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Design of Entrepreneurially Minded (EM) Effective Learning Strategies for Engineering Students: Course Structure, Grading Rubrics, Syllabus Design, and In-Class Mini Labs for Student Motivation and Learning

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Design of Entrepreneurially Minded (EM) Effective Learning Strategies for Engineering Students: Course Structure, Grading Rubrics, Syllabus Design, and In-Class Mini Labs for Student Motivation and Learning

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Abstract

In a series of effective learning strategies developed, applied, and implemented at two separate institutions of higher education, research has been dedicated to determining the effectiveness of the designed learning strategies on student learning, motivation, and success. The research has been dedicated to effectively develop grading rubric for homework and exams as well as develop an effective course structure for STEM courses. The present study is an autoethnography of an improved and modified version of an earlier developed course structure and its effectiveness in multiple modes of delivery. An important aspect of improvement in the course structure was addition of mini-labs, small concept experiments or practical problems in the classroom to bring an entrepreneurial mindset to the course. The present research also highlights the student motivation as this is another area of focus for modern instructional design. The study used the process of asking students to grade their own homework. The students were provided with the correct answers after submission of their assignments on the LMS and provided with a grading rubric developed in an earlier study to grade their work. This helped students learn the material more effectively, instilling and encouraging self-learning. This also helped the students to figure out weak areas of their learning and helped students improve their learning. It is important to note that the courses used for this type of grading technique are Junior level courses and it is recommended to use this technique for Junior and Senior level courses. The previously developed homework grading rubric proved itself to be an effective and successful student learning tool. Therefore, it is extended to develop and implement lab grading rubric to study its effectiveness on student learning and success. Another area of study to improve student motivation is effectiveness of the syllabus design on student learning and motivation by including the course area concept application pictures on the first page. Concept applications are discussed in the first class of the semester which is primarily designed to discuss course syllabus and motivation. Course motivation is also incorporated at the topic level through videos or thought experiments. A synthesis of the research in effective learning strategies establishes an effective course design applicable to multiple modes of delivery that supports student learning and encourages an entrepreneurial mindset.

Introduction

Online and hybrid courses have existed for many years but due to COVID-19, they became the primary form of instruction in universities all over the world. Academic institutions and faculty, who had zero or minimal experience in teaching the hybrid and online modes of instruction, were forced to transform their modes of instruction overnight. Faculty faced many challenges related to ensuring effective learning in different modes of instruction. The problems were faced by the faculty who had no prior experience in teaching the hybrid and online classes and had only taught traditional face-to-face (F2F) courses, as well as the faculty who had prior experience teaching online courses. At the same time, challenges were also faced by the students in learning the material effectively due to the loss of motivation for various reasons. This posed a massive problem for the universities and faculty, inspiring the present study which had earlier designed an effective course structure for hybrid courses in AY 2020-21 [1]. Since the higher education institutions moved towards fully F2F instruction starting Fall 2021, the present study is a further extension of the designed course structure aimed at hybrid mode to now F2F instruction. The present study also discusses syllabus design and further educational techniques to enhance student motivation and foster an entrepreneurial mindset at two separate institutes of higher education with different national rankings and which cater to different demography of student population. These aspects in the present study were intentionally included to make sure that the results are applicable to variety of higher education institutions with all student populations, especially the first-generation students.

The uniqueness of the present study is the design of course instruction structures for multiple multidisciplinary engineering courses at two higher education institutions. It will use the common course instruction structure that was developed and successfully implemented with excellent results by Arshad et al. [1]. Instructors in STEM have been teaching the courses by their own experiences and through experiences of their mentors and/or colleagues, but a specialized course delivery structure developed to help the faculty deliver the courses in the most effective manner is now extended to F2F instruction. Previous studies have been focused on one course in one given institution at a given time, which shows a deficiency in developing a holistic approach to solve a common engineering and STEM instructional problem. That's why this study provides a holistic picture and approach to the problem.

Course Structure

The study performed by Wiebe et al. [2] focused on the development of an online and face-to-face introductory engineering graphics course that presented analysis of student's usage of online resources to augment the instructional support received in class. The study fell short of coming up with a design of a common course structure for engineering and STEM related courses. Similarly, the study performed by He et al. [3] focused on investigating the flexible hybrid format. The study was performed on a fundamental electrical engineering course. This study explored other factors such as class attendance impact as well as the study time spent and student motivation on the exam performance.

Ahn et al. [4] investigated one component of the hybrid course format for the Mechanics of Materials course. The student's interaction with online videos in terms of their video-viewing behaviors was examined.

Kazeruni et al. [5] focused on the comparing two different pedagogical approaches between traditional engineering and business school courses to develop complementary skills amongst students by combining both approaches in a single course of Introduction to Nanobiotechnology and Nanobioscience. The study lacked in showing the design of the instructional course structure, which could have proven beneficial for the faculty.

A project-based approach was introduced for an aerospace engineering course that used the design, analysis, manufacturing, testing, and launching of mid-power solid propellant rockets by Spearrin and Bendana [6]. The approach is very helpful as it requires the students to solve various laboratory assignments as well as the working on the project. Individual professional portfolios and roles were assigned to the students within each team such as design and manufacturing engineer, etc. to motivate the students to show practical implications and real-life experience. Investigation of the student performance characteristics of hybrid class for the engineering course of Statics was performed by Myose et al. [7].

One thing common amongst all the studies cited so far is that none of the studies devised, investigated and implemented a course instruction structure for the specific courses studied. This provided the researchers in the present study a unique opportunity into the domain of creating a course structure that can help STEM instructors to teach effectively in all modes of course delivery, including the traditional face-to-face, hybrid, and online classes.

The present study designed and implemented an effective course delivery structure at Texas A&M University and Saint Ambrose University. To obtain comprehensive results, the study design utilized multiple modes of instruction, multiple instructors at two higher education institutions with varied student demographics. It requires high-level student engagement for the student learning and success. On part of faculty and instructors, it requires a lot of effort, hard work and innovation to make sure that the students learn the material effectively as well as retain the knowledge. Going through with this exercise as a new instructor and trying to find any material or course structures in the literature as well as discussion with senior and fellow faculty members, it became evident that there was a lack of a common designed engineering course delivery structure. Every instructor uses their own learning techniques which is more of a trial and error. Also, some techniques work well with certain student population/class segment but are not effective for other student populations. This produced an idea to develop a common course delivery structure embedded with the entrepreneurial mindset for engineering courses that ensures effective student learning and success as well as provides the instructors with an effective tool to prepare their teaching materials and pedagogical skills. Adoption of a common course structure to introduce the entrepreneurial mindset in engineering students as well as use for all modes of instructions, such as, online, hybrid and Face-to-Face instruction is valuable to effective student learning strategies.

Entrepreneurial Mindset

Development of entrepreneurial skills in engineering students has become an important objective for engineering instructors [8]. This is achieved either by addition of entrepreneurship courses to the curriculum, or modification of existing course curriculum to introduce students to pursue an entrepreneurial mindset through problem solving including real applications. Other options have been to introduce management track in undergraduate engineering studies. As an alternative route, Engineering Management graduate programs have also been developed. Hsiao et al. [8] performed a six-year survey of engineering students who had elected to enroll in a junior or senior entrepreneurship course. The study surveyed the students' perspectives on entrepreneurial qualities and evaluated entrepreneurial ideas technically, organizationally, and strategically.

Park et al. [9] focused the study on first-year engineering students. Engineering discovery courses were developed to offer freshman engineering students an opportunity to discover the entrepreneurial mindset through various course topics and activities integrated with entrepreneurially minded learning. Students practiced and exercised engineering design process during the second (spring) semester with an engineering entrepreneurial mindset through various class activities and design projects with selected topics. This also exposed the students to an engineer's role in a society and the related responsibilities along with creation of new innovative ideas.

Erdil et al. [10,11] studied a curricular model to develop an entrepreneurial mindset in engineering students which emanated from the Kern Entrepreneurial Engineering Network (KEEN)'s 3C's, of *curiosity*, *connections* and *creating value*. The study spanned across all four years of all engineering and computer science programs. Flipped classroom instructional model was used to focus on the integration of six short, self-paced, e-learning modules into courses.

Hylton et al. [12] performed a study to build the EM into the mechanical engineering curriculum which was motivated by the KEEN framework. Institutional definitions of the KEEN student outcomes as well as identification of courses for deployment of the outcomes was identified by a core group of college faculty to provide comprehensive, curriculum-wide exposure to the EM. Incentive and reporting structures were employed for onboarding faculty in an effort to ensure long-term sustainability of the curricular modifications.

EM-course structure poses a challenge of dealing with the student motivation. This study addresses the challenge and employs a holistic approach for the successful implementation of the designed course structure.

Tan [13] performed a study analyzing student motivation to investigate the impact of COVID-19 on the students studying in higher education institutions when the learning process switched from face-to-face to online learning. The study determined that there was loss in student motivation and learning performance. The findings showed the lack of motivation in the student population due to many factors such as lack of focus and unavailability of effective teaching methodologies to engage the students.

A similar study was performed by Gustiani [14], where the study was aimed at addressing student motivation during the Covid-19 pandemic era. This study also addressed the problem to sudden transformation from traditional face-to-face learning approach to remotely digital learning and suggested that the lack of students' motivation in online learning, where amotivation occurred due to poor external supporting facilities.

Fong [15] performed a study to investigate the effect of COVID-19 pandemic on students' learning, well-being, and academic motivation and determined that COVID-19 has had a profound effect on all of the above-mentioned student performance parameters. There were many factors including shifts to remote/hybrid learning, physical distancing, and concerns regarding health and financial prospects. Other factors affecting student motivation were

COVID-related discrimination and health disparities. This affected the minoritized individuals showing that demography plays an important role in student motivation.

Corpus et al. [16] reported that retrospective reports by college students have identified motivational declines associated with the COVID-19 pandemic. The study used Self-Determination Theory to examine which measured the student motivation change during COVID-19 in six types of motivation. Motivation trajectories were compared from Freshmen to Seniors by studying two cohorts of students. Measurement of motivation of Seniors was taken prior to the pandemic in one cohort of 206 students and during pandemic in another cohort of 270 students. Pre-pandemic cohort showed sharper declines in identified and intrinsic motivation but there were no differences in controlled motivation or amotivation.

Methods

Autoethnography

Autoethnography [17] is a technique that uses self-reflection for recognition, exploration, appreciation and documentation of personal experiences. The autoethnographic approach was applied to elaborate and understand the results obtained from the research goals. Both authors performed research based on a structured approach and collected data. The following questions were used to understand the results and answer the complexity of an effective learning strategy:

- What was the background and context of your teaching experience?
- What teaching and learning changes were implemented during the teaching experience?
- What were the lessons learned from your teaching experience?

These questions are addressed, answered and discussed in detail by the instructor under the Results and Discussion section.

Autoethnography engages the individual in cultural analysis and interpretation [18]. Self-analysis that emanates from such exercise produces purposeful implications for educators [19]. Starr [19] discusses autoethnography, its methodological implications as well as its value as a research method. The study also examines the relationship between autoethnography and the philosophical and practical implications.

Kahl [20] discusses the negative implications of pedagogical practices on student leading to student subjugation. To avoid student subjugation, the study encourages the instructors to engage in autoethnographic writing about their own teaching. This provides the necessary insight and knowledge to move toward implementation of critical communication pedagogy. The study also advocates for the advancement of autoethnography as pragmatic scholarship.

Warren [21] also proposes to employ reflexive autoethnography that the instructors should use to pose questions, such as, “what I believe about teaching” to “why I believe what I believe about teaching.” This enables more critically informed pedagogical philosophies that translate importantly to actual classroom choices.

1. Multidisciplinary Engineering Courses at Texas A&M University

Course Structure

The present study encompassed comprehensive application and study of the designed course structure to in-person Face-To-Face instruction as well as online and hybrid instruction during COVID-19 to Junior level engineering courses that included both the lecture & lab components at Texas A&M University for the Fall 2020 - Spring 2022 semesters. Although the course structure was applied to a number of Junior level mechanical engineering courses at Texas A&M shown in Table 1, the present study only focuses on detailing one course to discuss and disseminate the findings. Among the courses delivered at Texas A&M University, the course of Strength of Materials, highlighted in orange in Table 1, was selected to discuss the findings since it was delivered using the online, hybrid and Face-to-Face modes of instruction.

Table 1. Texas A&M courses taught with modes of instruction from Fall 2020 – Spring 2022

Courses	**Mode of Instruction**		
	Online	**Hybrid**	**Face-To-Face (F2F)**
MMET 303: Fluid Mechanics & Power	Fall 2020		Fall 2021
MMET 361: Product Design & Solid Modeling		Spring 2021	Fall 2021
MMET 370: Thermodynamics for Technologists	Fall 2020		Fall 2021
MMET 376: Strength of Materials	Fall 2020	Spring 2021	Spring 2022

Strength of Materials is a core engineering course taught nation and worldwide in engineering programs, such as mechanical, aerospace, civil and multidisciplinary engineering. The course was delivered in multiple semesters from Fall 2020 to Spring 2022 via online, hybrid, and face-to-face instructional formats. Figure 1 shows the improved version of the course structure flowchart that was designed, developed, and implemented at Texas A&M University in an earlier study [1]. The course delivery structure can also be extended to STEM courses as well. At the same time, its use can benefit student retention due to increased student motivation in learning the course material in engineering programs.

The designed course structure shown in Figure 1 constituted a pedagogical methodology that divided the class into various activity-based modules. The lecture part of the course was divided into learning modules that used PowerPoint presentations and OneNote (or digital whiteboard) to deliver lectures and solve in-class problems. It is important to note that not all engineering courses should be taught using PowerPoint presentations due to various reasons, such as student engagement and complexity of the taught course concepts. For example, Strength of Materials was taught using OneNote to write the concepts, derivations, explaining concepts using free body diagrams (FBDs), and posing concept questions so they students learn the material effectively. On the other hand, Thermodynamics and Fluid Mechanics should be taught using PowerPoint presentations due to the sheer number of concepts that need to be taught as well as the real-life concept application pictures that can be included into the PowerPoint presentations to teach the material effectively. It’s important for the instructor to decide the effective teaching tools and methodologies for each course to keep student engagement. Student engagement and feedback can be gauged by various tools such as one-minute paper, iClicker, concept questions and quizzes. The instructor should be ready to make changes to the teaching methodology for effective student learning and engagement. The YouTube videos module provided visual learning as well as student motivation by exposing the students to the practical application of the engineering concepts. The videos were then used as means of creating an interesting relevant practical problem that made use of the concept learned during the class. This gave confidence to the students in their ability to apply numerical solutions to practical problems as well as an experience of a real-life engineering application in a team/group-based activity. The possible solutions were then discussed in the class with instructor feedback. The important aspect of the study is to use in-class activities, such as, group problem solving. One other interesting aspect is to add mini-labs to the class where the instructor brought miniature working models of jet and automotive engines as well as used equipment to simulate tornadoes. This created immense student interest in the class and engaged the students in the course materials effectively.

Students were asked to submit one-minute paper at the end of every class. Students identified the most significant concept they learned in the class, the muddiest concept/portion in the class and mentioned questions on the one-minute paper. This technique helped the instructor to gather and gauge class learning, engagement, and participation at the end of every class. This feedback methodology fostered inclusive learning environment.

Labs were delivered in F2F mode of instruction in Fall 2021 and Spring 2022. The lab component was divided into two portions; experiment & discussion, and data share, where first the concepts and theory along with the experimental procedure were discussed and the experiment was performed. The data is obtained and discussed and then shared with the students online. All assignments, lab reports, projects, quizzes and exams were required to be submitted online and were graded online using annotations.

With this approach and course structure, entrepreneurial mindset (EM) is built into the courses. The connection of practical problems and mini-labs in the class help develop the EM into the course content and was also integrated into the courses through a term project.

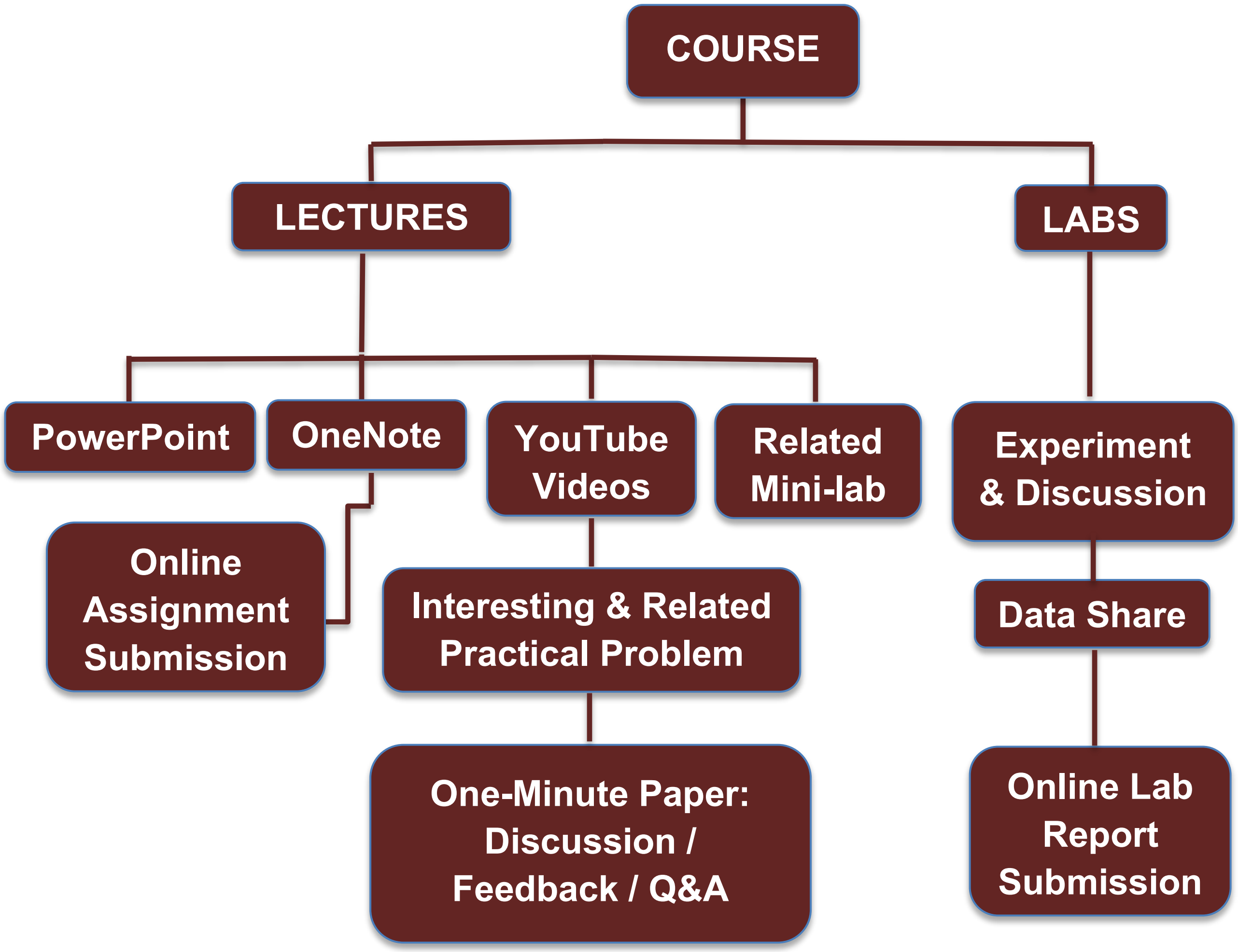


Figure 1. Modified & Improved Course structure employed at Texas A&M University. Original Course Structure used in a previous study [1]

Student Motivation

The present research also puts focus on student motivation. Modern instructional design is student-centric in terms of gauging and enhancing student learning. One of the important aspects missing from today's student populace is to take the ownership of self-learning. This can better be achieved by introducing student led learning techniques such as self-grading of the homework assignments and quizzes. The research is using the process of asking students to grade their own work. The students are provided with the correct answers after submission of their assignments on the LMS and provided with a grading rubric developed earlier [22] to grade their work. The grading rubric is provided to the students in the syllabus and is used for grading throughout the semester. This is going to help students learn the material more effectively and take ownership of their learning. This will also help students figure out the respective weak areas of their learning, and to help students improve their learning. It is important to note that the courses used for this type of grading technique are Junior level courses and it is recommended to use this technique for Junior and Senior level courses. The homework grading rubric [22] has been an effective and successful tool so it has been extended to labs to study its effectiveness on student learning and success. The grading rubric for labs in Figure 2 has been developed and implemented at Texas A&M University.

Table 2. Homework Grading Rubric [22]

Problem Structure	Description	Points
GIVEN	Information provided in the problem statement including various parameters and word statements	1
FIND	Unknown parameters required to be determined	1
GOVERNING EQUATIONS	Equations that will be used to determine the unknown parameters	1
ASSUMPTIONS	Correct assumptions required for the solution of the problem or to simplify the math	2
SOLUTIONS	Algebraic solution with correct order of determining the unknown parameters along with the Free-Body Diagrams. Every answer should be **BOXED**, and the word **"ANSWER"** mentioned along with the box. For these points, follow the grading instructions below.	5

Solution / Critical Thinking Problem	
5+/5 Points	Correct answer and thorough supporting work. Logical steps are used throughout the problem. Proper units and significant digits provided.
5/5 Points	Correct answer to within a sign (+/-), trivial (math) mistake, but shows thorough supporting work. Proper units and significant digits provided.
4/5 Points	Incorrect answer due to minor mistake in math or concept, thorough supporting work shown, but incorrect or insufficient. Possibly not all parts of problem completed or attempted.
3/5 Points	Incorrect answer due to a mistake in math or concept, thorough supporting work shown, but incorrect or insufficient. Possibly not all parts of problem completed or attempted.
2/5 Points	Incorrect answer due to major mistake in math or concept, some supporting work shown, but incorrect or insufficient. Possibly not

	all parts of problem completed or attempted.
1/5 Points	Incorrect answer or incomplete problem due to major error. Little or no supporting work shown.
0/5 Points	Unattempted problem or back-of-the-book answer, with no work shown at all.
Conceptual Question	
2/2 Points	Correct answer and thorough explanation/answer. Shows complete understanding of the concept.

TEXAS A&M UNIVERSITY
Laboratory Grading Rubric

- __/5 Title Page:
  - Course Number and Title, Name of Student, Recipient of Report
  - Number and Title of Experiment, Dates of Experiment and Submission

- __/10 Abstract
  - Statement of Problem (What was investigated?) Brief summary of the experiment (How was the investigation performed?)
  - Major Results and Conclusions

- __/10 Apparatus and Procedure:
  - Concise description of Experimental Setup (including pictures with labeling) and procedure (1 paragraph)
  - Assumptions Stated
  - Experimental and Ambient Conditions listed

- __/55 Results and Discussions:
  - __/10 Obtained results
  - __/10 Sample calculations
  - __/10 plots based on data
  - __/10 Data Analysis, Discussion and Comparison to Theory
  - __/15 Answers to the theory questions in the lab manual

- __/15 Conclusions:
  - __/10 Major Results Restated and Physically Meaningful Conclusions Drawn
  - __/5 Technical Recommendations for Further Research or Improvements to the experiments

- __/5 References:

Total: ___/100

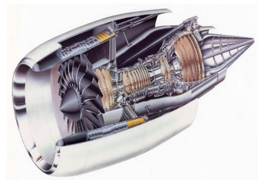
Figure 2. Laboratory Grading Rubric

Another area of study to improve student motivation is effectiveness of the syllabus design on student learning and motivation. This has been done by using course area application pictures on the first page and discussing those applications in the first class of the semester, which is dedicated to the discussion regarding the syllabus and course motivation. Additional motivation is used at the topic level through videos, mini-labs, or thought experiments. Figure 3 shows the first page of a few courses' syllabi designs employed at Texas A&M university.

DEPARTMENT OF MULTIDISCIPLINARY ENGINEERING

MMET 370: Thermodynamics for Technologists

FALL 2021



Section M01

Tues-Thurs 11:10 am-12:25 pm, Room: HECM 105
Lab: Friday 3:50-5:40 pm, Room: HECM 205

Instructor

Dr. Muzammil Arshad, "Dr. M."
Office: HECM 316.4
Email: marshad@tamu.edu
Phone: 956.271.1359

Office Hours

Tuesday: 10:00 - 11:00 am
Wednesday: 9:00 - 11:00 am

DEPARTMENT OF MULTIDISCIPLINARY ENGINEERING

MMET 303: Fluid Mechanics & Power

FALL 2021

Section M01

Tues-Thurs 2:20 – 3:35 pm, Room: HECM 106
Lab: Thursday 8:00-9:50 am, Room: HECM 205

Instructor

Dr. Muzammil Arshad, "Dr. M."
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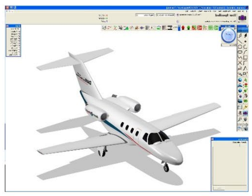
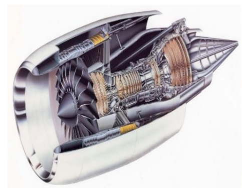
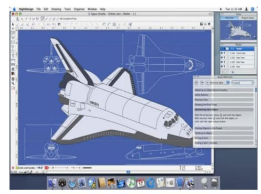
Phone: 956.271.1359

Office Hours

Tuesday: 10:00 - 11:00 am
Wednesday: 9:00 - 11:00 am

DEPARTMENT OF MULTIDISCIPLINARY ENGINEERING

MMET 361: Product Design & Solid Modeling
Fall 2021

Section M01
Mon-Wed 11:30 am – 12:20 pm, Room: HECM 107
Lab: Tuesday 8:00-9:50 am, Room: HECM 206

Instructor
Dr. Muzammil Arshad
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Email: marshad@tamu.edu
Phone: 956.271.1359

Office Hours
Tuesday: 10:00 - 11:00 am
Wednesday: 9:00 - 11:00 am

DEPARTMENT OF MULTIDISCIPLINARY ENGINEERING

MMET 376: Strength of Materials
SPRING 2022


Section M01
Tues-Thurs 2:20-3:35 pm, Room: HECM 222
Lab: Wednesday 5:50-7:40 pm, Room: HECM 214

Instructor
Dr. Muzammil Arshad, “Dr. M.”
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Email: marshad@tamu.edu
Phone: 956.271.1359

Figure 3. Course syllabus design employed at Texas A&M University

2. Mechanical Engineering Courses at St. Ambrose University

Course Structure

The courses taught St. Ambrose University (SAU) are all required traditional courses at the junior and senior level. Due to COVID-19, each course was offered in different modes for AY 2020-21 and 2021-22 as shown in Table 3. Students did not have a choice which mode of delivery to take as the delivery mode was dictated by campus COVID-19 policies. The hybrid structure was designed for implementation during the coronavirus pandemic [1] and has been employed for online-only delivery for the Spring 2021 courses and for F2F instruction in Electronics in Fall 2021 as well as the Spring 2022 courses. Although the course structure was applied to a number of Junior level mechanical engineering courses at St. Ambrose, the present study only focuses mainly on one course, Electronics, to discuss and disseminate the findings as it was taught in hybrid, briefly in online-only mode, and F2F. The following are the courses and their delivery mode under the present study:

Table 3. St. Ambrose courses taught with modes of instruction from Fall 2020 – Spring 2022

Courses	Mode of Instruction		
	Online	Hybrid	Face-To-Face (F2F)
PHY 306: Electronics		Fall 2020	Fall 2021
ME 405: Control Theory	Spring 2021		Spring 2022
ME 410: Heat and Mass Transfer	Spring 2021		Spring 2022

Hybrid classes are defined as one in which all students registered for the class are not able to attend in-person for each session. Specifically, for Electronics in Fall 2020, the class was split into two groups, and students attended one of the two one-hour lecture times. Additionally, when weather permitted, class was held outside and the entire class was able to attend if they wanted extra time in class with the instructor, but it was not expected. For the lab, the 100-minute lab was split in half, so students were able to attend lab each week but for half of the normal scheduled lab time. To facilitate shorter time in the lab, lab kits were provided to students. Before the lab, students were to do the lab as best they could. During lab time, students had the opportunity to get help with the lab. If they were confused or ran into an issue before lab, lab time was dedicated to working through those issues. After lab, students were to finish the lab and lab worksheet associated with each lab. For F2F labs, the full lab time allowed students to complete the labs and most of the worksheet during lab time, so no lab kits were distributed. For full-semester online-only courses, no labs were incorporated into the course; however, Electronics moved online for three weeks at the end of the term, but students already had lab kits so were able to do labs and projects at home.

The course structure is similar to Texas A&M University and comprises both lectures and labs. The course (lecture) content is similarly divided into learning modules for different topics; however, a flipped classroom was employed while using the course structure in Figure 1. Adhering to the flipped classroom approach, students were to engage with material before coming to the class online. Within the learning modules in the online learning management system, several options were given for students to engage. These included reading the textbook, watching lecture videos, submitting notes taken, and completing a comprehension quiz. Lecture videos were split into videos approximately 10 minutes or less by concept to keep them short. The pre-class engagement with the course is “PowerPoint” and “One Note” in Figure 1 as students read the book or watch PowerPoint video lectures which include the instructor writing on slides like a whiteboard.

With the initial look at a topic completed by students outside of class, active learning took place during class time. Examples of these activities include:

- discussing thought questions including motivating usefulness through connections in real-life or other classes working through example problems or worksheets as a class, in a group, or individually, and
- gamifying formative assessment with Kahoot quizzes or using fingers on hands as iClickers.

The in-class activities correspond to the motivation sequence “YouTube Video” to “Interesting & Related Practical Problem” to “Discussion/Feedback” in Figure 1.

After class, students had homework practice problems to complete to ascertain whether they fully comprehended the concepts of the learning module. Students were given solutions to the problems and the grading rubric for critical thinking and conceptual solutions shown in Table 2 developed earlier [22] right after submission (“Online Assignment Submission” in Figure 1) so they could assess their own understanding of the course material. Thus, the flipped classroom setup allowed for students to make the most of their time with the instructor through active learning by watching the lecture material before class using the developed course structure.

For labs, students conduct the experiment, share data as needed with other students, and complete a lab worksheet with discussion questions and data analysis requirements, which corresponds to the “Labs” sequence in Figure 1 except that each student selects only one lab for which to write a formal lab report as a summative assessment.

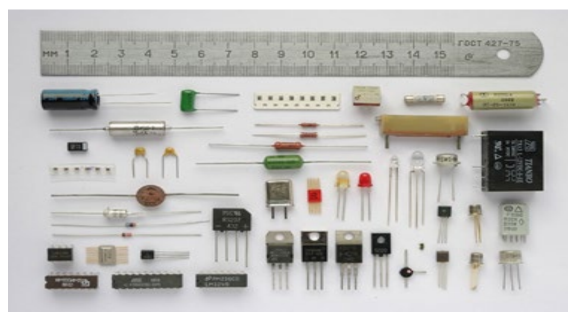
This course structure is the same for all three modes of delivery and matches the course structure used at Texas A&M shown in Figure 1. Though the course structure is the same, each course was still tailored to the students in the class based on the instructor’s professional judgement.

Student Motivation and Assessments

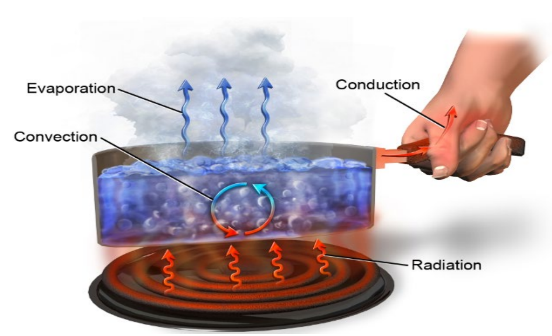
To determine student learning, a set of challenge assessments were developed that captured the course objectives and each course’s more specific learning targets. The challenge assessment approach was adopted from Talbert [23] and uses the EMRN rubric [24]. A variety of assessment types were used which include lab reports, quizzes, exams (quizzes have 1-2 questions, exams have 3-4 questions), presentations. For the presentations, students were given the choice of how to present their work including oral video presentation, report, comic strip, children's book, and their choice upon instructor approval. All quizzes and exams are designed to give all students double the time if needed. Additionally, to encourage student learning and decrease the stakes of each assessment, all assessments could be revised or retaken one time. Together these assessments and the ability to redo them aimed to motivate students by giving them choice and not unintentionally rewarding or penalizing a student inordinately who may excel or underperform on any one type of assessment. In addition to the challenge assessments, students could earn engagement credits by participating in the course through various ways before, during, and after class. Opportunities were numerous, not all were required, and effort not correctness mattered. This flexibility, choice, and low stakes environment encouraged the EM.

As at Texas A&M, another area of study to improve student motivation is effectiveness of the syllabus design on student learning and motivation. This has been done by using the course area pictures on the first page, including five or less high-level course objectives of highly relatable real-world skills, and discussing those pictures and course objectives in the first class of the semester which is dedicated to the discussion regarding the syllabus and course motivation. Additional motivation is used at the topic level through videos or thought experiments and gamifying formative assessment. Figure 4 shows the application pictures of the course syllabi at St. Ambrose.

a. Control Theory



b. Electronics



c. Heat Transfer

Figure 2. Course syllabus application pictures employed at St. Ambrose

Results and Discussion

Instructor 1 Reflection:

Background and Context:

I am an assistant professor at a research-intensive university which is the largest university in US by student enrollment located in Texas, United States (about 73,000 students). I have been employed there since January 2020. During COVID-19, the biggest challenge I encountered was student motivation and class attention. I started to evolve and innovate in my teaching methodologies and materials for student motivation, effective student learning and success. This gave rise to the idea of designing an effective course structure for engineering and STEM students [1], since such course structure were not existent, lacked innovation and did not cater to student needs. It became a success story in terms of student learning and success, which motivated me to further think, innovate and improve the course structure into a new and modified course structure shown in Figure 1. The modified course structure shown in Figure 1, proved beneficial for student engagement and learning. This course structure encouraged and implemented the entrepreneurial mindset (EM) into the courses. The connection of practical problems and mini-labs in the class helped in developing the EM into the course content. The coupling of EM with the above designed course structure integrated EM into the course content, refined the professional skills of students; technical and entrepreneurial, encouraged collaboration and communication. An important feature to EM is to bring it into continuous practice, semester after semester to develop and inculcate the habit of EM into the students. This helps the instructor in integration of best teaching practices, which produced a very effective learning methodology and strategy for effective student learning and success.

Examples of Teaching and Learning Changes Implemented:

- *Design of "Lectures" module in the Course Structure Flowchart*: The design of "Lectures" module was the most intensive in terms of brainstorming and gauging student motivation and learning. This module was designed to be most diverse in terms of using the pedagogical methodologies to motivate the students and capture student attention. A combination of various techniques, such as, PowerPoint presentations, using OneNote for problem solving, related mini-lab, YouTube videos as well as solving a practical related problem, and gathering student feedback at the end of each lecture in form of One-Minute Paper, ensured effective pedagogy as well as student motivation, learning and success. This comprehensive study and strategy inculcated entrepreneurial mindset (EM) into the students which is necessary for student success in the modern world.

- *Design of "Labs" module in the Course Structure Flowchart*: "Labs" module used the techniques of performing experiments in the lab as well discussion of related concepts and calculations for any given lab. The data was shared amongst the students at the end of the lab to compare and contrast the data collection and brainstorm any difference in the data collection based on any errors.

- *Syllabus Design and Rubrics*: To ensure clear expectations and transparency in the course delivery as well as student motivation, syllabus design and grading rubrics were given high priority. First class of the semester is critical in capturing student attention and motivation. Syllabi were designed keeping this fact in mind with related practical problems shown in pictures on the front page. The problems were explained in the class encouraging a class discussion to motivate the students towards the course material and explain its practical application. This technique resulted in higher student participation and motivation for the course. To ensure transparency and clear expectations, homework and lab grading rubrics were made part of the syllabi. The homework rubric had been implemented in a previous study in 2020 [9]. Keeping the trajectory of transparency and clear expectations, the lab rubric was also made part of the present study.

Lessons Learned:

The same course structure with lectures via PowerPoint followed by interactive learning via OneNote or the whiteboard with motivational discussion and videos and practical problems and then homework assignments for after class was used in multiple classes. Applying the course structure to various courses but with the same instructor allowed the researcher and instructor to gain more robust insights. These insights were populated from students and from the instructors themselves and were considered to be the barometer to verify the effectiveness of the designed course structure.

The evaluations for Texas A&M University showed very positive feedback regarding the course structure employed during the semester. The end of semester course evaluations/survey mean/average, for all courses under study shown in Table 1, was above the department and college mean/average. Major positive feedback and highlights of the student evaluations suggested that the instructor fostered an effective learning environment, used teaching methods that contributed to students' learning and encouraged students to take responsibility for their own learning. In the last 10 minutes of every class, students were asked to submit a one-minute paper. On the one-minute paper, the students were asked to identify the most significant concept they learned in the class, the muddiest concept/part in the class and if they have any questions or comments. It was made sure that all the questions were answered, and all muddiest parts are cleared so that students leave the class with contentment that they have learned the material and the concepts. By following the designed course structure and pedagogical methodologies for the hybrid classes, it was evident that the course structure contributed immensely towards student learning and success.

This study produced a high impact and produced very positive feedback from the students, generating the high course evaluations for the courses employing the designed course structure. Therefore, it can be deduced with confidence that the above-mentioned course structure is both effective and helpful for student learning and success in engineering courses for all modes of learning including the traditional Face-to-Face, hybrid and online modes of learning. It can further be concluded that the same course structure can be confidently used for all engineering courses and can be extended to other STEM courses as well.

Instructor 2 Reflection:

Background and Context:

I am an assistant professor at a teaching-intensive university located in Iowa, United States with undergraduate student enrollment of about 2300. I have been employed there since August 2017. During COVID-19, the biggest challenge I encountered was delivering effective teaching within the constraints of COVID policies. I took the opportunity to implement a very different course structure that built off previous efforts in effective learning strategies [1] and used the modified course structure shown in Figure 1. It also evolved into encouraging and implementing the entrepreneurial mindset (EM) into the courses. The connection of practical problems into assessments and providing motivational active learning helped in developing the EM into the course content. The coupling of EM with the above designed course structure integrated EM into the course content, refined the professional skills of students, encouraged professional communication, and fostered a supportive learning environment.

Examples of Teaching and Learning Changes Implemented:

- *Design of "Lectures" in the Course Structure Flowchart*: The design of "Lectures" was the most intensive in preparation as it encompassed recording video lectures for pre-class engagement as well as active learning activities for during the class lecture time that all aligned with the student learning objectives and assessments. These were designed to be the most diverse in terms of using the pedagogical methodologies to motivate the students and capture student attention. It allowed a combination of various techniques including lecturing and demonstrating problem-solving by writing on slides during videos, finding muddy points through review of pre-class concept to be able to answer student questions, gamifying review, group problem solving, think-pair-share, "clicker" questions, and open-ended questions. After class, problem set homeworks, "reading" quizzes, and class discussion forums gave students opportunities to practice and reflect on their learning given the solutions and the homework grading rubric. Students earned engagement credits for participating in pre-class, during class, and post-class activities. The multitude of options to earn engagement credits for engaging with course material as opposed to percent grading of correct work has been an effective pedagogy, motivational, and contributor to student learning and success. Additionally, it instills the entrepreneurial mindset (EM) into the students.

- *Design of "Labs" in the Course Structure Flowchart*: "Labs" used the techniques of performing experiments in the lab as well discussion of related concepts and calculations for any given lab through worksheets. For hybrid labs, students received lab kits for the semester and were to complete the labs on their own; however, half the usual lab time was dedicated to faculty interaction for addressing issues that arose. Lab videos demonstrations were also added that proved invaluable to the students.

- *Syllabus Design and Rubrics*: To ensure clear expectations and transparency in the course delivery as well as student motivation, syllabus design and rubrics/assessments were given high priority. Syllabi were designed with related pictures on the front page and five or less high-level course objectives of highly relatable real-world skills to capture student attention and induce motivation. To ensure transparency and clear expectations, the homework grading rubric implemented in a previous study in 2020 [9] and EMRN assessment rubric, which was the same for each assessment, were made part of the syllabi. The assessments continued to build EM by including projects in addition to quizzes and exams. For project assessments, students explored and evaluated problems and designs, and in their chosen formats professionally communicated their learning, including answering reflection questions. After feedback for both projects and quizzes/exams, students were given the opportunity to resubmit their work, and were allowed to reflect and resubmit. This cultivated a supportive learning environment.

Lessons Learned:

At St. Ambrose, the evaluations for hybrid and F2F instruction showed positive feedback. Additionally, the grades of students were high and measured effort and understanding. The end of course survey mean/average for all courses delivered hybrid and F2F were markedly higher than any previous years and in-line with or above the department and college mean/average. However, the same course structure did not yield such positive feedback for the full-semester online-only mode of delivery. This may be due to being forced to be online and/or video conferencing fatigue. The instructor noticed poor engagement from students during full-semester online synchronous class and a very low rate of attendance. The last three weeks of the Fall 2021 semester, St. Ambrose and thus Electronics switched from hybrid to online delivery. The transition was smooth as it was designed to be flexible and switch to an online-only format. The only changes were that class and lab times were virtually held and quizzes and exams were administered and graded online. There was still a shift for everyone to work in a virtual environment. For the labs, the students already had their lab kits, but many were unable to return the kits until the spring semester. Students continued to complete their engagement activities and attend class and lab virtually. Despite the abrupt switch to distance-delivery in a matter of three days, there was no need to redesign elements of the course and only a need to shift to move in-person class, lab, and quizzes and exams to a virtual format through video conferencing and extending the learning management system use to include administering quizzes and tests. Thus, the flexibility of the course structure applies to instructors as well as students. Further study of the course structure where students *choose* the online mode of delivery would be needed to better understand the effectiveness of the course structure for full-semester online-only courses.

The instructor solicited formal anonymous feedback in the middle of the semester in addition to the required end of course evaluations. The mid-course feedback from Electronics students were the best two years out of the last five years of teaching where the two years implementing the prescribed course structure. Students were very happy with numerous aspects including:

- The ability to move at their own pace and be independent,
- The lecture videos and the ability to watch them more than once,
- Good examples and in an interactive way,
- Group work,
- Communication of expectations,
- Organization of modules, and
- Ability to retake and resubmit summative assessments.

The most striking mid-semester feedback was that three students listed nothing when asked what one change they would like to see. However, one cannot satisfy all and there were aspects to consider how to improve. There were some students who wanted lectures during class instead of videos and some who wanted more examples. Many students were struggling with the labs offered in hybrid mode and were spending too much time on them. Based on the feedback, students yearned for lab demonstrations or help setting up the labs since they were starting and completing them outside of lab time. This feedback was incorporated mid-semester by providing videos on how to construct the circuit in the labs. Students expressed their appreciation for and usefulness of the videos. During full F2F, feedback on labs during full F2F yielded no issues except that there were still several students spending a considerable about of time on them. Upon reflection, the instructor feels that labs are formative, and thus no longer includes them in assessments but rather as engagement credit opportunities for learning. This should address the time issue and improve the learning environment in fall 2022.

Students also have the opportunity to comment on end of course evaluations. The only negative comments were about how the labs were frustrating and that one student didn't like to be in the hybrid structure instead of face-to-face instructional mode. Students said about the course:

> *"I really enjoyed the challenge assessment, they really helped me understand the concept we were learning."*

> *"I loved the way this course was designed. It took the pressure to perform well off so that way we could focus on actually learning the material. It made me love the subject matter way more than any other class."*

> *"Overall, I had a great experience with this class."*

> *"The video lectures and the extra study sessions were absolutely helpful."*

Overall, the response to the course design by students was positive. The course evaluations and student grades showed high impact and very positive feedback from students. With the need for the hybrid structure eliminated, students did not express issues with the labs. Students who engaged heavily in the course were rewarded with understanding the material, improved EM, and grades that matched their effort and understanding.

Conclusion

Studies performed at Texas A&M and Saint Ambrose University created a well-defined course structure for STEM courses. The study provided very effective results which were verified through student evaluations and instructor reflection. Initially, the study was inspired and motivated by the existence of hybrid courses due to COVID-19, but the results produced by the study showed far reaching results that the same structure can be employed for all modes of learning; face-to-face, hybrid and online if sudden or temporary circumstances required it. Further study of the online delivery mode needs to be conducted for a course where students can choose to be online to determine if it is the course structure or other factors that results in lower course evaluations. However, applying the structure used for hybrid was effective for F2F delivery at the two institutions in multiple classes and allowed pivoting of the course delivery mode if needed.

The designed course structure, shown in Figure 1, at Texas A&M and at St. Ambrose in the semesters and modes of delivery show in Table 1 and Table 3, respectively. The implementation of the designed course structure produced a high impact in terms of student engagement and fostering inclusive learning which produced very positive feedback from the students generating the very high course evaluations for the courses employing the designed course structure in hybrid and F2F modes. The flexibility offered for students and their learning was highly valued. Students were rewarded for engaging with the course material and those with high engagement learned the material. It can be deduced that the above-mentioned course structure is both effective and helpful for student learning and success in engineering courses for different modes of learning including the traditional Face-to-Face and hybrid modes. It can further be concluded that the same course structure can be employed for STEM related courses as the structure has been applied to multiple different courses at different universities with different student populations and class sizes.

Overall, the similar course structures at Texas A&M and St. Ambrose are effective from both an instructor and student perspective, and they can be offered in multiple delivery modes including face-to-face instruction, hybrid, and online.

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