



## Embedded Learning Modules for the Mechanical Engineering Curriculum

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# **Embedded Learning Modules for the Mechanical Engineering Curriculum**

## **Abstract**

This paper presents the details of a National Science Foundation (NSF) sponsored project to develop multimedia educational material to enhance the educational experience of undergraduate mechanical and manufacturing engineering majors. The project approach departed from the typical practice of developing supplementary instructional material for individual courses in favor of a scaffolded architecture which features scalable content for use in course groupings. Courses ranging from the sophomore to the senior level were arranged on thematic lines resulting in four groups or studios, namely: Materials, Thermo-Fluids, Design and Manufacturing, and Dynamics, Vibrations and Controls. For each group, learning modules that connect experimental methods with foundational course content have been developed. A fifth studio serves as a central library for tutorials and other supplementary informational materials on the use of various software packages that may be used in the aforementioned subject areas. In order to make the experience interactive, completion of the modules can entail usage of Java applets to explore experimental hypothesis, and worksheets to encourage in-depth learning of the content. The subject studios can facilitate undergraduate participation in research, enable lab based activities to be imbedded into lecture only classes, and create opportunities for independent learning and inquiry for students. This two year project has also featured the development of assessment instruments for longitudinally tracking the progress of students and making continuous improvements to the modules. Highlights of this data along with a summary of the incremental changes to the modules will be presented.

## **Introduction**

Reflection on the educational landscape in the US has become an increasingly common subject of political and household discussion as economic constraints call into question the value and return on investment provided by higher education. While scrutinizing higher education which has been central to the cultural and technological advancement of civilization solely on a monetary basis might seem irreverent or myopic, the vigorous ongoing debate on education has undeniably spurred action and innovation. The creation of new educational technologies in response to emerging societal changes is not surprising in that higher education plays a supporting role in the preparation of talent and knowledge which is central to scientific innovation. Therefore, higher education, in turn, cannot adopt a reactive posture and must

always seek innovation within itself through the content and style of instruction with which it reaches out to newer generations. The creation of the computational and experimental (ComEx) studios is a good example of an innovative learning assistance tool developed to ensure that the mechanical engineering curriculum provides a flexible and enduring preparation for their professional aspirations. A burgeoning need for improvement in the quality and number of STEM discipline graduates was again recently identified by the President's Council on Jobs and Competitiveness<sup>1</sup>. Projects such as ComEx which can be disseminated to other institutes is a good example of an instrument prepared under the auspices of the National Science Foundation (NSF) and contributing to the national goal of enhancing science education.

The ComEx studios were conceived with the intent of creating an augmentative instructional modality associated not only with discrete courses, but also to establish longitudinal progression of content. This characteristic distinguishes them from other initiatives such as massive online open courses (MOOCs) and discrete online learning modules. The former is worth commenting on briefly because it too is a product of innovation, or perhaps evolution, in education but founded on rather different instructional ideologies. MOOCs, which are complete courses available online, reflect tremendous advancements in the packaging of instructional materials in a form intended to achieve the original course outcomes typically facilitated by discussion forum based interaction with an instructor. Given the rapid pace of their development, issues associated with timely completion, cheating<sup>2</sup>, and overall effectiveness<sup>3</sup> are surfacing and data is being collected to devise solutions. However, universities are keen to include them in their instructional technology portfolios prompted perhaps by guarded optimism<sup>4</sup> to be at the forefront of the new educational culture. As the MOOC phenomenon moves towards maturity, the concurrent approach within the Department of Mechanical and Manufacturing Engineering was to assemble learning technologies and techniques that modernize the entire MME curriculum and deploy them in an appealing and contemporary package.

The ComEx project is imbedded within the MME curriculum. That is to say, unlike the preponderance of simulation and/or experiment based online learning modules that have been developed for specific courses<sup>5-8</sup>, whether they be in chemical, electrical, mechanical or manufacturing engineering, the ComEx studios focus on a set of thematically linked courses. The students utilize the modules as they advance through the MME curriculum. This attribute of the studios preserves continuity in content and operation within reasonably familiar environment.

The online learning modules within each ComEx studio have a synergistic experimental and computational architecture. Each module highlights experimental processes in four subject areas by adopting various multimedia techniques and engages students in an investigation of the emerging data through the application of simulation techniques involving various mathematical packages. Diverse assessment instruments designed to enable continuous improvement of the

material were deployed in tandem with the modules. Details of the modules and assessment tools are presented in the following section.

## ComEx Studios

### Inception

The impetus for the ComEx project materialized from the findings of a departmental level student assessment of competency in the application of numerical methods in engineering problems. And since simulations methods are being increasingly adopted in the analysis of systems ranging from advanced fabrics for use in diapers to control of flight surfaces in unmanned aerial vehicles, the development of skills necessary to understand a given system, select an appropriate numerical method, and perform the necessary analysis was given high priority. The ComEx studios are the vehicle for achieving this objective. Figure 1 illustrates the course sequence for students in the MME program.

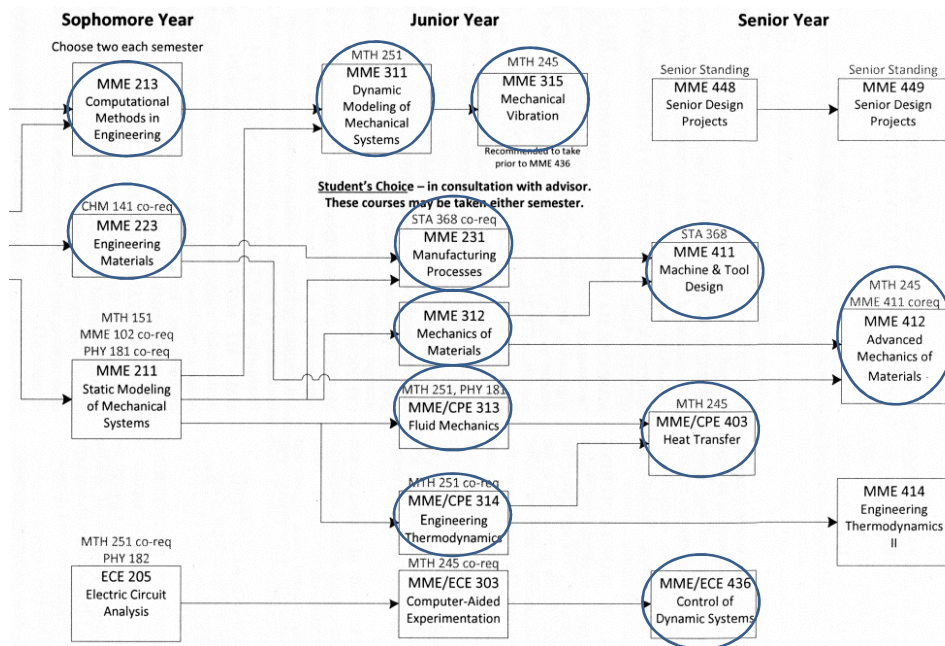


Figure 1. Diagram of the required MME courses. Circled courses have been included in the ComEx studios.

The selection of the courses with which ComEx studios would be associated was guided by the following criteria:

- 1) The learning modules would be used by all students in the program.
- 2) The nature of the course should present opportunities for an experimental-simulation analysis approach to problem solving.
- 3) Courses would be selected based on their content featuring some common characteristics and then grouped into one of four categories (Fluids and Thermodynamics, Materials,

Dynamics and Vibrations, and Manufacturing and Design). This arrangement is shown in Fig. 2.

The grouping of the courses shown in Fig. 2 also enables a scaffolding of assignments. This means that instructors can select complete or portions of learning modules to be completed in sequence by the students with continuation of content and nature of analysis. For example, the experimental data available in the Materials studio can be used in basic stress-strain curve based analysis (sophomore level materials science course), additional portions will allow tension-torsion analysis (junior level mechanics of materials course), and finally strain gage based data is to be used in analysis of structures (senior level advanced mechanics of materials).

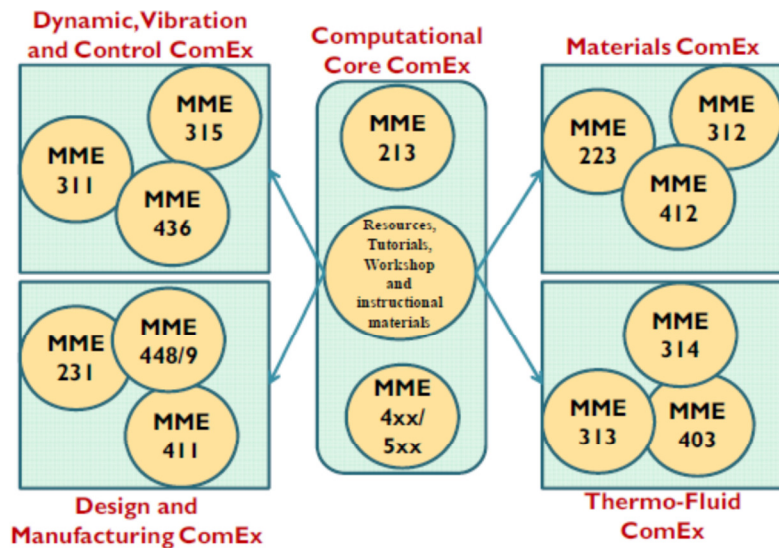


Figure 2. Illustration of the courses identified in Fig. 1 and grouped along thematic lines into five studios. MME213-Computational Methods in Engineering, MME223-Engineering Materials, MME231-Manufacturing Processes, MME311-Dynamics, MME312-Mechanics of Materials, MME313-Fluid Dynamics, MME314-Engineering Thermodynamics I, MME315-Mechanical Vibrations, MME403-Heat Transfer, MME411-Machine and Tool Design, MME412-Advanced Mechanics of Materials and MME448/449-Senior Capstone Design.

Furthermore, as the value of an undergraduate research experience is becoming more evident in the creation of a workforce able to adapt, demonstrate initiative, be creative and accomplish tasks independently, the creation of a fifth studio to provide access to tutorials encompassing a broad range of topics was considered imperative for supporting students starting research projects, as well as to provide a central resource library to the four subject studios. Content within each studio has been packaged in the form of learning modules. Harnack et al<sup>9</sup> have provided a detailed account of the structure, use and assessment of similarly designed modules for use in finite element modeling with very favorable outcomes. All of the learning modules are accessible through a central website, and an image of the home page is shown as Fig. 3.

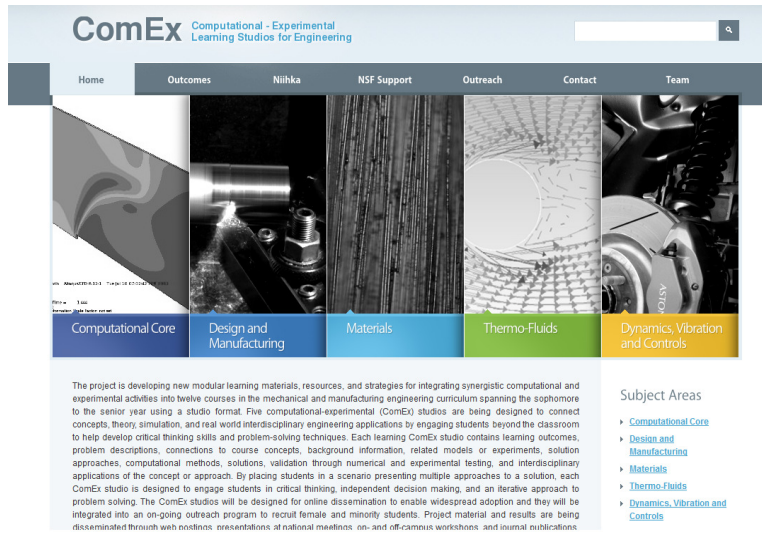


Figure 3. Image of the layout of the various components on the ComEx website.

## Format and Utilization

Allowing for instructor preferences and utilizing methods best suited to the individual subject areas, the approach has been to adopt a consistent format for the learning modules housed within each of the studios. In each module, students are provided a brief introduction and the educational outcomes the activities are intended to achieve. This is followed by an in-depth discussion of the topic. To maintain reader interest, short text sections have been complemented by the use of clickable photo galleries, demonstration videos of original experiments developed with student assistance, and interactive Java based applets. These are followed by worksheet based assignments which draw upon supplied experimental data. The worksheets serve instructional and assessment purposes by having the students apply their understanding of the material to realistic problems and by enabling the instructor to gauge this level of understanding by evaluating their performance.

The intent behind the provision of the experimental data was to allow the students to:

- assimilate new information
- understand how a physical system can be mathematically represented
- investigate the effect of changing specific parameters
- model an actual system/material using the supplied data
- enable instructors to utilize the data for additional analyses, or expand the scope of the module by including additional data sets.

The modules have been used in several classes. For example in the sophomore level Engineering Materials class (MME-223) the module on the fabrication and testing of composite materials was introduced to supplement course material on polymers. This is a very relevant topic with increasing industrial use of composites and also interest by the SAE Baja team in the fabrication process and structure of composites for use in their vehicle body panels. The module

was assigned as a two hour lab activity. The students utilized supplied experimental data to demonstrate their understanding of how the mechanical properties and relative composition of the constituents contributed to the properties of the composite. Students submitted their assignments as short reports organized into three sections: Introduction, Data Analysis, and Response to Questions. The accompanying worksheet can be easily changed by the instructor to alter the assignment requirements.

Another example of the utilization of the learning modules, but in a course not featuring a lab section, was in the case of Mechanical Vibrations (MME-315). The modules were designed to introduce students to the basic concepts of vibration analysis and tie analytical concepts to experimental results presented throughout the modules. The students are expected to utilize experimental data in identifying the properties of vibrating structures,(based on time domain and frequency domain signals) and eventually in designing control mechanism and isolators for vibration suppression. The students build computational models of the systems presented through experimentation and are able to compare the results. The material is presented in the context of a case study on understanding the ball striking performance of a baseball bat from modal analysis. Details of this module were presented in a separate study.

### **Assessment**

Developed and implemented over a two year timeline, the first set of learning modules were deployed at the end of the first year in three courses: Introduction to Engineering Materials, Fluids I and Vibrations. Online surveys were created for completion by students and four external faculty. The latter were invited to participate in the project based on their expertise in educational research and prior work on NSF Course, Curriculum, and Laboratory Improvement (CCLI) and Transforming Undergraduate Education in Science (TUES) projects.

The ComEx Student Survey was co-developed by ComEx project personnel and the E&A Center and administered online. This instrument consisted of three subscales with a total of 29 items designed to obtain information about students' experiences in using the ComEx Studios. The "Effectiveness of the ComEx Exercise/Activities" subscale consisted of nine items on a 5-point Likert-type scale ranging from strongly disagree (1) to strongly agree (5). The "Usefulness of the Components of the ComEx Activities" subscale asked students to respond to 12 items on a 3-point rating scale ranging from not at all useful (1) to very useful (3). The not applicable option was also provided to the respondents for this subscale. The "Quality of the ComEx Activities" subscale consisted of eight items on 3-point rating scales ranging from not clear (1) to very clear (3), not detailed (1) to very detailed (3), too little guidance (1) to too much guidance (3), too little work (1) to too much work (3), or not applicable (1) to very applicable (3). Each rating-scale item in this subscale was immediately followed by an open-response item asking students to further explain their choice. Samples of data from the student and external evaluator surveys are shown in Fig. 4 and Table 1 respectively.

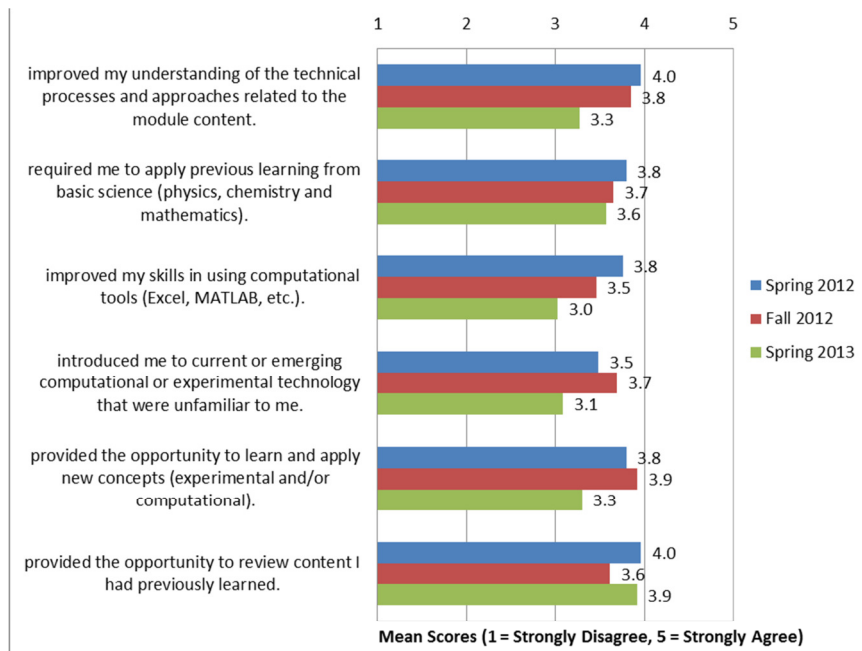


Figure 4. Sample of survey data from the ‘Characterization of the Properties of Composites’ learning module attached with MME223-Engineering Materials.

Between Spring 2012 and Spring 2013, 284 engineering students responded to this questionnaire after completing the ComEx Studio activities. Among them, 124 students were from the Engineering Materials course (55 in Spring 2012, 31 in Fall 2012, and 38 in Spring 2013). The majority of students in this course were white (82%), male (76%), sophomore (56%), and were Chemical Engineering (37%) or Mechanical Engineering (37%) majors.

The first round of assessment was conducted after the pilot rollout of the modules in Fall 2012, and evidence of closing the assessment loop can be seen in the changes that have so far been implemented. These include:

- 1) The preparation of pre and post module completion questionnaires for the students. This process was introduced to complement the existing self-assessment data and identify the specific knowledge and skills attained by the students.
- 2) The inclusion of interactive Java applets to create a more interactive experience and allow for immediate hypothesis testing.
- 3) Various modifications to the presentation of the content for a more streamlined browsing experience.

Cumulative data to the end of the Fall 2013 semester will be presented at the conference.



Table 1. External Evaluators' responses to the *External Expert Review Survey*

The ComEx exercises/activities ...	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
will improve students' understanding of the technical processes and approaches related to the module content.	0	0	0	2	1
require students to apply previous learning from other engineering courses	0	0	0	1	2
will improve students' skills in using computational tools (Finite element software, Excel, MATLAB, etc.).	0	0	0	1	2
introduce students to current or emerging computational or experimental technology that were unfamiliar to them.	0	0	1	0	2
strengthen students' interest in the content of this module.	0	0	1	1	1
provide access to the learning modules within the institution and enable utilization by other institutions	0	0	0	3	0

## Conclusions

The development of online learning modules in four subject areas and one in core computational exercises has been undertaken by the PIs. These modules can be used as an additional resource to complement methods and content introduced in class, or to append a new topic to a course. In the latter instance, the modules also serve the purpose of encouraging independent learning by the students. Module content within each subject studio is designed to be scalable to more advanced classes to establish continuity in content. The online nature of the content makes it readily available for use by other institutes and dissemination efforts will be made for the upcoming semesters. A second comprehensive assessment cycle is to be completed at the end of the second year. Current data from faculty reviewers and students has indicated that the content and format of the modules has been very conducive to the learning of new concepts. Likewise, the faculty of the concerned courses have expressed a very positive impression of the usefulness of the ComEx studios, which have also facilitated student participation in research through developmental activities and usage, the Core ComEx in particular, in the preparation for specific simulation tasks.

## Acknowledgments

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