Multi-Disciplinary Approach to an Undergraduate Engineering Analysis Course

Alta Knizley, Rogelio Luck, and Aaron Smith
Mechanical Engineering Department, Mississippi State University

Abstract

Courses in the Mechanical Engineering curriculum should support practical applications, address various subject areas, and relate to other coursework. However, students often find it difficult to completely grasp the connections between courses. At Mississippi State University, the junior-level Engineering Analysis course links mathematical approaches across most mechanical engineering subject areas. Therefore, this course has been selected to introduce a multi-disciplinary instructional component that maps concepts from various courses through a common mathematical framework, while tying practical applications to the course material. The instructional techniques employed include homework and projects designed to illustrate practical examples of engineering solutions, verification statements, and in-class examples explicitly illustrating conceptual material from other courses and practical applications of numerical techniques. Additionally, ample opportunity for open discussion of material application to the overarching curriculum is provided. The primary objective is to help students' view their collective education as connected pieces of a whole process.

Keywords

Multi-disciplinary, integrated curriculum, mechanical engineering, engineering education.

Introduction

Courses within the mechanical engineering curriculum complement one another through applications of mathematical analysis and physical law, and a thorough understanding of lower-level courses is integral for students to successfully complete subsequent design-oriented courses that require a firm knowledge of basic physical and mathematical principles, as do their future engineering careers. However, it is often difficult for students to gauge the broader utility of their education in early science and math courses (before exposure to the engineering application of principles), and, therefore, students often develop a mindset focused on simply successfully completing a single course as opposed to fully comprehending and gaining useful knowledge from each course within a curriculum. In other words, if students aren't yet aware of the usefulness of what they are learning, they may not tend to focus on retention of material. This issue has also been raised by Rahmat et al.[1], stating that after a more foundational math and science approach was introduced to engineering curriculum post WWII, a new problem has emerged where students do not relate foundational knowledge to engineering. A proposed solution included introducing real engineering problems to first-year students to ascertain conceptual solutions before learning the foundational knowledge.

Part of the difficulty in helping students relate course material lies in the traditional, and natural, method of teaching foundational engineering principles at early stages in the curriculum, while design stages are typically reserved for late-curriculum courses, once the foundational knowledge should be adequate to address more complex problems. Unfortunately, however, foundational knowledge is not always adequately retained when moving into higher-level courses, and instructors often spend significant course focus to review material that students should already have retained. As stated by Felder and Silverman[2], the engineering curriculum is presented in a deductive manner, with application-oriented material demonstrated post-principle presentation, and this methodology is difficult for inductive learners to comprehend. These students require motivation for learning through understanding the utility of the knowledge while learning it; they do not inherently trust that the knowledge will one day be useful when not provided with adequate context of application. While senior-year design courses do serve to wholly integrate the curriculum, the integration of principles in these courses often comes too late to best support many student learning styles.

In addition to integrating the conceptual topics and applications into early courses from a whole curriculum approach, it is also imperative to show students the industrial applications of course content[3]. These two important components of motivating student learning suggest incorporating inter- and multi-disciplinary approaches to engineering education. The distinction between the terms has been outlined by Ashford[4], who states that inter-disciplinary implies teaching between disciplines, ultimately leading to a merger of parent disciplines, while multi-disciplinary teaching indicates the assimilation of several different disciplines, focusing on multiple aspects at once (e.g., technology and cost, structural and thermal integrity) instead of only looking at one aspect of a project/problem at a time. Such multi-disciplinary approaches are also referred to as integrated curriculum approaches to engineering education. Harrison et al.[5] have developed an inter-disciplinary design course series that serves to link engineering and economics, and Grigg et al.[6] have developed an integrated curriculum across 8 courses in a civil engineering program that serve to strengthen the design and innovation skillsets of students, as well as garner industry support and allow for flexible implementation.

In this paper, a multi-disciplinary teaching approach to an early-level mechanical engineering (ME) course, Engineering Analysis, is examined. The approach, introduced over the Fall 2016 semester, utilizes instructional techniques including, but not limited to, homework and projects designed to illustrate practical examples of engineering solutions, verification statements requiring students' comments on the governing principles regulating the mathematics, and in-class examples that explicitly illustrate practical applications of numerical techniques as well as explicitly incorporate conceptual material from other ME courses. The primary objective of these instructional techniques is to broaden students' perspectives, such that they view their collective education as connected pieces of a whole process, as opposed to viewing a single course as simply a means to an end or as a stand-alone component. This paper will illustrate the effectiveness of the contribution of these instructional techniques toward meeting the primary objective, measured through quantitative survey data and performance indicators as well as through qualitative discussion with and observation of Engineering Analysis students.

Course Structure and Content Examples

The Engineering Analysis (ME 3113) course is a required course in the undergraduate ME curriculum, suggested for students to take during the first semester of junior year, and it, along with Thermodynamics I, is one of the first intellectually rigorous courses within the departmental curriculum to which students are exposed (junior- and sophomore-level general engineering courses are taught outside of the ME department). Two of the stated learning objectives from the class are for the students to be able to identify problems and formulate engineering solutions using multiple approaches and to be able to demonstrate thorough understanding (at basic level) of all topics covered in the course, notably including: analytical techniques involving roots of equations, linear algebra, numerical differentiation and integration, and ordinary differential equations. The nature of this course would make it easy to simply focus on demonstrating the mathematics without context, but that can lead to the learning obstacles described in the previous section. Instead, this course is being used to help students develop an understanding of the whole, integrated curriculum of mechanical engineering, encouraging them to think critically about the utility of subject matter in terms of connected coursework and practical application. The techniques used to do this are articulated below.

Homework problems for ME 3113 are carefully selected to integrate course material or to provide practical examples of the material. For instance, instead of simply having students solve an ODE using Euler's method, context was given to relate the ODE to heat transfer as shown in the problems presented in Fig. 1.

PROBLEM 3

A solid steel shaft at 27°C must be contracted so that it may be shrunk-fit into a hollow tube. It is placed in a refrigerated chamber that is maintained -33°C. The rate of change of the temperature of the solid shaft, θ, is given by:

$$\frac{d}{dt}\theta(t) = -5.33\cdot10^{-6}\cdot\left(-3.69\cdot10^{-6}\cdot\theta^4 + 2.33\cdot10^{-5}\cdot\theta^3 + 1.35\cdot10^{-3}\cdot\theta^2 + 5.42\cdot10^{-2}\cdot\theta + 5.588\right)\cdot(\theta + 33)$$

$$\theta(0) = 27\,°C$$

Using Euler's method, find the temperature of the steel shaft after 86400 seconds. Use a step size of 21600 seconds. Re-do the Euler approximation using a step size of 9600 seconds.

PROBLEM 4

In heat transfer, the temperature profile for steady conduction disseminated radially through a solid wire (inner radius $r_i = 0.0$ cm) with outer radius $r_o = 1$ cm, with constant heat generation (e_{gen}) and constant thermal conductivity (k), is governed by:

$$\frac{dT}{dr} = -\frac{e_{gen}}{2\cdot k}\cdot r$$

If heat generation is 38.6 MW/m^3 and thermal conductivity is 20 W/m·K, and centerline temperature $T(r_i) = 380$ K, use Euler's method to approximate the temperature profile, T(r), using 50 points on the interval from r_i to r_o. Determine the surface temperature (in K) at $r = r_o$ using your approximate Euler solution.

Figure 1. Example of Euler's method problems.

In addition to using contextual problems, students are required to complete a verification section for each problem. The verification section requires students to think critically about the problem and their solution to determine if the solution is reasonable in a practical sense.

In-class examples are also utilized to provide show multi-disciplinary and practical applications of the mathematics presented in the course. Some of the examples to which students have responded well include the "smoking example," to demonstrate systems of equations from mass flow balances in a restaurant, and the "water heater example," to solve an ODE describing temperature of water exiting a household water heater. The smoking example came from the course textbook[7], and its practical application includes determining the carbon monoxide exposure to children from the smoking section of a restaurant and the efficacy of adding a screen to reduce carbon monoxide. The water heater example uses thermodynamics to determine a governing ODE for water temperature exiting a household water heater. Practical values for water heater volume capacity, shower flow rates, and power requirements are found during class through quick google searches, and temperatures are estimated based on realistic and reasonable values. This easily-relatable information is then utilized to determine how long one can shower before the water gets "cold" (skin temperature), and how long one has to wait to take a hot shower after a roommate took too long to shower. With these examples, students see that the mathematical analysis matches the data they've gathered in their own empirical experiences. During each practical example, in-class discussion is opened through questions designed to encourage critical thinking about broad applications of the material. Other practical examples shown and discussed in the course have included a runge-kutta model for a piston-cylinder, bridging dynamical and thermodynamic modeling, modeling systems of equations using truss problems and electrical circuit applications, and showing how a household washing machine can be modeled as a mass-spring-damper system.

Projects are also utilized in ME 3113 to encourage student development and understanding of practical application and multi-disciplinary applications. Additionally, the projects serve to require students to engage in independent learning and form a mathematical model of a physical scenario on their own. The Fall 2016 ME 3113 course included two major projects to tie Engineering Analysis course material to practical, contemporary, and relatable challenges. Project 1 required students to explore the accuracy of the Pokemon Go app as it measures distances, on linear and curved paths at walking and running paces, given that the app takes location data each minute and models a linear path between location data points. Students were required to model the path given by the app vs the true path, to determine the error of the app distance log for each path at each pace, and to research distance measuring apps to make a recommendation. Project 2 required students to investigate the effect of damping on motorcycle performance. Students were to model a motorcycle suspension as a mass-spring-damper system, and evaluate seat and handlebar displacements (and velocities) for underdamped, critically damped, and overdamped scenarios, as well as to research each damping scenario and discuss their ideal damping case for a motorcycle.

Results

Students responded well to the course structure. Students took voluntary surveys throughout the semester, and select questions and available responses are given in Table 1. Survey data for student response to questions listed in Table 1 is shown in Fig. 2 - 3. The survey respondent number is indicated by N, and there were a total of 69 students enrolled in the class.

Table 1. Survey Questions

Q1	N=61	**To me, the most interesting (or most applicable/relevant) topic that we have covered so far is:**
	A	Introduction to Mathcad
	B	Taylor series and its applications
	C	Euler's method to numerically solve first order ODEs
	D	Roots (Newton's method, Picard iterations)
	E	Systems of Equations (trusses, electrical systems, mass flow) with matrix applications
	F	I haven't found any topic that we've discussed in class interesting or applicable.

Q2	N=61	**HW2, P3 and 4 helped me better understand the practical applications of heat transfer and/or the cross-over relationships between subject areas within the ME curriculum**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q3	N=61	**HW2 P5 helped me better understand the practical applications of thermodynamics and/or the cross-over relationships between subject areas within the ME curriculum.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q4	N=61	**HW2 P6 helped me better understand the practical applications of fluids and/or the cross-over relationships between subject areas within the ME curriculum.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q5	N=61	**At this point in the semester (midterm), I feel more confident in my understanding of the how the breadth of the ME curriculum integrates subject matter than I did at the start of the semester.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q6	N=47	**The water heater example provided me with an example of a practical application of differential equations, thermodynamics, and/or heat transfer.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q7	N=47	**The water heater example helped me to understand the relationship between engineering analysis and thermodynamics and/or heat transfer.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree
Q8	N=47	**The water heater example helped me to understand the relevance of differential equations in an engineering solution.**
	1 to 5	Likert scale; 5=Strongly agree, 1=Strongly disagree

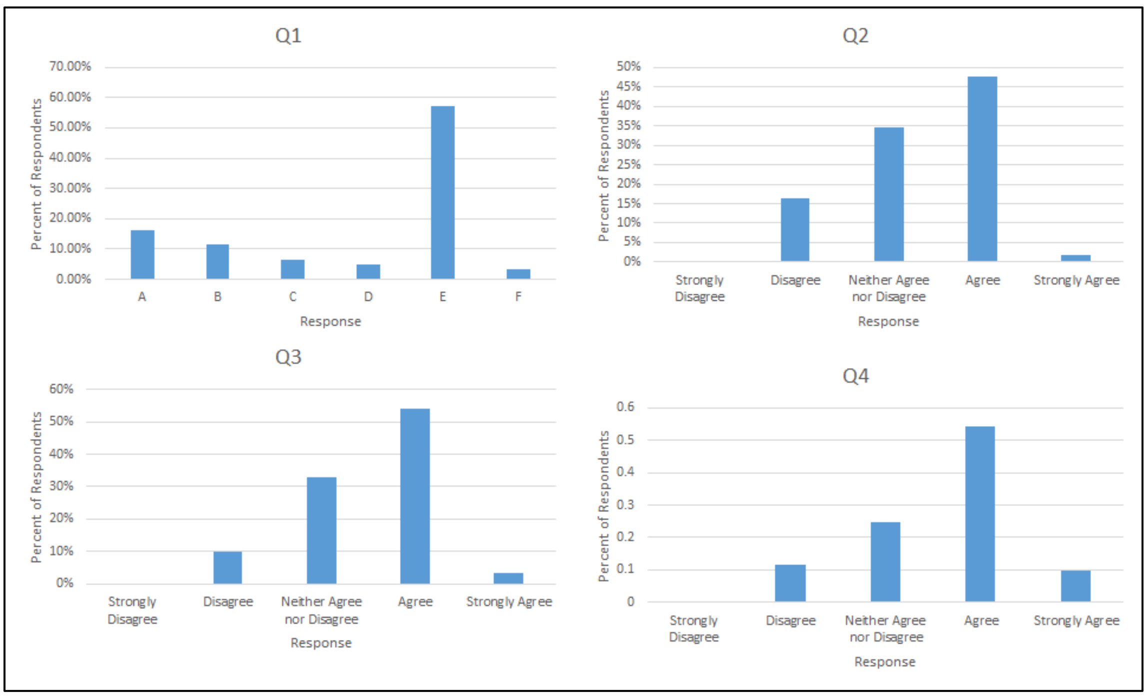

Figure 2. Survey results, Q1-Q4.

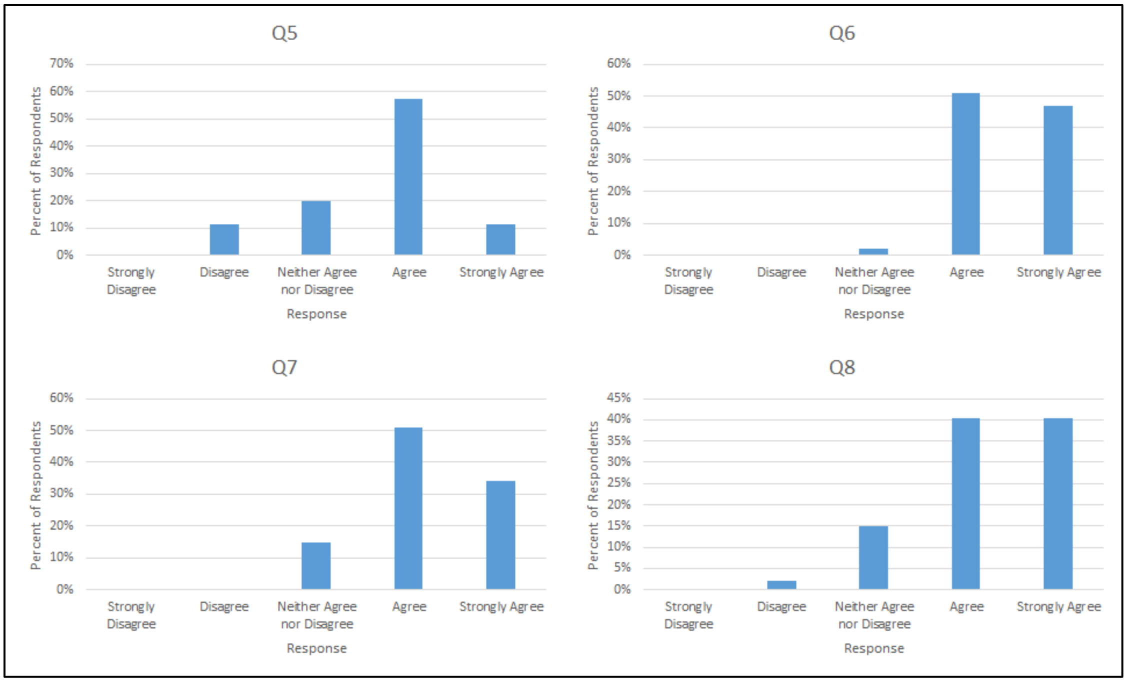

Figure 3. Survey results, Q5-Q8

The results displayed in Fig. 2-3 indicate that the students are satisfied with the presentation of material in the course and that they learned on a multi-disciplinary scale. Student comments in the surveys also indicate satisfaction with the course, as well as indicating comprehensive learning. The comments were overwhelmingly positive, and a sample of comments signifying that the primary objective was met includes:

- I really enjoyed having a real world application of what we have been learning
- I enjoyed this lecture a lot! It helped me think of more creative ways to observe everyday activities!
- Great real life example that gained my interest due to its relevancy
- This class has shown me how math we learned in engineering can be applied to real life
- Overall I see the importance of small things we have learned through out the ME curriculum. When learning Taylor Series in cal II I was thinking to my self that I would never use this, but now I see how useful of a tool it is.
- The varying topics of the homework have helped show me the broad scope of ME, and the various applications of MathCad

Additionally, beginning-of-semester (3-4 weeks into semester, Survey 1) and end-of-semester (all coursework completed, Survey 2) surveys were distributed to determine students' perceptions and growth throughout the Fall 2016 semester ME 3113 course. A comparison of student responses to select representative questions at the beginning and end of term is given in Figure 4. 43 students responded to Survey 1, while 44 students responded to Survey 2. Overall, the survey data clearly shows that the students are more confident in their abilities and their understanding of mechanical engineering subjects and applications after the completion of this course. At the end of the semester, 93% of survey respondents expressed satisfaction with the amount of knowledge gained through the ME 3113 course.

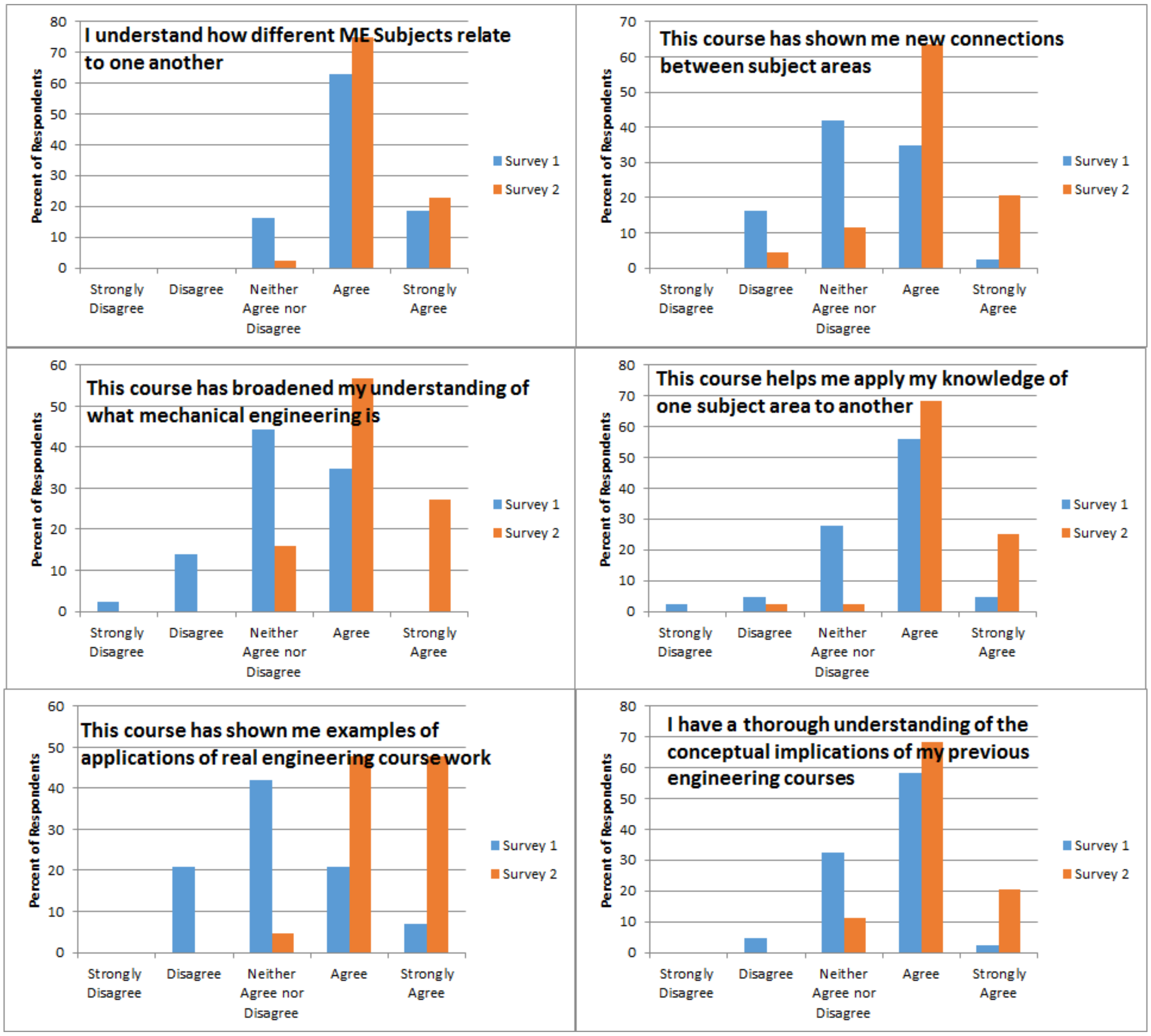

Figure 4. Selected Survey Questions, Beginning and End of Semester Comparison

Conclusions

In the junior-level Engineering Analysis course, a conscious effort was made to help students understand relationships between early curriculum subject matter and practical engineering applications, as well as to help them understand the integrated nature of the mechanical engineering curriculum. This effort is displayed through homework and example problems, in class discussion, and projects. From survey assessment data and student comments, indicators reveal that the methodology is successful in achieving this broadening of student perspective and that students respond favorably to the methodology used in this course. On the whole, student feedback reveals that they have improved their knowledge of engineering analysis as well as their understanding of mechanical engineering, on the whole, through the framework of this ME 3113 course.

References

1. bin OK Rahmat, Riza Atiq, Kamarudin Mohd Yusof, and Roszilah Hamid. "Relating basic courses to engineering problems." Procedia-Social and Behavioral Sciences 60 (2012): 52-55.

2. Felder, Richard M., and Linda K. Silverman. "Learning and teaching styles in engineering education." Engineering education 78.7 (1988): 674-681.
3. Mills, Julie E., and David F. Treagust. "Engineering education—Is problem-based or project-based learning the answer." Australasian journal of engineering education 3.2 (2003): 2-16.
4. Ashford, Nicholas A. "Major challenges to engineering education for sustainable development: what has to change to make it creative, effective, and acceptable to the established disciplines?." International Journal of Sustainability in Higher Education 5.3 (2004): 239-250.
5. Harrison, Gareth P., D. Ewen Macpherson, and David A. Williams. "Promoting interdisciplinarity in engineering teaching." European Journal of Engineering Education 32.3 (2007): 285-293.
6. Grigg, Neil S., et al. "Integrated civil engineering curriculum: Five-year review." Journal of Professional Issues in Engineering Education and Practice 130.3 (2004): 160-165.
7. Chapra Steven, C., and P. Canale Raymond. Numerical methods for engineers. Tata McGraw-Hill Publishing Company, 2015.

Alta Knizley

Alta Knizley is an Assistant Clinical Professor in the Mechanical Engineering Department at Mississippi State University. She obtained her Ph.D. in Mechanical Engineering from Mississippi State University in 2013. She has an avid interest in undergraduate education and a strong background in energy-related course curriculum.

Rogelio Luck

Rogelio Luck received the B.S. degree from Texas Tech University in 1984, and the M.S. and Ph.D. degrees from Penn State Univ., all in Mechanical Engineering. In 1989 he joined the faculty of the Mechanical Engineering Dept. at Mississippi State University where he is currently the Associate Department Head and TVA Professor. His recent research interest is in the area of Cooling, Heating, and Power.

Aaron Smith

Aaron Smith is an Assistant Clinical Professor in the Mechanical Engineering Department at Mississippi State University. He obtained his Ph.D. in Mechanical Engineering from Mississippi State University in 2012.