

Work in Progress: Enhancing Engineering Education through Course Alignment: A Structured Approach to Integrating Learning Outcomes, Content, and Assessment

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Abstract

Effective course design is critical in engineering education to ensure students achieve the intended learning outcomes. This paper introduces a structured approach to course alignment and mapping, with a focus on creating measurable learning outcomes and integrating them with course content, assessments, and instructional strategies. Using Bloom's Taxonomy as a guiding framework, the approach begins by developing clear, actionable learning outcomes. Course content and assessments are then aligned with these outcomes to ensure coherence. A course mapping matrix visually represents this alignment, enhancing course structure and improving the student learning experience.

This method was applied to the Engineering Computations course, leading to significant improvements in both student engagement and performance. Quantitative results showed an increase in average assessment scores after implementing the course alignment, while qualitative feedback from student surveys indicated improved satisfaction with course organization and perceived relevance of the material.

By offering a detailed case study, this paper provides practical insights into how structured course design and alignment can enhance the effectiveness of teaching methods and assessments in electrical engineering education. The findings suggest that this approach can be successfully applied to other courses to improve student outcomes and enrich the learning experience.

Introduction

Constructive alignment is a vital framework for designing curriculum and assessments that align with course learning outcomes, introduced by Biggs and Tang [1]. This approach emphasizes synchronizing teaching methods, activities, and assessments with course objectives to ensure students achieve the desired outcomes. By integrating active learning and assessment strategies, constructive alignment becomes a cornerstone for effective instructional design. Biggs [2] particularly noted its utility in engineering education, ensuring that learning outcomes, teaching activities, and assessments form a coherent structure.

Watson et al. [3] demonstrated the application of constructive alignment in engineering programs through course mapping matrices, which visualize and align course components. This approach led to measurable improvements in student performance. Similarly, Malmqvist et al. [4] explored its role in supporting CDIO (Conceive, Design, Implement, Operate) frameworks, connecting theoretical knowledge with real-world problem-solving in engineering education.

The concept of "backward design," introduced by Wiggins and McTighe [5], complements constructive alignment by encouraging educators to begin with desired learning outcomes,

develop assessments, and then create instructional activities. This process ensures coherence between objectives, assessments, and instructional practices, fostering deeper understanding and mastery. Clear objectives and alignment across course components are essential to creating meaningful educational experiences.

Bloom's Taxonomy, revisited by Anderson and Krathwohl [6], provides a foundational framework for aligning learning objectives with assessments and instructional strategies. They revised the taxonomy and introduced a two-dimensional model, encompassing knowledge dimensions and cognitive processes, which aids in categorizing objectives and aligning them with activities and assessments. Fink [7] expanded on this by proposing an integrated course design model that aligns learning goals, feedback, assessments, and teaching activities. His approach emphasizes the importance of cohesive course elements to create engaging and significant learning experiences.

In addition, Harden [8] highlighted practical methods for curriculum mapping, using visual representations to align objectives, content, and assessments. While his work primarily focuses on medical education, these methods are widely applicable across disciplines and support continuous improvement in curriculum design.

The importance of course alignment has been acknowledged for decades. Tyler [9] established foundational principles of curriculum development, emphasizing the necessity of clear objectives and aligned assessments. Anderson and Krathwohl's [6] work built on Tyler's ideas, providing practical tools for crafting measurable learning outcomes. Problem-based learning (PBL) also demonstrates alignment in course design, enhancing critical thinking and knowledge retention by connecting content with active learning strategies, as discussed by Norman and Schmidt [10].

Further contributions to course alignment come from Diamond [11], who offered a comprehensive guide to curriculum design, stressing the importance of aligning goals, activities, and assessments. His work remains a valuable resource for developing course maps that support learning outcomes.

In engineering education, alignment is crucial for balancing theoretical and practical knowledge. Felder and Silverman [12] emphasized tailoring teaching methods to accommodate diverse learning styles, while Froyd and Ohland [13] advocated for pedagogical reforms that incorporate active learning, teamwork, and contextual relevance. These efforts underscore the role of alignment in fostering effective and engaging educational experiences in technical fields.

Engineering Computation Course and Learning Outcomes

Aligned with ABET requirements for the electrical engineering curriculum, this course covers essential topics such as the applications of probability, statistics, and linear algebra, which are fundamental to the field. Introduced in 2013, the Engineering Computation course provides a robust foundation in computational and analytical methods relevant to electrical engineering. The core topics include:

- Understand and apply MATLAB and Simulink for solving electrical engineering problems
- Interpret and present data using appropriate representation and characterization techniques

- Calculate and interpret probability and statistics with applications in electrical engineering
- Understand and apply confidence intervals and hypothesis testing
- Understand and apply failure and reliability analysis in electrical engineering
- Model, simulate, and evaluate engineering systems
- Solve systems of differential equations
- Solve algebraic equations relevant to engineering applications
- Apply linear algebra concepts to electrical engineering problems, including:
 - Model electrical circuits
 - Analyze two-port system responses

The course aims to equip students with the following competencies:

1. Demonstrate proficiency in using MATLAB and Simulink as computational tools.
2. Effectively display, interpret, and analyze diverse representations of data.
3. Calculate and interpret fundamental statistical measures, such as mean and variance.
4. Calculate probabilities and apply common continuous probability distributions to engineering problems.
5. Understand and apply confidence intervals and hypothesis testing for decision-making in product acceptability and reliability.
6. Apply probability principles to evaluate generation system reliability.
7. Use linear algebra techniques to solve systems of equations manually and computationally in electrical engineering contexts.
8. Calculate eigenvalues and eigenvectors, diagonalize matrices, and apply these concepts to analyze control systems.
9. Determine state-variable representations of systems and analyze their dynamic characteristics.
10. Demonstrate effective communication skills through written lab reports and oral presentations.
11. Collaborate effectively in group settings and contribute to team-based tasks.

Course Evolution

Previously, the course emphasized broad content coverage and predefined learning outcomes. While students were provided with a syllabus and course outcomes, there was limited structured alignment or mapping to demonstrate the connection between various course components. Consequently, students often expressed uncertainty, asking questions like, "What am I supposed to learn from this?" or "How does this quiz or lecture align with the overall goals of the course?"

The introduction of structured course mapping and alignment has since addressed these concerns, providing students with a clear understanding of how individual lessons, assignments, and assessments contribute to their achievement of the course's overarching objectives.

Course Mapping and Alignment: A Structured Approach to Enhance Learning

Course mapping and alignment are essential processes in designing an effective and student-focused curriculum. The first step in this approach is establishing a clear and direct relationship between course outcomes, unit and lesson outcomes, and assessment activities. This alignment ensures that every element of the course contributes toward achieving the desired learning outcomes. Additionally, it provides transparency for students, showing how each component of the course—lectures, assignments, and assessments—supports their learning journey.

Establishing Alignment Across Course Elements

Course outcomes define what students are expected to learn, and course mapping will show how they will learn it, and how their learning will be measured. These outcomes are mapped to specific units and lessons, with corresponding assessments designed to evaluate the level of mastery at each stage. For example, consider the course outcome 4 "Skill in calculating probabilities and applying common continuous probability distributions". This outcome is addressed through three units. For instance, Unit 1 focuses on calculating the probability of events using tools such as tree and Venn diagrams. This unit is further divided into four lessons, such as Introduction to Random Experiments and Sample Space, etc. Figure 1 illustrates the unit mapping process, while Table 1 in the appendix provides a detailed course structure. These tools offer a visual and organized representation of the course's alignment.

Breaking down course outcomes into unit and lesson-specific objectives provides students with a clear understanding of what they need to achieve at each stage of the course. This structured approach reduces common uncertainties, such as, "Will this be on the test?"

Each lesson and unit is accompanied by targeted assessments, such as weekly quizzes, homework and computer assignments, which are explicitly designed to cover the material taught. For example, in a 70-minute lecture, 2–4 lessons might be covered, with weekly quizzes or assignments reinforcing the content. Assessments are aligned with the unit outcomes to ensure comprehensive evaluation.

Students feedback:

At the end of the semester, students were invited to participate in a survey aimed at evaluating the effectiveness of the newly implemented unit-based course structure. The survey was carefully designed to gather both quantitative and qualitative feedback, ensuring a comprehensive understanding of students' experiences and perceptions. The combination of closed ended (scaled and yes/no) and open-ended questions was intended to balance structured data collection with opportunities for nuanced insights.

The survey was administered online through a secure platform to ensure accessibility and ease of completion. Students were provided with a unique link via email. To capture comprehensive reflections on their experience, the survey was made available during the final week of the

semester. To encourage honest and candid responses, it was designed to be anonymous, ensuring individual responses could not be traced back to any student. Although participation was optional, students were strongly encouraged to respond. Multiple reminders were sent through class announcements and email to emphasize the importance of their feedback in shaping future course improvements.

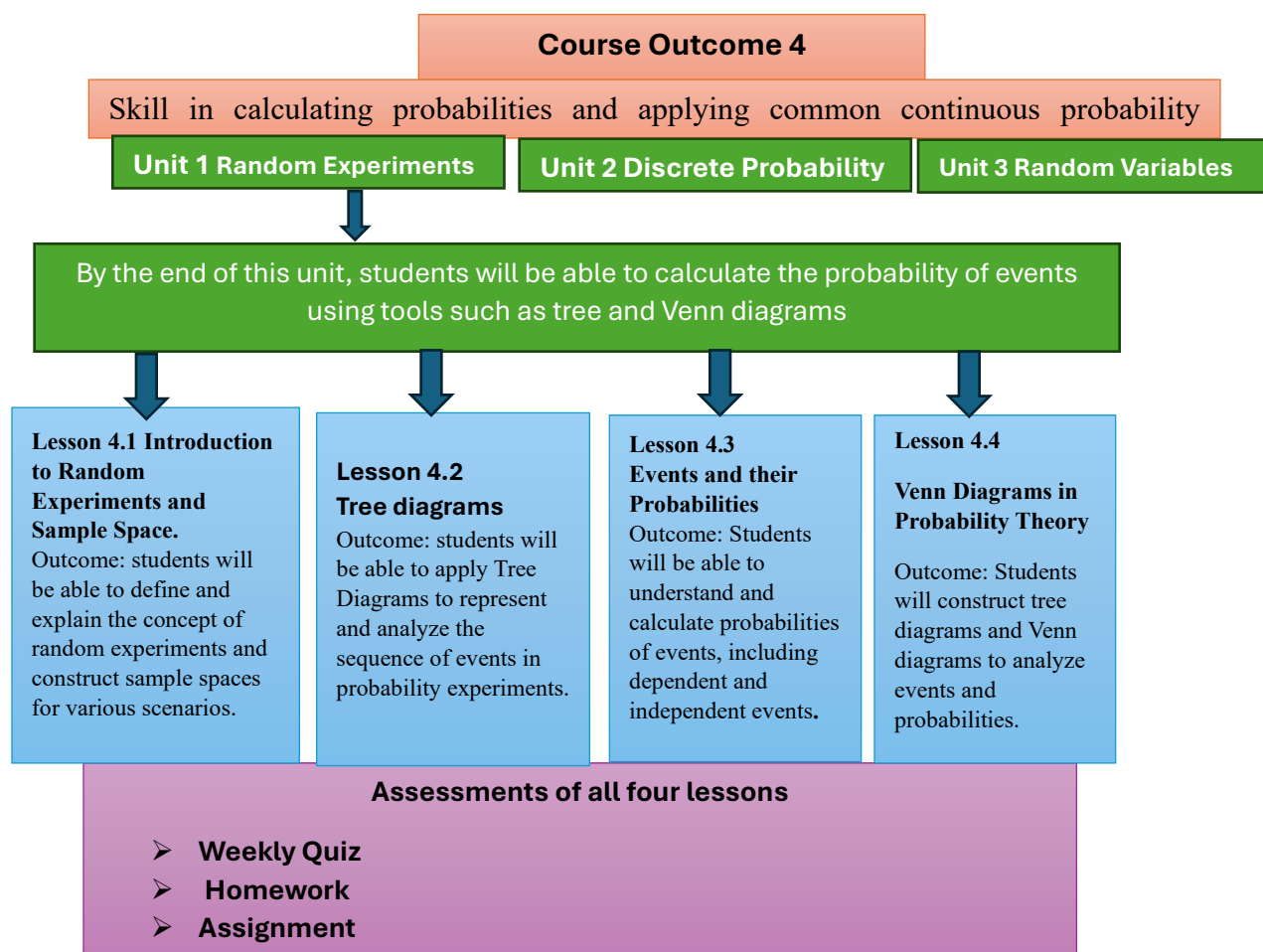


Figure 1. Course mapping and alignment

A. Survey Questions:

1. **Understanding the Course Structure:** To evaluate whether students grasp the overall organization.

- On a scale of 1 to 5, how clearly does the unit-based structure help you understand the course roadmap?
- Do you find the breakdown of the course into units and lessons helpful for understanding the material? (Yes/No, with optional open-text explanation)

2. Learning Experience:

- How effectively do the assignments in each unit reinforce your understanding of the lessons?
- What aspects of the unit-based approach have most contributed to your learning? (Open-ended)

3. Engagement:

- Do you feel more engaged with the course due to the modular breakdown into units and lessons? Why or why not? (Open-ended)

4. Suggestions for Improvement:

- Are there any specific improvements you would suggest for the unit-based structure or assignments? (Open-ended)
- What additional resources or support would help you succeed in this course? (Open-ended)

5. Overall Feedback:

- Overall, how satisfied are you with the restructured course format? (Scale: Very Satisfied to Very Dissatisfied)
- Do you have any additional comments or feedback about the course structure? (Open-ended)

B. Results

Twenty students responded to the survey. Overall, 18 students felt that the unit-based structure helped them better understand the course layout, while 2 students felt that the unit-based structure made no difference in their learning. Figure 2 shows the students' ratings of the unit-based structure.

When students were asked to answer yes or no regarding whether the structure was helpful, 14 students responded yes, and 6 students responded no. However, they provided much more detailed and helpful comments.

Students overwhelmingly satisfied and found the unit-based breakdown helpful for both understanding the material and managing their learning process effectively. The approach promoted clarity, focus, and confidence while providing tools for organization and engagement.

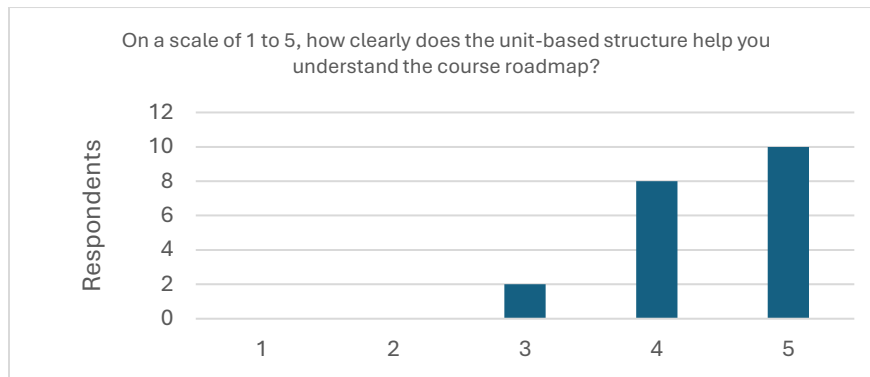


Figure 2. the students' ratings of the unit- based structure.

Their open-ended comments were analyzed and summarized as follow:

Clarity and Structure

Students appreciated the clear breakdown of the course into smaller units, which made the material less overwhelming and easier to follow. Many valued knowing what to expect in each unit, allowing them to plan their study time effectively.

Focus and Retention

The focused lessons helped students retain information more effectively. Smaller, manageable goals for each unit reduced stress and enhanced overall comprehension.

Logical Progression

The logical progression of units contributed to a better understanding of the course's overall goals. The modular approach allowed students to build on prior lessons, creating a stronger foundation.

Assessment Alignment

Assignments were directly tied to the lessons, which reinforced key concepts and solidified understanding. Students appreciated the assignments as challenging yet relevant, adding meaningful value to their learning experience.

Engagement and Motivation

The unit-based structure kept students engaged, as they could clearly see their progress after completing each unit. Additionally, the unit format provided a sense of accomplishment, motivating them to continue their studies.

Review and Organization

The ability to revisit specific units for test preparation proved highly beneficial. Students found that the structured format encouraged organization and consistent study habits.

Confidence Building

Clear learning objectives for each unit boosted students' confidence by showing how each unit

contributed to the bigger picture. The smaller lessons helped them stay on track and avoid procrastination.

Although positive comments highlight that the modular structure is helpful for organization and provides clarity, a few students feel that more interactive or hands-on activities would keep them more engaged. Some find certain course parts challenging to connect, while others feel the pace can be slow. Negative comments express dissatisfaction with the rigid modular design, as it lacks flexibility and does not provide an integrated approach. Some users prefer practical examples over the modular breakdown, and others find the repetition in the units hard to stay engaged with.

Critical feedback includes suggestions for improving the course structure, such as breaking longer units into smaller sub-units and ensuring better alignment between assignments and lessons for increased effectiveness. Some users would appreciate more challenging problems in assignments to deepen their understanding, while others recommend adding checklists of key takeaways at the end of each unit for better clarity and retention.

Conclusion:

Many engineering professors start as engineers before transitioning to teaching, often with minimal training in pedagogy. In my early years of teaching, I focused on creating course content and materials, continuously refining them to enhance student learning. However, I occasionally noticed that students struggled to understand the course structure, the relevance of the information, and how different elements were interconnected. While the relationships between the course components have always been clear to me, I had not formally documented or published them.

The Engineering Computation course is one of the more challenging offerings in our department, with a strong emphasis on mathematics. While students are eager to probe into electrical engineering applications, they must first develop a solid foundation in math to succeed. This often leads to questions like, "What am I supposed to gain from this?" and "Why are we learning this?" The goal of course mapping and alignment was to address these questions by providing students with a clear understanding of the course objectives and the connections between its components. While mapping this course, I realized that some assignments and content did not align with the course outcomes. As a result, I removed those elements and developed new content to ensure a stronger focus on the lesson and unit objectives.

Previously, the average score for this course was approximately 80 out of 100. Following the adoption of the structured approach, the mean class grade increased to 85. However, it remains uncertain whether this improvement was solely due to the unit-based approach or if it was influenced by the inherent characteristics of the class cohort. We plan to apply this method for the second half of semester, and the first half would be just using traditional method. In this case, students have two cases to compare with. A detail study is needed to accurately validate the approach. However, students' feedback highlights that the structured approach to course alignment and mapping in Engineering Computation was effectiveness, particularly through the application of Bloom's Taxonomy.

Lastly, the process of course mapping and alignment is neither challenging nor time-consuming with the assistance of ChatGPT. By providing the course coverage, outcomes, and content, ChatGPT was able to generate units, lessons, and related assignments efficiently. However, fine-tuning is necessary to align the generated lessons and units with the specific teaching materials and objectives of the course.

Future work could focus on refining the modular approach by incorporating more interactive and hands-on activities to address feedback regarding engagement. Additionally, expanding the use of this structured alignment method across other disciplines or multi-disciplinary courses could validate its broader applicability. Continuous enhancement through feedback loops, including more diverse assessment methods and adaptive learning tools, would further tailor the learning experience to meet individual student needs.

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Appendix

	Lesson	Outcomes	Assessments
Unit 1: Descriptive Statistics	1. Introduction to Descriptive Statistics 2. Calculation of Mean (Sample and Population) 3. Understanding and Computing Variance, Standard Deviation and Its Interpretation 4. Range and Median in Data Analysis	Students will understand the fundamental concepts of descriptive statistics. - Students will calculate and interpret the mean, variance, and standard deviation for both sample and population data. - Students will analyze the distribution of data using range and median as measures of central tendency.	Quiz1 Homework
Unit 2: Graphical Summaries of Sampled Data	1. Overview of Graphical Data Representation 2. Constructing and Interpreting Histograms 3. Stem-and-Leaf Plots for Data Summarization	- Students will learn how to visually represent data using histograms and stem-and-leaf plots. - Students will develop the ability to interpret and draw conclusions from graphical data summaries.	Quiz 2 Computer Assignment 1
Unit 3: Random Experiments	1. Introduction to Random Experiments and Sample Space, 2. Constructing and Interpreting Tree Diagrams 3. Understanding events and their probabilities 4. Venn Diagrams in Probability Theory	- Students will understand the concept of random experiments and how to define sample spaces. - Students will construct tree diagrams and Venn diagrams to analyze events and probabilities.	Quiz 3 Homework
Unit 4: Probability - Discrete	1. Basics of Probability Calculation 2. Counting Techniques in Probability 3. Conditional Probability and Its Applications 4. Understanding and Applying the Total Probability Rule 5. Random Sampling from a Batch 6. Independence in Probability 7. Series and Parallel Systems in Probability Analysis	- Students will grasp the foundational principles of discrete probability. - Students will apply counting techniques and calculate probabilities for various events. - Students will understand and use the concepts of conditional probability, independence, and series/parallel systems.	Assignment 2
Unit 5: Random Variables	1. Introduction to Random Variables and Probability Distributions 2. Understanding and Calculating Density Functions 3. Mean and Variance of Continuous Density Functions 4. Cumulative Distribution Functions 5. Uniform, Exponential, and Gaussian Distributions 6. Introduction to Non-standard Gaussian Distributions	- Students will understand the concept of random variables and their probability distributions. - Students will compute and interpret density functions, means, and variances of continuous random variables. - Students will be able to differentiate between various probability distributions.	Quiz 4
Unit 6: Confidence Intervals	1. Steps to Estimate the Mean and Its Confidence Interval 2. Determining Sample Size for Confidence Intervals 3. One-sided vs. Two-sided Confidence Intervals 4. Large Sample Size and Unknown Variance Analysis 5. Small Sample Size Considerations: T-Distribution	- Students will learn to calculate and interpret confidence intervals for means and proportions. - Students will understand the impact of sample size and variance on confidence interval estimation.	Quiz 5 Assignment 3 Exam 1: covers Unit 1-6

	6. Confidence Interval on the Variance Using Chi-Square Distribution 7. Confidence Interval for a Population Proportion with Large Samples 8. Choosing the Appropriate Sample Size		
Unit 7: Hypothesis Testing	1. Introduction to Hypothesis Testing on Mean 2. Understanding and Calculating P-values 3. Hypothesis Testing When Variance is Unknown 4. Differentiating Between Type I and Type II Errors	- Students will understand the principles and procedures of hypothesis testing. - Students will be able to perform hypothesis tests and interpret p-values. - Students will distinguish between Type I and II errors and understand their implications.	Quiz 6
Unit 8: Application of Probability in Electrical Engineering	1. Reliability of Communication Systems 2. Analyzing Loss of Load Probability in Power Systems	- Students will apply probability concepts to analyze the reliability of communication systems. - Students will assess loss of load probability in electrical engineering contexts, linking theoretical knowledge to practical applications.	Assignment 4
Unit 9: Linear Algebra	1. Introduction to Linearity - Definition and properties of linear systems. - Applications in electrical circuits. 2. Arrays, Matrices, and Vectors - Understanding arrays and matrices. - Operations with vectors. 3. Applications in Circuit Analysis - Applying linear algebra to solve electrical circuits. 4. Matrix Operations - Transpose, addition, subtraction, scalar multiplication, and identity matrix. - Dot product and matrix multiplication. 5. Determinants - Calculation of determinants. - Properties of determinants.	- Understand the concepts of linearity and its application to electrical engineering problems. - Perform operations with matrices and vectors, including addition, subtraction, and multiplication. - Apply matrix algebra to solve circuit equations and analyze electrical circuits. - Calculate determinants and understand their properties in the context of electrical engineering.	Quiz 7
Unit 10: Solution of Linear System of Equations	Lessons: 1. Cramer's Rule - Step-by-step procedure and examples. 2. Gaussian Elimination - Step-by-step procedure and examples. 3. Circuit Applications - Solving circuit problems using linear systems. 4. Matrix Inversion - Inverse of a matrix using cofactor expansion and Gaussian elimination. - Inverse of a matrix using Gaussian elimination. 5. Vector Dependence and Independence - Understanding linear dependence and independence of vectors. 6. Rank of a Matrix - Calculation and significance in determining solutions. 7. Types of Solutions - Unique, infinite, and no solution cases.	- Solve linear systems using Cramer's rule and Gaussian elimination. - Apply these methods to solve real-world circuit problems. - Calculate the inverse of a matrix using different methods. - Determine the rank of a matrix and understand its implications for system solutions. - Distinguish between unique, infinite, and no solution cases in linear systems.	Assignment 5 Exam II covers units 6-10 Quiz 8

Unit 11: System Representations	<ol style="list-style-type: none"> 1. Differential Equations <ul style="list-style-type: none"> - Formulation and application in system modeling. 2. Transfer Functions <ul style="list-style-type: none"> - Definition, derivation, and limitations. 3. State-Space Model <ul style="list-style-type: none"> - Introduction to state-space representation. 	<ul style="list-style-type: none"> - Understand the formulation and application of differential equations in system modeling. - Derive and interpret transfer functions for various systems. - Recognize the limitations of transfer functions and the advantages of state-space models. 	Quiz 9
Unit 12: State-Space Model	<ol style="list-style-type: none"> 1. State Variables and State Vector Differential Equations <ul style="list-style-type: none"> - Definition and formulation of state variables. - Deriving state vector differential equations. 2. Application to RLC Circuits <ul style="list-style-type: none"> - Applying state-space models to analyze RLC circuits. 3. Using MATLAB for State-Space Models <ul style="list-style-type: none"> - Solving state-space equations and plotting results in MATLAB. 	<ul style="list-style-type: none"> - Formulate and solve state-space models for electrical systems. - Apply these models to analyze RLC circuits. - Utilize MATLAB for solving state-space models and visualizing results. 	Assignment 6
Unit 13: Eigenvalues and Eigenvectors	<ol style="list-style-type: none"> 1. Diagonalization <ul style="list-style-type: none"> - Process of diagonalizing a matrix. - Importance in simplifying system equations. 2. Applications in Differential Equations <ul style="list-style-type: none"> - Solving differential equations using eigenvalues and eigenvectors. 3. Converting Higher-Order to First-Order Equations <ul style="list-style-type: none"> - Techniques for simplifying differential equations. 	<ul style="list-style-type: none"> - Calculate and interpret eigenvalues and eigenvectors for system analysis. - Diagonalize matrices to simplify the solution of differential equations. - Convert higher-order differential equations to first-order form using eigenvalues and eigenvectors. 	Quiz 10
Unit 14: Converting System Representation	<ol style="list-style-type: none"> 1. State-Space to Transfer Functions <ul style="list-style-type: none"> - Conversion techniques and examples. 2. Differential Equations to Transfer Functions <ul style="list-style-type: none"> - Methodology for converting differential equations into transfer functions. 3. Transfer Functions to State-Space <ul style="list-style-type: none"> - Reverse conversion from transfer functions to state-space representation. 4. Using Simulink <ul style="list-style-type: none"> - Simulating and solving differential equations using Simulink. 	<ul style="list-style-type: none"> - Convert system representations between state-space, transfer function, and differential equation forms. - Apply these conversion techniques to solve complex engineering problems. - Utilize Simulink for simulation and analysis of system models. 	Assignment 7
Unit 15: Two-Port Networks	<ol style="list-style-type: none"> 1. Impedance Parameters <ul style="list-style-type: none"> - Definition and calculation of impedance parameters. 2. Admittance Parameters <ul style="list-style-type: none"> - Understanding and calculating admittance parameters. 3. Hybrid Parameters <ul style="list-style-type: none"> - Introduction to hybrid parameters and their applications. 4. Parameter Conversion <ul style="list-style-type: none"> - Techniques for converting between different network parameters. 	<ul style="list-style-type: none"> - Define and calculate impedance, admittance, and hybrid parameters for two-port networks. - Convert between various network parameters and apply these concepts to analyze electrical circuits. 	Assignment 8 Quiz 11 Exam III covers Units 11-15