' second work term: Teamwork and self-learning II (1)

mathematics content. Actually, this was a strategic move, ensuring that this important material would never risk again of being disconnected from the rest.

Also, new teaching methodologies are applied, most notably through the use of cooperative learning. Although some of our colleagues still use a number of conventional lectures, learning through interaction with other students is emphasized in all of our activities.

Because of the strong team component of the new curriculum, methods to ensure the proper evaluation of individual students have been developed and applied. There are still quite a number
of individual evaluation activities, but these are more numerous and varied than in our previous curriculum. In team activities, there is also a strong co-evaluation component in which team members are evaluated by their peers on the knowledge, know-how and attitude components which were part of the project. The final grade in a course is thus obtained from a combination of individual and team evaluation, and reflects the level of competency achieved as compared to term competency goals.

Finally, we take advantage of web-based tools for communicating with the students, for presenting or archiving class material, and for performing some evaluation activities.

3 Example of the first semester

To illustrate how the curriculum is put together and delivered, the first semester is presented here in more detail. In particular, we examine the vertical integration of course material within the term, what do integration projects actually look like and how the team teaching concept is implemented.

Figure 3 Graphical representation of courses in the first semester.

3.1 Course and material organization

The first semester comprises six courses, as illustrated in Figure 3:

- **Newtonian Mechanics** (4 credits): covers particle and rigid body dynamics using Newton’s three laws, including statics.

- **Differential Equations and Calculus** (3 credits): review of single integration analytical methods, also covers numerical integration, ordinary differential equations and multiple integrals.

- **Linear Algebra** (3 credits): review of vector and matrix properties and operations, also covers properties and operations on linear systems, including numerical methods.

- **Computers in engineering** (3 credits): covers symbolic and numerical computation using...
Matlab, programming principles using Matlab, Fortran and C++.

- **Machine Tool Laboratory** (1 credit): shop class in which students learn to use the lathe, milling and drilling machine tools.

- **Introduction to Engineering** (1 credit): a broad overview of the practice of mechanical engineering through weekly lectures from mechanical engineers in industry and a review of the history of the field, as well as a look into past and current trends and outstanding issues.

The lateral courses have for main objective the introduction of engineering practice early on to achieve and maintain a high level of student motivation during the first semester. The four middle courses are closely linked through the vertical integration scheme, which is illustrated in Figure 4.

**Figure 4** Vertical integration within the first semester.

As seen in the figure, the central components of the semester are the four topics within the Newtonian Dynamics course (particle kinematics, particle kinetics, rigid body kinematics and rigid body kinetics) to which are grafted the mathematical components that are necessary to derive the theoretical material and solve problems in dynamics. For example, the beginning of the Dynamics course requires the use of various coordinate systems, which are covered in parallel in the Differential Equations course, and coordinate transforms, which are presented as matrix manipulation at the same time in the Linear Algebra class. Throughout the semester, the presentation of the mathematical material thus closely follows the needs of the Dynamics course in a similar manner, as illustrated in Figure 4. As well, the Computers course has for objective the implementation of numerical schemes, which are developed in the math courses and used to solve...
dynamics problems.

In this context, it is obvious that our students realize the usefulness of mathematical methods early on and that this favors both short and long term retention of this material. To further promote the close relationship between these four courses, a number of common assignments are scheduled throughout the term and a major design endeavor is required as a term integration project.

3.2 Integration projects

These integration projects are assigned early in the semester to teams of four students. (The makeup of the student teams is done by the teaching team on the basis of academic strength, as estimated from the student applications, in order to achieve overall balance from one team to the other.) A first semester integration project requires a midterm progress report and end-of-term engineering project report, presented according to the state-of-the-art and standards of the profession. These report must comprise: an introduction to the topic, a review of available literature, a definition of the problem, a description of the various hypotheses and methods used, a discussion of the proposed solution and a recommendation for future work.

The topics for the integration projects are chosen to cover the material presented in those four courses, so a typical project would involve:

- modeling the dynamics of a physical system which usually results in set of differential equations with associated initial conditions,
- the analytical solution of the exact/approximate system,
- the numerical integration of the exact system.
- Along the way a number of linear algebra concepts would have to be used, such as coordinate transforms using transformation matrices, the solution of linear systems and the determination of eigenvalues.

These projects are real projects with real-life (i.e. poorly defined or incomplete) design requirements; each team proposes its own solution which must satisfy or exceed a maximum of requirements. In addition to the obvious technical competencies that are required to fulfill the project requirements, students must also start to develop personal competencies in teamwork, communications and professionalism to get the job done.

For illustration purposes, here is the list of projects that have been worked on by our first semester students:

- 1996 (two projects, as we were quite ambitious!): the design of a suspension for a centrifugal fan in a household air exchanger (in collaboration with Venmar Ventilation Inc.) and the redesign of the windshield wiper system for a coach bus (in collaboration with Prévost Car Inc).
- 1997: the design of a new robotics space arm to replace the Canadarm aboard the Space Shuttle (in collaboration with the Canadian Space Agency and Spar Aerospace Inc.)
- 1998: the design of the proper orbit and of the three-axis stabilization system for the Radarsat-2 satellite (in collaboration with the Canadian Space Agency).
- 1999: the design of a flight simulator ride for an attraction park (in collaboration with CAE Electronics Ltd).
- 2000: the design of a force-feedback mouse for visually-impaired computer users.
- 2001: the design of the suspension for a mountain bike (in collaboration with the DeVinci bicycle company).

3.3 Evaluation

Our evaluation strategy comprises a number of complementary components between individual and team evaluations and also single subject and integrated activities. Individual single subject evaluations are performed on a weekly basis for each of the four technical courses at a set 2-hour period within the schedule; there are no midterms. This encourages students to keep up to date with the class material as the consequences of falling behind can be dramatic; this also eliminates last-minute cramming characteristic of midterms. A further advantage is the reduced pressure as there are a fair number of opportunities for a student to recover after a substandard week. Individual single topic final exams are also in use in the four technical topics and they cover the material covered throughout the semester.

Integrated individual evaluation is achieved through assignments common to two or more courses and integrated team evaluation is done with the integration projects. It should be noted that integration projects are graded as a whole and thus the individual dynamics, math and computer components are not evaluated separately. The same project mark is applied towards the final grade in all four technical courses. The individual project mark is obtained from the team mark after modulation from the results of peer evaluation.

3.4 Team teaching

For the first semester faculty team, close interaction is required to ensure that the desired level of integration is achieved between the different topics. In addition, teamwork is required to ensure an even student workload throughout the term and to respond to student feedback. This is accomplished via three distinct weekly activities: a synthesis hour, a student feedback meeting and a faculty team meeting.

The synthesis hour takes place at the end of the schedule for the week, for us on Friday morning between 11:30 and 12:30. During this hour, the six faculty members present the students a summary of the material covered during the week and emphasize the links between the different components.

The weekly student feedback meeting is held just after the synthesis meeting; its goal is to collect, from six elected student representatives, information aimed at improving each class as the term proceeds. This information can pertain to the workload or to improperly understood material, for example. With this feedback mechanism, improvements can be performed on the fly rather than having to wait for the end-of-term faculty evaluations.

The faculty team meeting takes place on Friday afternoon. During this meeting, the programming of the upcoming week is fine-tuned and responses to the student feedback meeting are discussed.
3.5 Special schedule for the first two weeks

Finally, to ensure that our students get off to a good start in their university studies, we devote the beginning of the first semester to a two-week initiation to mechanical engineering. During these two weeks, regular classes are suspended and replaced by a number of activities that allow the students to get used to their new environment and to gradually plunge into the study and practice of mechanical engineering. These include: refresher mathematics workshops; personal computer workshops; the start of machine tool laboratory sessions; introductory workshops on teamwork, communications and professionalism; and a two-week team design competition.

4 Summary

We have presented the revised mechanical engineering curriculum at the Université de Sherbrooke. We have used a competency-based approach to produce a closely integrated program. We have also shown the details of the first semester to illustrate the “mechanics” of the curriculum.


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