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Curricular Improvements Through Computation and Experiment Based Learning Modules

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ABSTRACT

Engineers often need to predict how a part, mechanism or machine will perform in service, and this insight is typically achieved thorough computer simulations. Therefore, instruction in the creation and application of simulation models is essential for aspiring engineers. The purpose of this project was to develop a unified approach to teaching computational analysis and model validation against experimental response. The design of the project entailed the creation of a set of innovative computational-experimental studios, each of which houses at least two learning modules. Various assignments have been imbedded to engage students. Assessment instruments for use by students and external faculty reviewers were implemented. The studios have contributed to the development of proficiencies in using mathematical software to create models and test their output against experimental data. The studios have expanded the scope of topics covered in courses, created independent learning opportunities and enabled the creation of multimedia content available to other institutes.

Key Words: engineering curriculum, simulations methods, learning modules

INTRODUCTION

Engineering is a very dynamic field. This raises several challenges for schools committed to providing their students an engineering experience that is both modern and robust. The programs of study must adequately prepare students for careers that involve new technologies and, perhaps more importantly, impart skills that allow students to assimilate new information effectively and independently. Interweaving these new objectives into the core science and engineering concepts can lead to swelling course content as faculty struggle to revamp their syllabi. This project was conceived with the purpose of creating a tool by which schools could introduce meaningful changes to engineering curricula, vis-à-vis content and style of instruction, in an efficient and progressive manner. Its realization has entailed the development and systematic implementation of learning modules housed within five online Com-Ex (computational-experimental) studios.

Too often subject areas in engineering are perceived as discrete islands of knowledge, for example, a course on fluid dynamics is seen to have little in common with mechanics of materials which may be taken the following semester. Content confinement it is not merely a matter of perception, but rather a corollary of the structure of traditional engineering curricula which attempt to concurrently impart familiarization in multiple fields – adopting a discrete and not collective approach. The CoMEx project is based on a more all-inclusive approach of grouping courses along thematic lines to highlight any continuity of content. This has, naturally, required the participation of multiple faculty, but the outcomes have produced meaningful changes at the course and curriculum level.

The first step in creating a more unified curriculum in the Department of Mechanical and Manufacturing Engineering (MME) began with the identification of an area of activity which featured prominently in several courses. *Computational modeling and experimentation was selected as the centerpiece for this curriculum enhancement initiative*. The decision emerged from the findings of a departmental survey conducted in association with the Miami University Center for Enhancement of Learning and Teaching. The survey targeted sophomore through senior level students in six required engineering courses in MME. The survey was designed to primarily assess, i) a student's ability to recognize engineering problems best addressed by modeling and numerical methods, ii) familiarity with computer aided engineering tools for analysis, and iii) the use of numerical techniques in validating and predicting performance of materials/parts/systems. Rather than a self-assessment format, the questionnaire posed specific engineering problems. The results, as shown in Khan et. al. (2010), revealed that student preparation in this area deserved attention and a curriculum level change which specifically featured enhanced utilization of computational techniques was considered. Given the transformation of manufacturing across myriad sectors to include more advanced and accelerated product and process development, a renewed emphasis on numerical techniques was endorsed by the department's Advisory Council. This provided additional motivation for the ComEx project. A similar, albeit on a smaller scale, study was undertaken by Heckler and Rosenblatt (2011) to analyze the instructional dynamics and content of a course in engineering materials. Their data was useful in the design of instructional material to facilitate a more flexible understanding of the course content. Within the umbrella of computational-experimental based activities, the next challenge addressed was the creation of suitable content with different subject areas and a delivery platform that created an engaging experience for students.

The use of online tools to augment traditional learning modalities such as lectures, student presentations, hands-on labs and peer reviews both in and outside the classroom has been growing steadily in the field of engineering science. Visualization of a physical system such as a bridge or a cross-bow with superposed (force) vectors to enable understanding of their operation has been presented by Deliktas (2011), and is a good example of the preparation and adoption of online learning aids. A study by Koe et al. (2010) in which 3-D simulations of manufacturing processes were introduced to complement the lab activities found that the new material not only facilitated learning machining operations, but also improved motivation. A similar use of animated solid models, but in the area of hydroelectric energy, yielded strong evidence of enhanced understanding being linked to the quality of the visualizations, see De Sousa et al. (2012). It is pertinent to add that preexisting course material may not transfer efficiently to a new online environment, and, therefore, nuances pertaining to the packaging and delivery of online content are just as important as the academic rigor of the new assignments. This conclusion is supported by survey data gathered by Tare and Bennett (2008) who found that while students believed online tools were effective, in part due to the immediate feedback and ability to repeat modules until an agreeable score was achieved, there was a perception that online learning was not efficient perhaps because of the need for precise syntax and the requirement that responses to all answers be correct to receive full credit. The ComEx module's worksheets require written responses, thereby eschewing the latter concern.

It is imperative that the online experience be designed such that it affords opportunities to investigate possibilities beyond those presented for consideration by the instructor and/or accompanying set of directions. One of the key attributes of any new simulation based learning aid must be that it engages the student by providing options for exploring how specific process/material/environmental parameters can affect the results generated by the simulation program/tool. This characteristic has been researched by Taraban et al. (2007) who showed "students expressed significantly more cognitive activity on computer screens requiring interaction compared to text-based screens." Fraser et al. (2007) prepared three simulations in the area of fluid dynamics using Visual Basic programming and Excel. These simulation tools provided students the ability to vary a set of parameters to observe the ensuing changes to the simulation output. One of the primary vehicles for providing convenient user interaction with simulation programs or tools is the graphical user interface (GUI). A few examples highlighting the variety of engineering areas for which MatLab Simulink based GUIs have been developed include: autocorrelation and noise concepts by Dolecek (2011), chemical engineering process control by Ali and Idriss (2010), study of dynamical systems with broad graphical output options by Llado and Sanchez (2011), and controls and robotics by Aliane (2010). Enhanced student interaction with course material can also be achieved by computer based simulation used to create virtual labs. Examples include a tensile testing experiment, Goeser et al. (2011), in which test parameters and materials can be chosen by students; remote robot programming and control, Wu and Wu (2008); remote robot operation in mechatronics reported by Shyr (2009); and multiple experiments in mechanics and vibrations, Aziz et al. (2009). While several of the reported studies have included some form of assessment which has provided useful data on the efficacy of these approaches, Streveler et al (2012) conclude “While enjoying the opportunity of learning the content at their own pace, most students would prefer the immediate clarifications and explanations offered by an instructor during a learning process.” Accordingly, most of the ComEx learning modules have been designed for use as supporting class material and can be assigned for completion in a lab type setting with faculty or graduate student/teaching assistant oversight to stimulate discussion and exploration of model parameter through the simulation tools, while preserving the ability to assimilate information at one’s own pace.

The following section of the paper, titled Project Description, provides details of the organization of the instructional material and how it has been grafted into the curriculum. Since each subject studio, or even the individual learning modules, can be adopted independently by faculty at other institutions and may provide ideas for the creation of similar tools, details of the structure, composition and utilization of a typical module have been included. This is followed by an analysis of assessment data collected from four semesters. The paper concludes with a discussion of future tasks and conclusions derived from this project.

PROJECT DESCRIPTION

The ongoing ComEx project is curriculum wide, and features learning modules in several areas, which are highlighted in the following section. The learning modules are also distinct in their form and function when compared to some of the examples cited in the Introduction because they are designed for vertical integration of content within a common thematic area. For example, the materials module described in this paper is scalable such that the content can be used in conjunction with a 200, 300, and 400 level (sophomore, junior and senior) course in materials science and/or mechanics of materials. Three characteristics differentiate the learning modules developed for the ComEx project from the aforementioned studies: scope, format, and the installation of a research element.

Scope: Scalable learning modules have been developed in five areas which represent thematic course groupings: i) Dynamics, Vibrations and Controls, ii) Design and Manufacturing, iii) Computational Core, iv) Materials, and v) Thermo-Fluids. Details are presented in the following section. The aim is to not only aid student learning within a particular course, but also demonstrate the longitudinal progression of knowledge, for example the two modules in the Material studio demonstrate how concepts from materials science (sophomore level course) are applied in mechanical analysis of structures (junior level course), and collectively lead to three dimensional analysis of stress states (senior level advanced mechanics of materials course). This attribute of the learning modules enables them to be described as being scalable. Furthermore, faculty can create additional modules within each studio to suit their program requirements. Some of these modules also facilitate experiential learning in traditionally lecture based courses (for example mechanical vibration, mechanics of materials and design courses in our department) through experimental demonstration, data analysis and validation studies.

Format: The presentation of the activities and assignments within each of the studios varies as well. In addition to introducing computer simulation techniques, the learning modules provide data from a host of related videotaped experiments. Data selection and analysis must be undertaken by the students. Details of the studios are provided in the following section along with a discussion of the Materials Studio. This is followed by a discussion of the imbedded assessment process and data gathered from two semesters.

Research derived content: A notable characteristic of each learning module is that the content draws upon faculty research and teaching interests. While faculty that are active in scientific and pedagogical research can create learning opportunities that contribute towards a broader educational experience for students, this process is not without its limitations. For example, undergraduate research positions may be very limited, thus precluding a large number of students from engaging in research based experiential learning opportunities. Furthermore, packaging a research derived problem for easy use in a classroom setting may pose challenges associated with the use of multimedia and development of web based content.

It is envisioned that creation of the learning modules is expected to benefit the engineering curriculum by:

- Creating a forum for engaging all students in a class.
- Leveraging multimedia resources to achieve active participation.
- Enabling students to recognize the continuity in content among certain courses.
- Providing evidence of demonstrable and meaningful changes in the attainment of program outcomes through well-structured and regular assessment measures.
- Supporting faculty in research and in the development of material for sprint courses and workshops.

In the following sub-section, specific details of the content and the nature of the assignments completed by students in presented. This is followed by a discussion of the links between the modules, and how they can be completed as a part of a course.

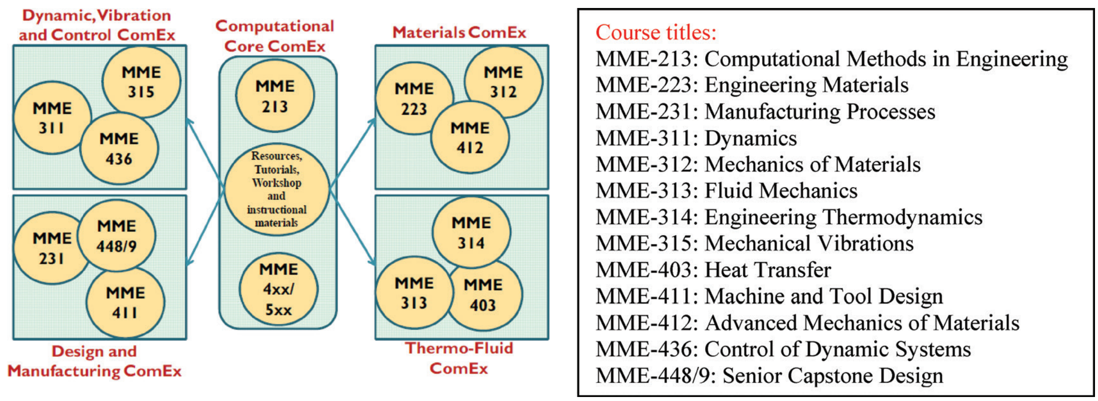

Figure 1. Illustration of course grouping within the ComEx studios. 4xx/5xx denotes a possible future course, for example one in the area of finite element analysis, created for the Core ComEx. Circle overlap is symbolic of shared concepts among courses.

Module Architecture

The course groupings within the five ComEx areas (i. Dynamics, Vibrations and Controls, ii. Design and Manufacturing, iii. Computational Core, iv. Materials and v. Thermo-Fluids) are illustrated in Figure 1. The Computational Core studio does not represent a unique subject area. Rather, it has been conceived as a central repository for tutorials and multimedia instructional material on various software packages and examples that may be used to facilitate completion of the computational facets of the other four studios. The careful selection of tutorials, for example on the use of Maple or Matlab, for solving differential equations, based on a consideration of assignments in various courses enables faculty to recommend their study and trial use towards the solution of problems. This practice not only reduces the utilization of lab or class time to introduce computational techniques, but also requires students to undertake independent learning. The latter point is particularly important because in rapidly advancing and competitive work environments in which graduates might make several job transitions, the ability to confidently assimilate new information through continuous learning is vital, and can be effectively instilled through the undergraduate educational programs.

The rationale behind the creation four subject domains stemmed from the desire to group courses so that synergies could be created through progression of content and depth of experimental-computational analysis. This has been explained in the final paragraphs of the Introduction and in the preceding section. Each of the four *subject* studios are comprised of at least two learning modules. The structure of each learning module is based on the computational modeling of a given experimental system. The provision of multiple experimental data sets for use in the completion of computational and experimental exercises was given particular emphasis. The intent is to present problem scenarios in which the selection of the relevant data sets is at the discretion of the student and not narrowly prescribed in the instructions. This has been done to emulate professional situations in which an employee/researcher must decide on the nature of testing required to ascertain the specific properties of interest. The provision of tutorials on more than one mathematical package also extends similar latitude to the students in the context of the computational analysis. Details of the Materials studio are provided in this paper to elaborate how the learning objectives and the need to append lab derived activities to non-lab based courses has guided the design and preparation of the learning modules.

In order to ensure that the modules deliver the same educational outcomes when used at other institutions, a topic centered introduction to the concepts is provided in each module before the student worksheet. The specific topic and activities of each module were conceived by faculty and graduate student teams for each of the four subject areas. This was done so that faculty could augment course content with ongoing research derived applications and create demonstrational videos and experimental data/content using their lab facilities. For example, the Materials Testing learning module, explained later in this paper, was created by the faculty typically assigned to teach Engineering Materials (MME223) and MME312 (Mechanics of Materials) in collaboration with the faculty for MME412 (Advanced Mechanics of Materials), see Figure 1. This was done to ensure that there was a direct understanding of the course content and, thus, an accurate targeting of the areas most effectively bolstered through the use of the ComEx modules. The ability of this resource to expand the sphere of discussion, demonstration, and engagement with students by adding a research derived perspective has been favorably received by the faculty and external reviewers who have used the modules.

Learning Module: Content and Deliverables

The first learning module in the Materials Studio is aimed at the characterization of the mechanical properties of composite materials. This module has been assigned four times in the sophomore level Engineering Materials class, which has a small lab component (six labs per semester). While basic polymeric materials are covered in class, the properties of carbon and glass fiber composites, while being quite relevant to the production of several high performance products such as bicycles and wind turbines, represents a specialized area difficult to incorporate into the course. However, the experimental techniques that can be applied to the determination of the properties of composite materials are covered in a regular lab, and data from such testing on samples is provided in the data library. This learning module contributes new content to the course and requires students to leverage their understanding of basic stress-strain curve based materials property analysis to characterize the deformation of a new material. The format of the module is briefly described here and can be viewed fully at http://comex.csi.miamioh.edu/.

Introduction: This section begins with a brief enumeration of the learning outcomes and presents an overview of the subject area relying specifically on aerospace application of composite materials. Illustrations of fuselage sections of the new Boeing 787 are presented to highlight the relevance of the subject area.

Experimentation: Since the modules adopt an online format, a concerted effort has been made to make any presentation of experimental components as interesting as possible. To that end, all steps associated with the preparation of composites and their testing have been presented in detail using pop-up photo galleries and a video. The video, edited into three sections, describes the testing program, instrumentation, and execution of a tensile test. The demonstrated tests have been used to gather the data supplied as a part of the module.

Computational Approach: In an effort to demonstrate how computational methods can be used to validate and predict deformation behavior, recalling that this is the theme of the ComEx project, the module then explores the question of how analytical solutions compare to the experimental findings. To achieve this, the basic theory of the elastic response of composites using the Rule of Mixtures is presented, and students must decide how the required material parameters are to be extracted from the experimental data. A Java applet has been prepared that enables students to explore the effects of changing the moduli (fiber or matrix) and volume fraction on the modulus of a composite.

Analysis: A worksheet is included in the module and is designed to encourage critical thinking by tasking students with an estimate of the accuracy of the analytical approach (application of the Rule of Mixtures) by comparison against experimental data, which is presented as a library. Selection of the relevant data, processing and plotting, and determination of key material parameters precedes the juxtaposition of the experimental and simulation data.

The presentation of these components is illustrated in Figure 2. The module is assigned as a small project to be completed independently. Students upload the completed worksheet showing their analysis accompanied by three Excel files demonstrating the methods used to calculate the material parameters.

Links Between Modules

Layered content has been deliberately incorporated into the learning modules to achieve vertical integration of the learning outcomes. For example, material from the existing composites module will be augmented by data from tension torsion experiments on cylindrical specimen designed to

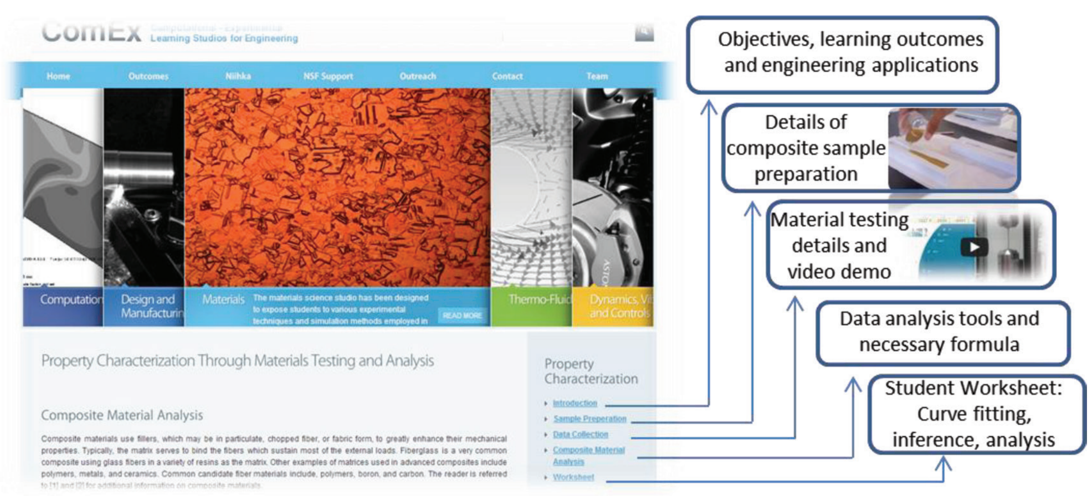

Figure 2. Illustration of key sections of the materials learning module. All ComEx modules share this basic design.

highlight some of the concepts in MME-312, Mechanics of Materials, which is the second course in the Materials ComEx, see Figure 1. Composites with more complex fiber orientation and measurement of strain at various angles will be featured in upcoming modules attached to MME-412, Advanced Mechanics of Materials. Comparison of the data with finite element analysis will also increase the sophistication of the computational techniques used by the students. This progressive content utilization is illustrated in Figure 3.

Utilization

The ComEx learning modules can be completed as a guided lab activity by an instructor or teaching assistant, assigned as a take-home lab or individual homework assignment, used as a training resource, or integrated into material for an online course. This flexibility is particularly important for large class settings. While the assessment data in the following section will reveal relatively smaller class sizes at the host school, ComEx modules have been used in faculty guided lab sessions (modules on vibrations) as well as in homework form (modules on composite materials) with good results. Therefore, instructors are at liberty do decide how the modules will be deployed best given their staffing, enrollment, facilities and syllabi constraints.

With the increasing rollout of online courses at various institutions, the ComEx modules are well suited for instructional and assessment tasks. Since each module explains the underlying theory and analysis in the context of the included problem scenario, students are provided an additional

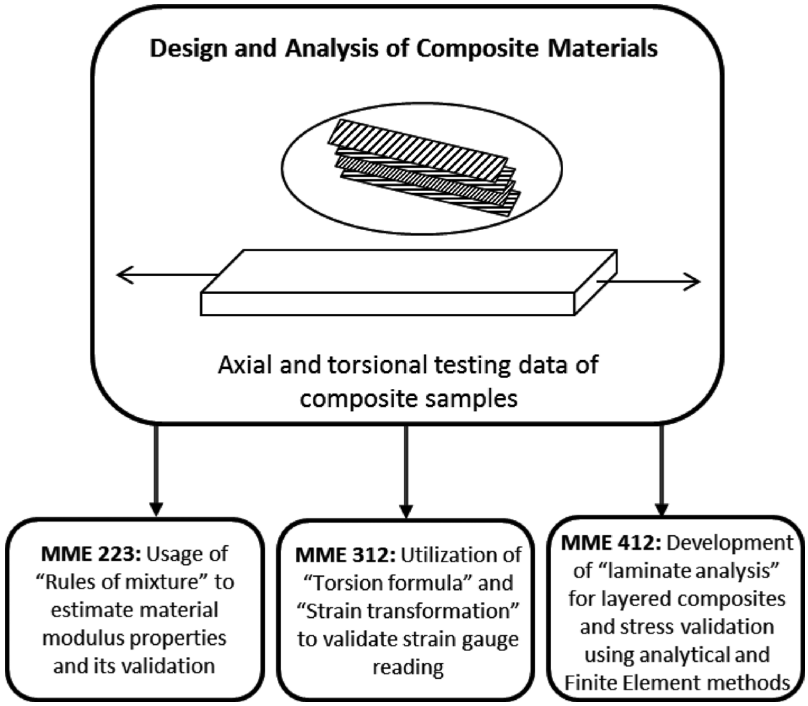

Figure 3. Illustration of progressive content utilization in the learning modules across multiple courses.

exposure to fundamental concepts. Completion and submission of the accompanying worksheet is meant to gauge the level of understanding of the material.

ASSESSMENT

The *Miami University ComEx Student Survey* was co-developed by ComEx project personnel and Ohio's Evaluation and Assessment Center and was administered to participating students online. This instrument consisted of three subscales with a total of 29 items designed to obtain information about students' experiences using the ComEx Studios in three categories. 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 also was provided for this subscale. Questions in the third category, "Quality of the ComEx Activities," 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. This questionnaire was designed to be completed online, and while user anonymity was maintained, the use of alias logins enabled the collection of data from individual users as they progressed through the modules. Results from four semesters for a learning module in the Materials studio are presented here.

Student Evaluation

All students in the Engineering Materials class were asked to complete a short online survey form. It poses questions regarding the format and content of the module(s). Table 1 provides data on the number and majors of the students completing the modules. Figures 4a-4c illustrate the data from four semesters of assigning the Property Characterization Through Tensile Testing learning module to students enrolled in MME-223 (Engineering Materials). The assignment was designated either as a Special Assignment/Homework which carried a higher points weight than regular assignments, or as a take-home lab. One-way ANOVA was conducted using SPSS 21.0 to show the differences in the responses of students in the MME 223 course across four semesters (Spring 2012 to Fall 2013). Significant findings from the survey data showed that the majority of MME 223 students agreed that ComEx exercises/activities improved their understanding of course content and facilitated integration of knowledge across disciplines.

Overall, MME 223 students in Spring 2012, see Figure 4a, had the most favorable perceptions of the benefit of the ComEx exercises/activities (subscale M = 3.79), while students in the Spring 2013

Major	Spr. 2012	Fall 2012	Spr. 2013	Fall 2013
Chemical Engineering	8	3	3	0
Engineering Management, Manufacturing Engineering[1]	7	5	4	2
General Engineering	2	1	2	0
Manufacturing Engineering	3	4	0	2
Mechanical Engineering	35	18	28	23
Criminal Justice	0	0	0	1
Total	55	31	37	28

[1]Specialization in manufacturing engineering.

Table 1. Representation of various majors in 200-materials course in which the tensile testing of composite materials module was assigned.

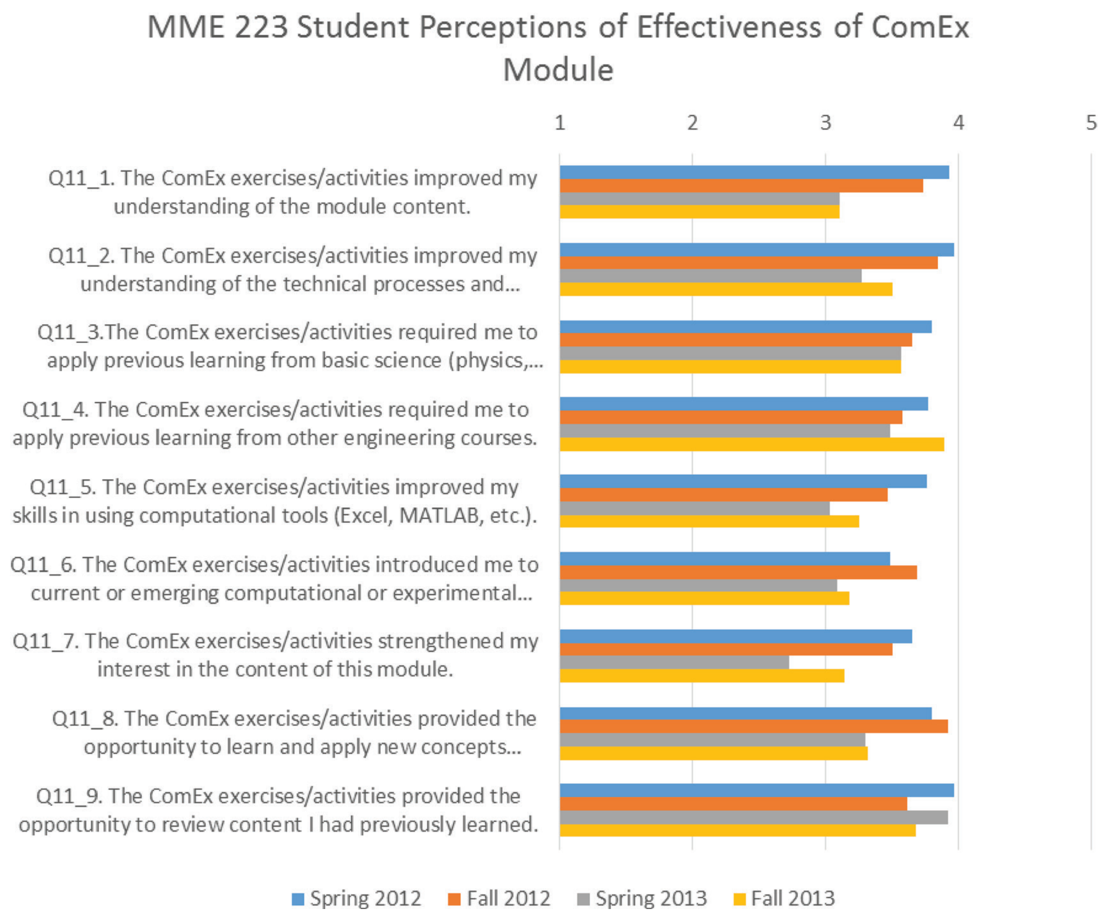

Figure 4a. Survey data on ComEx effectiveness in MME-223, Engineering Materials. Data from 5-point Likert-type scale ranging from strongly disagree (1) to strongly agree (5).

MME 223 course had the least favorable perceptions of benefit (subscale M = 3.28). It should be noted that most subscale scores are high-average (above 3.0 on a 5-point scale) across all terms. MME 223 students from all semesters reported that most passive learning components and active learning components of the modules were very useful. It is pertinent to add that incremental improvements to the learning modules had been made each semester. Furthermore, two additional factors may have influenced the data shown in Figure 4a: Instructional responsibilities alternated between two faculty and in the Fall and Spring semesters, the learning module was assigned in the last week of classes as opposed to earlier in the semester as had previously been the case.

When asked about the usefulness and quality of different aspects of ComEx Studio activities, Figures 4b and 4c, MME 223 students across semesters reported that objectives/outcomes of the activities and information regarding assessment of completed work were moderately clear. Students also

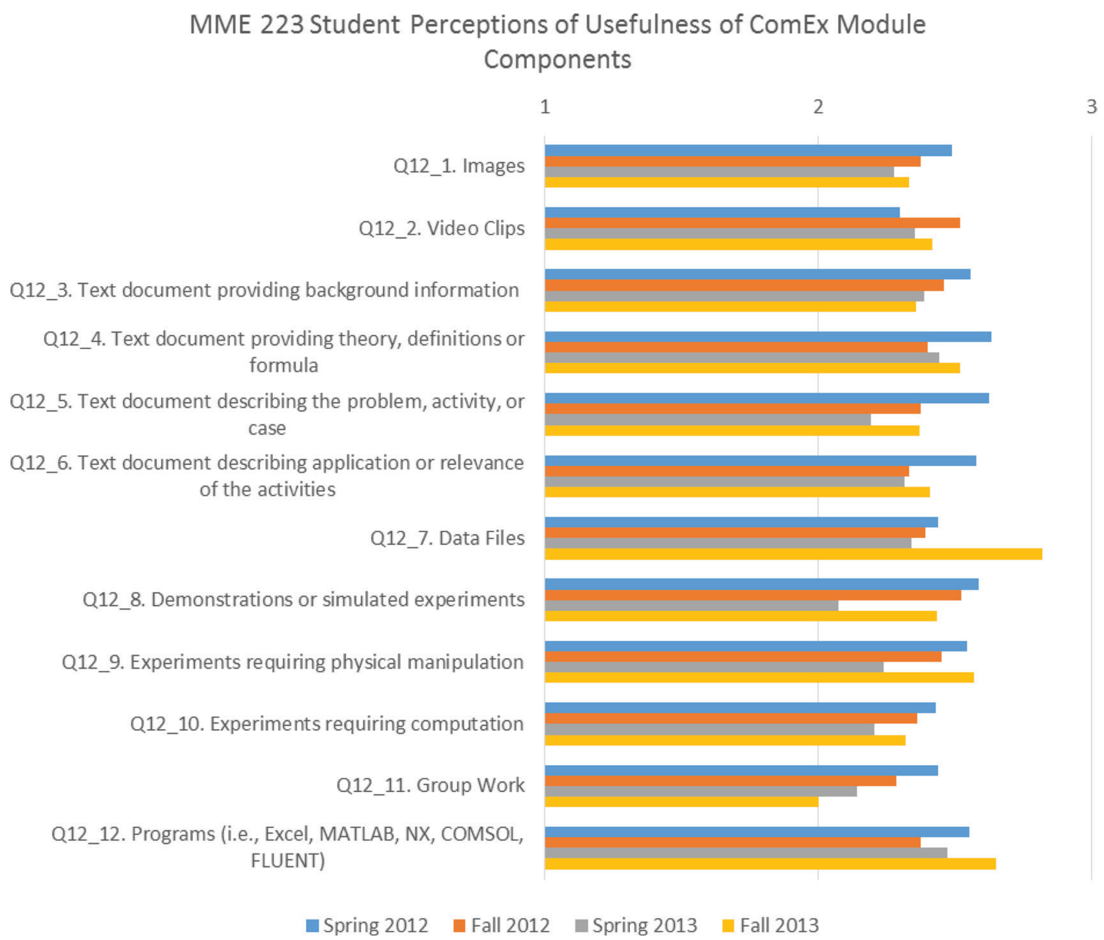

Figure 4b. Survey data on ComEx usefulness in MME-223, Engineering Materials. Data from a 3-point rating scale ranging from not at all useful (1) to very useful (3).

reported that a moderate level of detail was provided pertaining to the work required, but that more guidance should have been provided by the module materials. Students generally felt that an appropriate amount of work was required to complete the activities and that the activities were highly applicable to course material and moderately applicable to their current or future career/research interests.

External Evaluators

Three external evaluators (faculty with experience in NSF programs such as Course, Curriculum and Laboratory Improvement (CCLI), Transforming Undergraduate Education in Science (TUES) or online teaching) participated in the external evaluation of the project. Two visited Miami University and during their visit discussed various aspects of project, website layout, architecture of assignments,

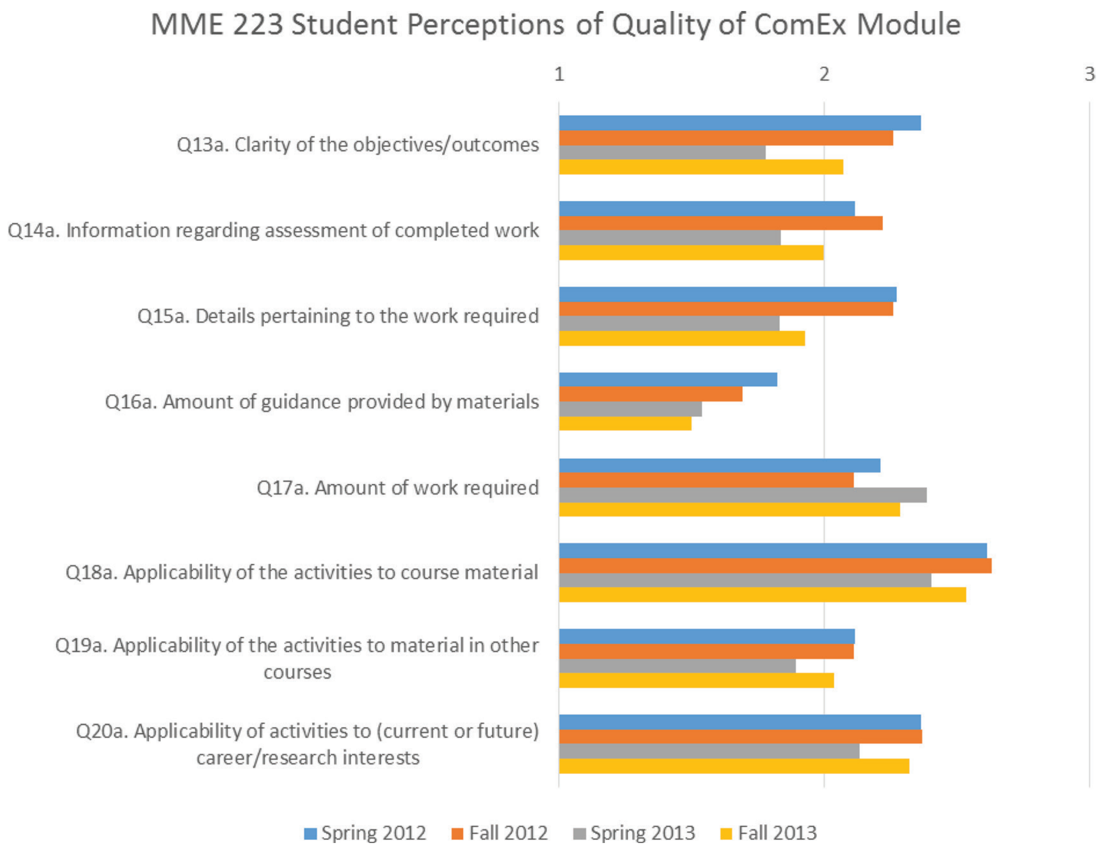

Figure 4c. Survey data on ComEx quality in MME-223, Engineering Materials. Data from a 3-point rating scales ranging from not clear (1) to very clear (3), not detailed (1) to very detailed (3), too little guidance (1) to too much guidance (3), too little work (1) to too much work (3), or not applicable (1) to very applicable (3).

and conversed with students. One evaluator reviewed the material (website, survey results, project summary) remotely and completed a project evaluation report. A small section of the questionnaire is provided in Figure 5, which has been modified to show the responses of the three evaluators. One evaluator's background is in Physics and in a summary comment it was clarified that lack of intimate knowledge of the engineering curriculum resulted in an 'Undecided' response to a few queries. Additional sections of the questionnaire focused on the quality of the instructional materials (videos, supporting text, images etc.) and the rigor of the assignments/worksheets. A favorable assessment from the reviewers was received which included advice to expand the extent to which assignments/worksheets required students to have to make decisions vis-à-vis the numerical tools and data sets. This characteristic is being given particular attention in the design of the new learning modules and

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

Figure 5. Excerpt and data from external evaluator survey form.

in the revision of the existing material. The progressive nature of the modules was noted by one of the reviewers: *"Additionally, the common elements of courses (eg, software analyses common to multiple classes) can be efficiently coordinated through ComEx among multiple classes. The activities and tools developed are consistent with those students will encounter as an engineer."*

Faculty Assessment

Regular meetings by the five faculty members to discuss their impressions of the efficacy of the modules, propose adjustments, and plan for future modules has been very productive. Given the progressive nature of the modules, it was considered imperative to entertain suggestions from faculty teaching higher level courses in order to tailor the content from the sophomore level in order to establish a scaffold style approach toward the learning of advanced concepts.

Additional Assessment

To assess the depth of student understanding of a given concept, pre and post assessment quizes were developed in which questions were mapped to the learning outcomes of the activity.

Q#	% Correct Whole Group	% Correct Upper 27%	% Correct Lower 27%	Discrim.
Q. 1	75	100	44	0.55
Q. 2	67	77	44	0.33
Q. 3	35	66	22	0.44
Q. 4	72	100	55	0.44
Q. 5	24	44	0	0.44
Q. 6	54	100	11	0.88

Table 2. Post-module completion quiz assessment data for the modal analysis quiz (Spring 2014, 32 students).

For example, the design of the quiz and results from an item analysis for the module "Sweet Spot of a Baseball Bat from Vibration Modal Analysis" contained in the Vibrations ComEx and used in the Mechanical Vibrations course, MME-315, are reported in Singh and Khan [2014] for Spring and Fall 2013. The item analysis results from a post-activity questionnaire administered in Spring 2014 are presented in Table 2. Item analyis were carried out to identify the difficulty level of the questions. For example, the questions having a discriminant index >0.2 indicates that these quiz questions discriminated between the students with more understanding and students with less understanding of a given concept. The grouping of lower and upper 27% of the participating students helps identify the questions (and related concepts) which needs more attention.

Examination of the testing data from the semesters in which pre and post-activity testing was performed has revealed that the upper 27% of students have shown a significant improvement on most of the questions following the completion of the module while the data for the lower 27% showed mixed results. Additional testing to improve the efficacy and broaden the impact of the modules is planned for future semesters.

CONTINUED DEVELOPMENT AND EXPANDED UTILIZATION

Planned improvements to the ComEx modules include:

- The highlighting of a greater number of analogous systems in each module to enable students to better appreciate the relevance and broad applicability of the computational activities.
- Creation of a more consistent 'feel,' or user experience across the studios by better aligning the architecture of the various learning modules.

- The inclusion of more data sets to expand the scope of the analysis.
- Further consideration of the preparation of graphical user interface (GUI) tools to enable students to explore the ramifications of variations in model parameters.
- Promotion of the ComEx content to other institutes has been achieved through presentations at prominent conferences, notably ASME, ASEE and FIE. The attempt has been to highlight the process, existing content and assessment methodology such that other faculty can build similar learning modules, directly utilize the modules available on the ComEx site, and leverage suitable assessment methods to refine their experiences. The PIs are able to provide any supporting material such worksheet solutions, assessment instruments, and assistance in creating additional data sets. The content has so far been utilized by one college with positive feedback.

CONCLUSIONS

Recognizing that the interdependency of computational and experimental analysis is an inherent characteristic of multiple areas of engineering, the ongoing project is aimed at creating instructional materials that expose students to the various processes involved in testing, simulating, and validating the performance of mechanical and thermodynamic systems. Online learning modules designed to be used by multiple courses in the mechanical engineering curriculum have been developed, and the initial data has provided strong evidence of the efficacy of this approach. Web based access of multimedia content such as Java applets, videos and images imbedded into the text in intended to facilitate dissemination. The learning modules share a similar format and the specific subject of each was inspired by the research interests of the faculty. This aspect makes the learning modules particularly well suited for introducing new supplementary content to a course. It also serves as a model which other institutions might choose to emulate or modify in the creation of similar modules.

The ComEx resources are designed for use across the curriculum and, accordingly, longitudinal tracking of the development of computational, analytical and validation skills of students is being undertaken. A robust assessment plan, broad faculty involvement, graduate and undergraduate student participation in the preparation of the content and web presentation have all been critical to the progress of the project. The creation of additional pre/post quizzes and the design of comparative studies to accompany the online modules is planned. These new assessment instruments may be utilized by external faculty to assess the effectiveness of student understanding.

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