WEEF 2013 CARTAGENA COLOMBIA
World Engineering Education Forum
Septiembre 24 a 27
CENTRO DE CONVENCIONES CARTAGENA DE INDIAS

Innovation in research and engineering education: key factors for global competitiveness
Innovación en investigación y educación en ingeniería: factores claves para la competitividad global

WIP; FROM GENERAL TO INTEGRATED; AN EVOLUTIONARY ENGINEERING CURRICULUM DESIGN APPROACH

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Abstract

The University of Maine has recently established the Brunswick Engineering Program, a first and second year engineering program that utilizes an integrated curriculum, and that covers the equivalent of the Freshman and Sophomore years of the B.Sc. in Mechanical, Electrical, Civil and Computer Engineering (the students then complete their Junior and Senior years at the respective departments at the main campus). The programs' principal objective is to expand the engineering educational alternatives in the Maine Mid-Coast region, while at the same time implementing advances in engineering pedagogy with the aim of achieving a high level of curriculum integration. It is expected that these measures will enhance the learning experience and increase retention of the nonresidential student body.

While many approaches for integration exist, in this particular case, and in order to incorporate the specific constraints of each destination degree program, the first step taken was to create a general curriculum, as the starting point from which to apply integrative measures, both horizontally and vertically across the two year program duration. Pedagogic approaches such as problem based learning and classroom flipping are combined with subject integration strategies (such as irregular subject delivery and shared projects among the courses) that result in an increased correlation among the subjects. The result is a first year curriculum (second year curriculum still under development) composed of two core courses each semester, Integrated Engineering 1 and 2, and Engineering Studio 1 and 2, representing the equivalent of the traditional first year calculus and physics sequence, as well as an engineering computing course, an engineering graphics course, engineering mechanics (statics), and the traditional albeit in this case general introduction to engineering course. Additional courses such as chemistry and English are delivered the traditional way. In the second year this structure is continued, however the Engineering Studio course splits into a track catering for the Electrical and Computer Engineering program and a separate one for the Mechanical and Civil Engineering degree program.

This work-in-progress describes the procedure utilized to design and evolve the curriculum, and in particular addresses how the transition from a general first year engineering curriculum to a curriculum that integrates the delivery of most of the mathematics, science and engineering components in the context of engineering applications is being accomplished.

Keywords: integrated curriculum; curriculum design

Resumen

La Universidad de Maine recientemente estableció el Brunswick Engineering Program, un programa de ingeniería que consiste del primer y segundo curso del Bachelor en Ingeniería Mecánica, Eléctrica, Civil e Informática, con la particularidad de implementar un currículo integrado (al finalizar los dos primeros años los estudiantes completan su tercer y cuarto año en los respectivos departamentos en el campus principal). El principal objetivo de este Programa es el ampliar las alternativas educativas de ingeniería en la zona de la costa central de Maine, conjuntamente con la aplicación de avances pedagógicos de ingeniería a través de la integración curricular. Se espera que estas medidas mejorarán la experiencia de aprendizaje y aumentaran la retención de los estudiantes.

Si bien existen muchos enfoques para la integración, en este caso en particular, y con el fin de incorporar las exigencias específicas de facultad en el campus principal, el primer paso fue la creación de un currículo generalizado como punto de partida al que aplicar medidas de integración durante toda la duración del programa de dos años. Enfoques pedagógicos como el aprendizaje basado en problemas y el "flipped classroom" se combinan con estrategias de integración de las materias (como por ejemplo un orden alterado de las materias basadas en la necesidad puntual de aprendizaje combinada con proyectos compartidos entre los cursos). Estas medidas resultan en un aumento de la correlación entre los temas. El resultado de estas medidas es un plan de estudios del primer año (el currículo del segundo año todavía esta en desarrollo), compuesto por dos cursos básicos cada semestre, "Integrated Engineering" 1 y 2, e "Engineering Studio" 1 y 2, lo que representa el equivalente a la secuencia tradicional de Matemáticas (Calculus 1 y 2) y física (Physics 1 y 2), así como como el equivalente de un curso de ingeniería informática, un curso de gráficos de ingeniería (CAD), ingeniería mecánica (estática), y el tradicional (aunque en este caso con enfoque general) Introducción a la carrera de ingeniería ("Introduction to Engineering"). Cursos adicionales como la química e inglés se dan de forma tradicional. En el segundo año se continua con esta estructura, sin embargo, diferentes modalidades del curso de "Engineering Studio" divide el programa común en dos vías, una para la carrera de Ingeniería Eléctrica e Informática y otra para el programa de grado de Ingeniería Mecánica y Civil.

Este trabajo en curso describe el procedimiento utilizado para diseñar y desarrollar este plan de estudios, y en particular como evolucionar de un primer plan de estudios de ingeniería "general" a un plan de estudios que combina la mayoría de los componentes de las matemáticas, la ciencia y la ingeniería en el contexto de integración curricular.

Palabras clave: *currículo integrado; diseño curricular*

1. Introduction

The Brunswick Engineering Program is an innovative program initiated by UMaine College of Engineering in 2012 at the former Brunswick Naval Air Station, on the Mid-Coast Campus of Southern Maine Community

College. The BEP is characterized by a close-knit program community, with a low student to faculty ratio and extensive faculty availability for advising and mentoring. This results in a highly supportive environment conducive to student retention (Stromei 2002; "Going the Distance: Best Practices and Strategies for Retaining Engineering, Engineering Technologyand Computing Students" 2012). In addition to providing such a supportive environment, the BEP is developing a first and second year engineering program that is based on curricular integration, problem based learning, peer instruction and more, following the recommendations of previous experiences and pilot programs (Corleto et al. 1996; Roedel et al. 1997; Al-Holou et al. 1999). Multiple learning modes are used to crosslink the material to provide a design-based, hands-on, open-ended project based curriculum that is strongly connected to "real" engineering.

Many first year integration experiences have emerged over the past two decades and the variety of approaches has been extensively documented in the literature. Examples of large scale applications include the Foundation Coalition (Corleto et al. 1996; Roedel et al. 1997; Al-Holou et al. 1999), Southeastern University and College Coalition for Engineering Education (SUCCEED), and the Gateway Coalition ("The Story of the Gateway Engineering Education Coalition Project at Columbia" 2013). Olin college, (Somerville et al. 2005), and due to its startup nature, had the opportunity to implement a completely new curriculum, which displays perhaps the highest level of integration.

Moving the student into the center of the learning effort and making him an active participant in his education is the underlying paradigm in all implementations (Froyd and Ohland 2005). Typically employed approaches include Problem Based Learning, experiential learning (Conger et al. 2010; Kolb 1984; Bailey and Chambers 2004), flipping the classroom and concept based learning (Mazur and Watkins; Crouch and Mazur 2001; Litzinger et al. 2010).

Applying these techniques reaps the highest benefit in a multidisciplinary setting, where (for example) the teaching of mathematics is directly linked to the physical principles and engineering applications of these principles. The immediate perspective the students gain on where the learned principles "fit in" in their chosen profession not only enhances understanding of the concepts, but also continuously motivates aspiring engineers to continue their studies by making them feel like engineers from day one.

The work presented here discusses a framework for development of an integrated first and second year engineering curriculum that satisfies a series of core criteria. As such, this curriculum does not represent a complete departure from the traditional courses offered at the main campus, but rather establishes a structured design procedure that based on traditional components allows evolution towards higher levels of integration.

2. Discussion

The Brunswick Engineering program was established with the aim of offering a local entry point into engineering education at the to date underserved Mid-Coast Maine region, while at the same time piloting the implementation of modern pedagogic developments in order to enhance student understanding and retention.

2.1. Program objectives

The development of the integrated curriculum at the BEP entails parallel efforts regarding both the incorporation of student centered pedagogy into the delivery of the material, and simultaneously developing a "general" engineering curriculum that includes all necessary learning outcomes to cover the equivalent classic courses at the main Campus.

The resulting high-level BEP curriculum design criteria can be defined as:

1. Teach mathematics and science in the context of engineering applications
2. Allow seamless transition of the students into the Junior and Senior years at the Orono Campus
3. Be teachable within the available BEP framework
4. Ensure a coherent and well structured vertical sequencing of topics that allows a structured buildup of knowledge and skills (not just a collection of necessary learning outcomes)

Criterion 1 is primarily concerned with the pedagogical approach and identifying appropriate synergies in the individual traditional course learning outcomes. Criterion 2 requires developing course compositions that satisfy all required learning outcomes (this is perhaps the core principle in the curricular sequencing process), while the assessment and rigor components may be again classified under pedagogical implementation of the curriculum. Criterion three imposes boundary conditions on what is feasible and what not in the curricular design process based on location and financial considerations. The curricular design process is illustrated in Figure 1:

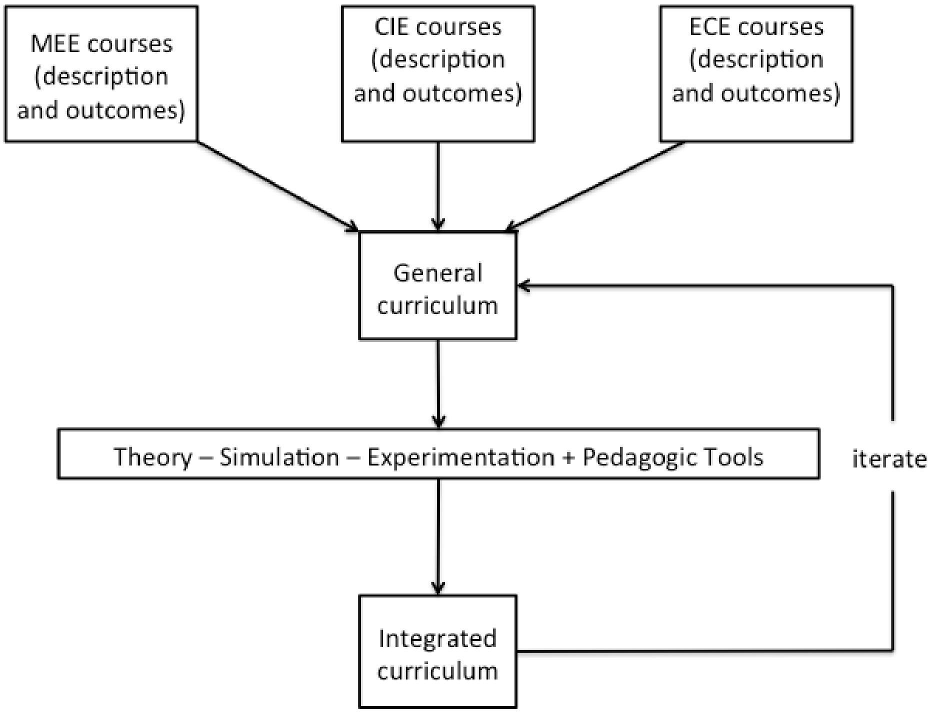

Figure 1. Curricular design process

From the curricular design criteria listed above a series of performance indicators can be constructed, that in turn can be classified under the headings "pedagogical Implementation" and "curricular sequencing".

2.2. Curricular sequencing (developing the General Curriculum)

The General Curriculum represents the starting point for the integrated curriculum. As such, the composition of the courses already reflects synergies that will be continuously deepened in each iteration of the course. The curricular sequencing performance indicators (PI) to assess the suitability of the developed curriculum are:

1. *(Criterion 2): Teach a curriculum with a similar to identical number of credit hours than the equivalent traditional Orono curriculum*[1]
2. *(Criterion 2): Incorporate all learning outcomes that constitute the equivalent Orono courses*
3. *(Criterion 3): Develop a curriculum that is common for Mechanical, Electrical Civil and Computer Engineering Degree students for the first three semester (minimize the number of degree specific courses required).*
4. *(Criterion 3): Develop instructional laboratory facilities that provide adequate means to deliver the required content in a student centered pedagogical fashion*

It is difficult to assess Criterion 4 (“Ensure a coherent and well structured vertical sequencing of topics that allows a structured buildup of knowledge and skills”), as there is no readily available metric for curricular “flow”. However, in the context of the curricular integration and the associated experiential activities and design projects, appropriate flow is demonstrated by increasing complexity of these experiences, as defined for example by achieving higher categories in the cognitive and affective domains of the Bloom’s Taxonomy (“Bloom's Taxonomy of Learning Domains” 2013). The development of appropriate assessment tools for this dimension of the curriculum is an ongoing process.

In order to satisfy PI 1 and 2 above, a “general” curriculum layout that satisfies all four degree-programs needs to be composed. This general curriculum directly incorporates all learning outcomes of the equivalent traditional courses (PI 2), however arranged in a sequence that explores synergies and allows the multiple learning modes described above. The Integrated courses of this general curriculum reflect the same credit hour weighing (PI 1) than the component traditional courses (for example, IEN110, a 10ch course, is composed of 4ch of Calculus 1, traditionally a 4ch course, 4ch of Physics 1 incl lab, also traditionally a 4 ch course, and 2ch of a 4ch computer course that will be completed in a later integrated course). Only in very limited instances (throughout the first two years only 2 additional credit hours are added) a credit hour is added to allow for the expanded experiential component necessary for successful integration.

The early introduction of engineering design tools and the engineering design process becomes a key component in this curricular development process to satisfy PI 3 and 4. The general nature of the curriculum (that requires the replacement of the degree specific introductory courses of the traditional curriculum with components that are applicable to all represented disciplines – PI 3) and the need to productively able to apply the “theory, simulation and experimentation” process and the problem-based-learning and experiential learning context of the program, creates the need for the students to have design knowledge and ability to apply modern design tools. This consideration is in alignment with ABET’s student outcomes that further emphasize the design component in the curriculum, a trend that has been consolidating over the past decades (Yokomoto et al. 1998; Piket-May and Avery 1996; Richardson et al. 1998).

PI 4 addresses the availability of engineering and science laboratories that incorporate hardware that not only allows the demonstration and experimenting with fundamental concepts, but rather one that also permits a high degree of flexibility in creating discovery exercises and project based learning applications.

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[1] A 2-6 credit hour discrepancy is unavoidable due to the differing credit hour loading and core requirements of the different Degree Programs that need to be included into the General Curriculum delivered at the BEP

An advantage has been the choice of a modular system that shares the same software interface and A/D sensor connectivity Students become familiar with the system after a series of introductory experiences, and can increasingly focus on the phenomena and projects rather than learning and relearning the hardware or software interface. On the other hand, with this system it is important to rapidly move into open-ended experiences rather than traditional labs following detailed instructions so as to maintain the dynamic of discovery and not a rogue “fill in the blanks” experience.

The resulting first year curriculum is depicted in Figure 2:

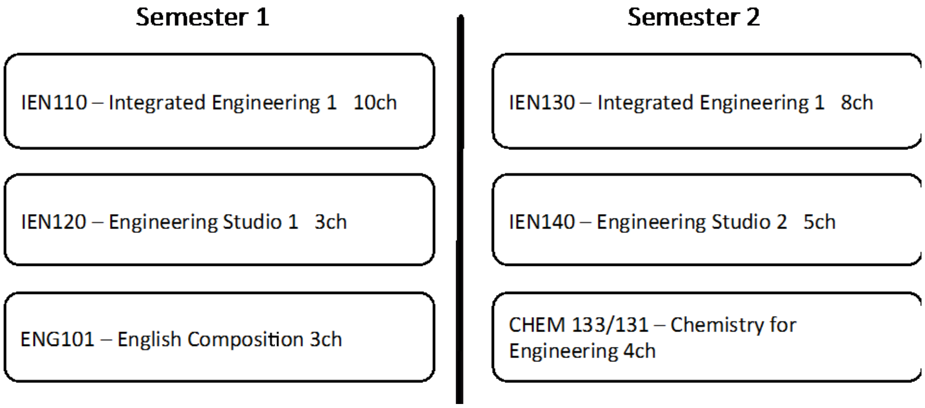

Figure 2. BEP year 1 integrated curriculum.

2.3. Evolution from general to integrated: Pedagogical Implementation

For Criterion 1 (Teach mathematics and science in the context of engineering applications) the following performance indicators may be defined:

1. *(Criterion 1): Increase first and second year student retention*
2. *(Criterion 1): Develop in-depth understanding of subject matter*
3. *(Criterion 2): Ensure equivalent rigor in the delivery of the courses*

Student retention is related to a variety of factors related to both curricular elements as well as environmental variables. A particular standout for engineering students is early de-motivation for not being able to link mathematics and science elements to engineering applications (Bernold, Spurlin, and Anson 2007). Mitigating this “disconnect” is a defining characteristic of the Integrated Curriculum. Integrated courses, and very often via a multi-mode learning approach that combines theory with simulations and experimentation, seek to link the mathematical and physical concepts with engineering problems that are presented at the appropriate level of complexity for the particular class. A typical example of the implementation of this principle at the BEP is a design project at the end of semesters 1 and 2 that bridge both integrated courses (figure 3).

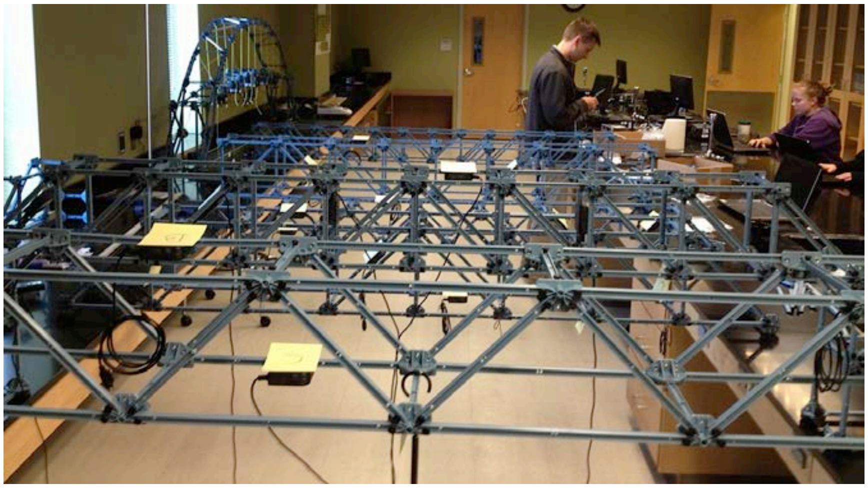

Figure 3. Design, simulation, building and testing of truss bridges (common semester project).

The second performance indicator (*Develop in-depth understanding of subject matter*) is the result of both sequencing and pedagogic activities, and can be assessed with standard assessment tools such as homework and tests (however emphasis is also placed on developing the conceptual understanding of the students). The approach followed here, in addition to the traditional means of projects, exams and homework, is based on techniques such as flipping the classroom, peer instruction, concept based learning, problem based learning and experiential activities, and can be assessed with the help of existing Concept Inventories, such as the Force Concept Inventory, the Statics Concept Inventory, and more. This assessment process, combined with similar or equal examinations than those administered in the context of traditional courses at the main campus, also ensure *appropriate rigor*, which in turn is a performance indicator for Program Criterion 2 ("Allow seamless transition of the students into the Junior and Senior years at the Orono Campus").

The development and implementation of the student centered pedagogical methods requires an iterative approach. Continuous assessment of the effectiveness of the instruction and techniques is made, and courses revised based on these reviews. Examples of review based revisions may include expanding or reducing experiential components in function of the student achievements towards the LO's; areas where the students reflect difficulties will be enhanced with more or more extensive experiential modes, whereas areas that are well understood and that receive extensive treatment may receive an adjustment in exposure.

3. Conclusion

The development of an integrated curriculum at the University of Maine's Brunswick Engineering Program is following a structured approach, based on defining overarching curriculum criteria and developing associated performance indicators. The structure of the criteria invokes a two step curricular design approach; first a general curriculum is developed that incorporates and integrates all the necessary (and feasible) components, and then the delivery via student centered pedagogy in a multiple learning mode approach (theory, simulation, experimentation) is carried out in an evolutionary fashion, with continuous review and feedback loops. Two sets of performance indicators are defined; one in support of the curricular sequencing, and another in support of the student centered pedagogy. While they represent two distinct phases (the first can be viewed as being focused on the design phase of the curriculum, while the second focuses on the implementation), they are strongly interlinked, and both sets of PI's are being continuously assessed to be able to integrate appropriate revisions into the curriculum's evolution.

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