Curriculum Revision to Better Integrate Mechanical Engineering Science and Practice in the 2nd and 3rd Undergraduate Years

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Introduction

The mechanical engineering program at Michigan Tech has been engaged in a curriculum revision process since 2010. The implementation of the new curriculum will take place over three years, starting in Fall 2014. The revision recognizes that engineering work, engineering students, and educational methods are changing.

The program faculty considered recommendations from external entities, investigated innovative curricula at other institutions, and solicited input from departmental faculty and staff. The Engineer of 2020 will change job functions more frequently than engineers of the past, and thus the NAE cites practical intuition and agility as desired attributes.[1] A Carnegie Foundation report[2] finds that "the tradition of putting theory before practice…[allows] little opportunity for students to have the kind of deep learning experiences that mirror professional practice." Based on analysis of industry needs, two of the seven recommendations of the ASME 2030 task force are more practice-based engineering education and curricular flexibility.[3] Education researchers have identified a "valley of despair" in the 2nd and 3rd years.[4] Whereas students do project work in the first and fourth years, in the second and third years, many do not see the connection between course work and engineering work; as a result, both motivation and confidence decrease. Finally, engineering work today relies heavily on computational tools that are now widely available. The new tools can create more realistic models of complicated real systems. More consistent use of these tools throughout the curriculum can further strengthen student understanding of the fundamentals and allow them to address more complex problems.

New engineering programs, such as those at Olin College[5] and James Madison University[6], are taking a different approach to engineering education by challenging lower division students with complex open-ended problems and by infusing project work throughout the four-year curriculum. The large number of mechanical engineering students at Michigan Tech presents challenges to implementing more project-based courses, but size has advantages too: well equipped laboratories, a mature industry sponsored capstone design program, and diverse faculty expertise.

This paper will describe the process we followed to develop a new curriculum in addition to providing details about the new curriculum itself.

Curriculum Design Process

In Fall 2010 an ad-hoc Curriculum Revision Committee (CRC) was assembled. The CRC has had 8-10 members representing the various technical areas of the department. It has attempted to follow a structured design process in designing a new curriculum. Table 1 summarizes the process. The stages shown in Table 1 are roughly chronological, but the process was not as linear as it appears.

Table 1: Curriculum revision process

Design Process Stage	Activities
Identify the problem.	Review literature, seek input from industry partners, and consider first-hand experiences with students.
Identify desired attributes of graduates (such as critical thinker, ethical) and desired knowledge/skills of graduates (such as finite element analysis and communication).	Survey industry partners and department faculty.
Identify objectives and constraints.	CRC compiles.
Benchmark other curricula.	Review literature, explore university web sites, and invite seminar speakers.
Generate concepts for new curriculum.	CRC and department faculty and staff brainstorm.
Select concepts for new curriculum.	Departmental faculty and staff provide feedback on options; CRC creates draft proposal and seeks further feedback.
Design new courses: identify learning objectives.	CRC proposes learning objectives for four new practice-based courses; faculty and staff provide input with sticky notes in lounge, and at follow-up meeting with survey to rate importance of each objective.
Design new courses: identify learning assessments and learning activities.	Course coordinators and smaller groups are working on each course.
Develop implementation plan.	Small group of CRC members, administrators and student advisors are working on this.
Pilot test new course activities.	Takes place in Spring and Summer 2014.
Implement new courses; gather student feedback, assess, and improve.	Begins in Fall 2014.

The CRC faculty had numerous discussions about identifying the problem. Many drew on their first-hand experiences in advising capstone design and other student project teams. Most agreed that students have difficulty applying engineering knowledge and skills to real-world projects. The CRC also studied the literature about projected changes in engineering work and how current curricula may not adequately prepare graduates. One of the changes in engineering work is the heavy use of simulation tools.

In terms of design requirements, one of the objectives of the new curriculum is to produce graduates with desired attributes, knowledge, and skills. With industry and faculty input, we compiled a set of those. Other objectives included limits on the amount of faculty time needed to implement and sustain the new curriculum, higher student motivation, and ease of making future curriculum changes, among others. Constraints included meeting university and college course requirements, meeting ABET requirements, and accommodating a range of abilities of incoming students, among others.

Concept generation took place at various times in the process and in multiple venues. For example, at a meeting in Spring 2011, faculty and staff did an exercise of designing a curriculum that was guaranteed to fail in 10 years and subsequently to design one that would be wildly successful in 10 years.[7]

Concept selection also took place in an iterative way. A department meeting in spring 2012 focused on the questions of: where to introduce more application/practice; how to provide more opportunity for depth; how best to teach computer tools. With regard to the first question, faculty discussed the options of adding more projects to the core engineering science courses versus adding separate project courses to the curriculum. In the end, we selected the second option: it would not require that every course be taught in a different way and it would facilitate multi-disciplinary projects. For the second question, faculty considered the options of more electives versus a five-year BS/MS program. We chose the option of more electives: it aligned with the ASME Vision 2030 recommendations, and it was unclear that the BS/MS program would be attractive to a large percentage of our students. For the third question we considered the options of explicit instruction in ME courses versus independent study using widely available tutorials. Our selection was a hybrid. Some explicit instruction will be done in the course where a new tool is introduced. Faculty members agree that the tools need to be part of multiple courses so that students do not have time to forget what they have learned (as happened in the old curriculum). Refresher training will be the responsibility of the students. Later in the process, faculty voted on whether to add additional electives credits by dropping a Circuits course or an Economics course from the old curriculum. The faculty was strongly in favor of keeping both courses.

In terms of course design, the CRC considered the idea of a request for proposals (RFP) process. While there was some positive response to that approach, we recognized a need for significant coordination amongst the designs of each course. In the end, we identified course coordinators for each new course and small groups of overlapping faculty that would work on each.

Many logistical issues need to be worked out for the implementation of the new curriculum. Following the example of another engineering department at Michigan Tech, we will phase in the new curriculum over three years. New 2nd year courses will begin in the 2014-15 academic year. The old 2nd year courses will be taught for the last time in 2014-15 to catch students who failed a 2nd year course or went on co-op in the previous year. New 3rd year courses will begin in 2015-16. The old 3rd year courses will be taught for the last time in 2015-16. And new 4th year courses (additional elective offerings) will begin in 2016-17. Based on projections of the numbers of students in the old and new courses, we are determining numbers of sections to offer, the faculty and TA requirements, and the schedules of classrooms and lab spaces. Additional teaching resources are required for the first two transition years, and the department chair has made the commitment to meet those needs.

New course activities will be piloted in Spring and Summer 2014 using undergraduate students and graduate teaching assistants. The CRC is considering options for how to continue to receive student input during new course implementation. Things will not go perfectly, and it will be important to rapidly and regularly address problems as they arise.

Description of New Curriculum

Midway through the process, in 2012, the CRC adopted a vision for the curriculum revision. This helped us to communicate succinctly to others what we are trying to achieve.

- Employers will aggressively compete for our graduates, who have extensive **hands-on training in solving engineering problems**.
- Graduate programs will aggressively compete for our graduates, who, in addition to practical problem solving skills, have developed **expertise in a sub-specialty of mechanical engineering**.
- Students have a passion to solve problems that **make a difference in their communities**, and they take ownership of their learning.
- The curriculum enables faculty and students to engage in **cross-disciplinary projects** that strengthen critical, creative, and interdisciplinary thinking.
- Faculty are committed to doing whatever it takes—including pushing beyond boundaries, **working collaboratively**, adjusting course content and adopting **new teaching approaches**—to best realize the rest of the vision.

There was strong faculty desire that the curriculum provide more opportunity for practice and at the same time more opportunity for depth. What tradeoffs would need to be made to accomplish these two somewhat contradictory goals?

The new curriculum makes two major changes:

1. It introduces four new practice-based courses that replace four lab courses and a 3rd year design processes course. These are project-based courses that integrate a number of content threads in the second and third years: application of core course concepts; programming, modeling, and simulation; laboratory skills including instrumentation, measurement, data acquisition, data analysis and experiment design; structured design process; making and tinkering; communication.

2. It reduces the number of core courses and increases the number of technical electives.

Table 2 summarizes the change in the credit distribution. "Practice" in the old curriculum consisted of four laboratory courses (5 credits) and a junior level engineering design process course (3 credits). The new curriculum replaces these with a sequence of four courses that span the 2nd and 3rd years. In the ME core, the three course sequence of Dynamics, Vibrations, and Controls reduces to a two course sequence. Similarly, the three-course sequence of Thermodynamics, Fluids, and Heat Transfer reduces to a two-course sequence. The two-course sequence for mechanism design reduces to one course. Some of the material removed from the core courses will move to the practice courses while other material will move into elective courses. The higher number of elective credits permits students to take a sequence in a particular area and thus deepen expertise.

With respect to ABET requirements, the purpose of the new curriculum is to improve attainment of student outcomes and program educational objectives. The new curriculum adds one credit of engineering topics. The new practice-based courses are intended to improve student preparation for the senior capstone design course (which remains unchanged). Furthermore, the added emphasis on application of core mechanical engineering concepts to real-world problems should enhance student ability to work professionally in thermal and mechanical systems areas.

In terms of the classes taught within the ME department, ME core reduces from 61% of the ME course credits to 47%. ME practice plus capstone design increases from 22% to 26%. Technical electives (assuming all are taught within ME) increase from 17% to 27%.

Table 2: Credit distribution in the old and new curriculum

	Old Curriculum	New Curriculum
General Education	24	24
Economic Decision Analysis	3	3
Math and Science	31	31
1st Year Engineering	6	6
Circuits and Materials Science*	6	6
Capstone Design	4	4
Free Elective	3	3
ME Practice	**8**	**10**
ME Core	**33**	**26**
Technical Electives	**9**	**15**
Total	**127**	**128**

* One of the credits of the materials science course is categorized as science in the ABET accounting of credits.

Figure 1 shows the flowchart for the new curriculum. The first-year is (mostly) common for all engineering students. The sequence of four practice-based courses creates a spine connecting the first year engineering and capstone design courses. Pre-requisites on the practice-based courses link them to ME core courses, but flexibility in student scheduling was also a consideration when deciding on the pre-requisites.

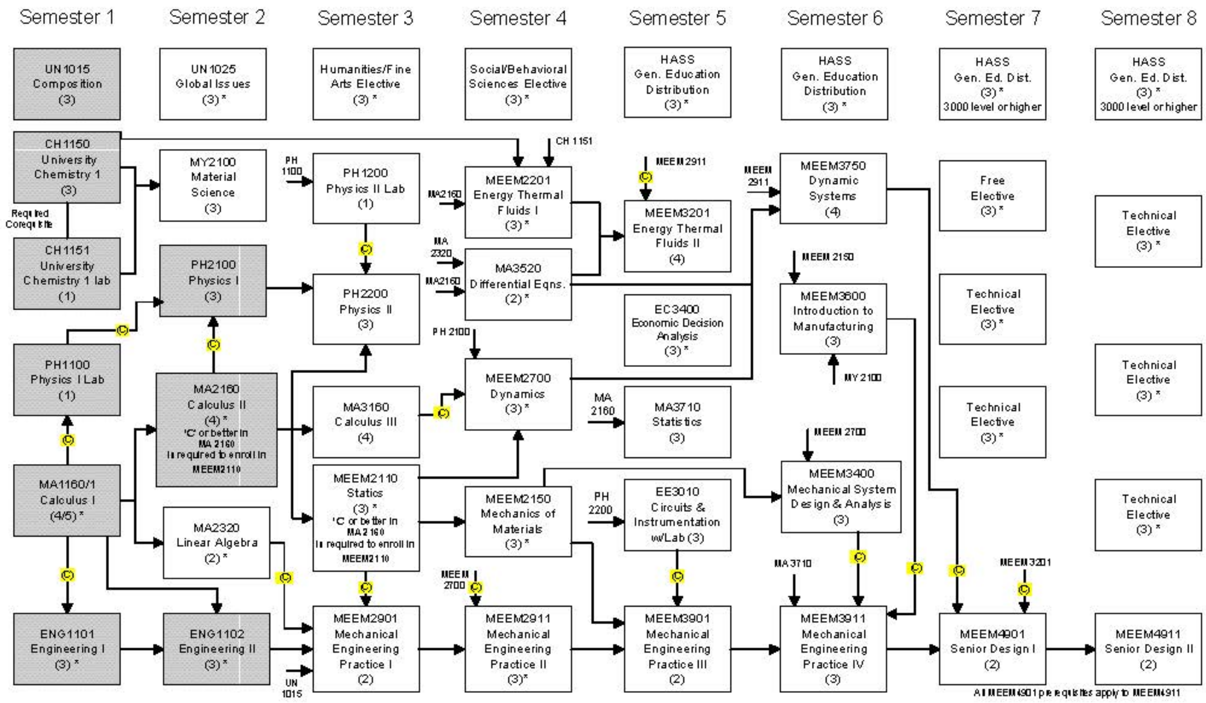

Figure 1: Flowchart for the new curriculum

Description of Practice-Based Courses

During the revision process, the CRC identified a number of threads of knowledge/skills that would comprise the four practice-based courses:

- Application of ME core concepts (thermal and fluid systems, design, manufacturing, solid mechanics, and dynamic systems)
- Programming, modeling and simulation
- Laboratory skills including instrumentation, measurement, data acquisition, data analysis, and experiment design
- Structured design process
- Making and tinkering
- Communication

The courses will incorporate some of the lab activities from the old curriculum, but they will include (especially in the later courses) more open-ended projects where students learn and work more independently. The courses will also teach the structured design processes (formerly taught in one junior level class), building on the introduction students receive in the first year engineering courses. The CRC identified learning objectives for all the threads and distributed them amongst the four courses. Table 3 shows samples of learning objectives for the four courses.

Table 3: Examples of learning objectives for the four ME practice (MEP) courses

Course	Sampling of learning objectives
MEP1	Create CAD models of parts and assemblies Select and use appropriate transducers Perform and analyze tension and bending tests
MEP2	Make measurements that relate to heat and work Perform and interpret finite element analysis simulations of trusses and frames Write effective technical reports individually and as a team
MEP3	Apply energy balance and First Law analysis to systems Identify mode shapes and natural frequencies from measured data Optimize component designs for a selected manufacturing process
MEP4	Implement open and closed loop control systems Troubleshoot electrical and mechanical dynamics and vibrations problems Apply design optimization techniques

To give a brief overview, in MEP1 students take things apart (reverse engineering), break things (material testing), and develop lab and computer skills. In MEP2, students make things, experiment with conversions between electrical, thermal, and mechanical energy, and learn the limitations of models. MEP3 focuses on synthesis, system design, and using evidence to make decisions. In MEP4, students diagnose, optimize, and innovate.

Core Course Revisions

One of the challenging aspects of the curriculum revision was reducing the number of ME core credits. Table 4 summarizes the changes and the content that was removed.

Table 4: Summary of changes to ME core courses

Old course sequence	New course sequence	Comments
Dynamics Mechanical Vibrations Dynamic Systems and Controls	Dynamics Dynamic Systems	Less time for review of pre-req material; some vibrations and controls content moves to technical electives.
Thermodynamics Fluid Mechanics Heat Transfer	Energy-Thermal-Fluids I Energy-Thermal-Fluids II	Some topics combined in new ways; some content moves to technical electives.
Product Realization I Product Realization II	Mechanical System Design and Analysis	Strengthen focus on synthesis and modeling; reduce focus on standard component design.

The two-course sequence of statics and mechanics of materials remains unchanged because these are also service courses to other engineering departments. A manufacturing processes course in the old curriculum will receive updating, move to later in the curriculum, and lose its associated lab (part of which is incorporated in the practice-based courses).

Electives Courses

Additional electives will be offered that will allow students to deepen their knowledge in different areas of mechanical engineering such as dynamic systems, thermal systems, solid mechanics and manufacturing.

Conclusions

Our new curriculum has been designed to address the changing engineering workplace, changing students, and changing educational methods. Four new practice-based courses will better engage students to put into practice the engineering concepts they are learning. Additional elective course opportunities will allow them to follow their passions. We are four years into the revision process, and full implementation will take another three years. It has been a slow process. Keys to maintaining the momentum have been an enthusiastic group of faculty on the CRC and strong support from the department chair. Future challenges include ensuring effective coordination amongst courses and involving additional faculty in the teaching of project-based courses.

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