M1 – Basics of complex Numbers

{

"cell\_ID": "m1-LearningOutcomes",

"cell\_concepts": ["Complex Numbers", "Addition", "Multiplication"],

"cell\_outcomes": [

"Know the outcomes of learning Basics of Complex Numbers"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers",

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-warmup",

"cell\_concepts": ["Quadratic Equations", "Complex Numbers", "Number Systems", "Application of Complex Numbers"],

"cell\_outcomes": [

"Test the Understanding on how to solve quadratic equations with real and complex solutions",

"Identify the place of complex numbers within the hierarchy of number systems",

"Discuss the necessity of complex numbers in describing certain physical systems"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers",

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-background",

"cell\_concepts": ["Complex Numbers", "Quantum Computing", "Cryptography", "Number Systems"],

"cell\_outcomes": [

"Understand the foundational role of complex numbers in quantum computing and cryptography",

"Identify and differentiate between various number systems, leading up to and including real numbers",

"Recognize the emergence and necessity of complex numbers in extending the real number system"

],

"cell\_prereqs": [],

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"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-imaginaryNumbers",

"cell\_concepts": ["Imaginary Numbers", "Complex Numbers", "Polynomial Equations"],

"cell\_outcomes": [

"Understand the motivation behind the introduction of complex numbers",

"Learn the definition and properties of the imaginary unit i",

"Perform arithmetic operations with imaginary numbers and recognize patterns in powers of i"

],

"cell\_prereqs": ["m1-background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-quiz-1.1",

"cell\_concepts": ["Imaginary Numbers", "Complex Numbers", "Quadratic Equations", "Powers of i"],

"cell\_outcomes": [

"Solve quadratic equations involving imaginary numbers",

"Simplify expressions involving powers of the imaginary unit i"

],

"cell\_prereqs": ["m1-imaginaryNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m1-quiz-1.1-interactive"],

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"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-quiz-1.1-interactive",

"cell\_concepts": ["Imaginary Numbers", "Complex Numbers", "Quadratic Equations", "Powers of i"],

"cell\_outcomes": [

"Solve quadratic equations involving imaginary numbers",

"Simplify expressions involving powers of the imaginary unit i"

],

"cell\_prereqs": ["m1-imaginaryNumbers"],

"cell\_type": ["text"],

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"cell\_estimated\_time": "10",

"cell\_alternates": ["m1-quiz-1.1"],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-complexNumbers",

"cell\_concepts": ["Complex Numbers", "Real Numbers", "Imaginary Numbers"],

"cell\_outcomes": [

"Define complex numbers and understand their composition",

"Identify the real and imaginary parts of a complex number",

"Recognize complex numbers as a broader set of numbers encompassing real and imaginary numbers"

],

"cell\_prereqs": ["m1-imaginaryNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-operationsComplex",

"cell\_concepts": ["Complex Numbers", "Addition", "Multiplication"],

"cell\_outcomes": [

"Perform addition and multiplication operations on complex numbers",

"Understand how to combine real and imaginary parts in arithmetic operations",

"Apply the defined operations to solve problems involving complex numbers"

],

"cell\_prereqs": ["m1-complexNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-quiz-1.2",

"cell\_concepts": ["Quadratic Equations", "Complex Numbers", "Addition", "Multiplication", "Scalar Multiplication"],

"cell\_outcomes": [

"Solve quadratic equations with complex solutions",

"Perform addition, multiplication, and scalar multiplication operations on complex numbers",

"Apply algebraic methods to complex number operations for solving problems"

],

"cell\_prereqs": [ "m1-operationsComplex","m1-complexNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "15",

"cell\_alternates": ["m1-quiz-1.2-interactive"],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-quiz-1.2-interactive",

"cell\_concepts": ["Quadratic Equations", "Complex Numbers", "Addition", "Multiplication", "Scalar Multiplication"],

"cell\_outcomes": [

"Solve quadratic equations with complex solutions",

"Perform addition, multiplication, and scalar multiplication operations on complex numbers",

"Apply algebraic methods to complex number operations for solving problems"

],

"cell\_prereqs": [ "m1-operationsComplex","m1-complexNumbers"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "15",

"cell\_alternates": ["m1-quiz-1.2"],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-quiz-1.3-interactive",

"cell\_concepts": ["Quadratic Equations", "Complex Numbers", "Addition", "Multiplication", "Scalar Multiplication"],

"cell\_outcomes": [

"Solve quadratic equations with complex solutions",

"Perform addition, multiplication, and scalar multiplication operations on complex numbers",

"Apply algebraic methods to complex number operations for solving problems"

],

"cell\_prereqs": ["m1-imaginaryNumbers ", "m1-operationsComplex","m1-complexNumbers"],

"cell\_type": ["quiz"],

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"cell\_estimated\_time": "15",

"cell\_alternates": ["m1-quiz-1.2"],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-summary",

"cell\_concepts": ["Complex Numbers", "Addition", "Multiplication", "Geometrical Interpretations"],

"cell\_outcomes": [

"Recap the basic operations on complex numbers",

"Preview the advanced operations and geometrical interpretations of complex numbers"

],

"cell\_prereqs": ["Complex Numbers", "Basic Algebra", "Operations on Complex Numbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m1-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module" ],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

M2 - Properties of Complex Numbers

{

"cell\_ID": "m2-LearningOutcomes",

"cell\_concepts": ["Complex Numbers", "Representation", "Properties", "Modulus", "Conjugate", "Division"],

"cell\_outcomes": [

"Know the outcomes of learning Basics of Complex Numbers",

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-background",

"cell\_concepts": ["Complex Numbers", "Geometric Representation", "Ordered Pairs", "Addition", "Multiplication"],

"cell\_outcomes": [

"Develop intuition for complex numbers through geometric representation",

"Represent complex numbers as ordered pairs",

"Perform addition and multiplication on complex numbers represented as ordered pairs"

],

"cell\_prereqs": ["m1-complexNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-properties",

"cell\_concepts": ["Complex Numbers", "Addition", "Multiplication", "Commutative Property", "Associative Property"],

"cell\_outcomes": [

"Understand the commutative and associative properties of addition and multiplication with complex numbers"

],

"cell\_prereqs":["m2-background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-propertiesContd",

"cell\_concepts": ["Complex Numbers", "Distributive Property", "Negation", "Subtraction", "Division"],

"cell\_outcomes": [

"Understand the distributive property of multiplication over addition with complex numbers",

"Apply negation to complex numbers",

"Perform subtraction of complex numbers",

"Understand and perform division of complex numbers",

],

"cell\_prereqs":["m2-background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-quiz-2.1",

"cell\_concepts": ["Complex Numbers", "Cartesian Representation", "Multiplication", "Verification"],

"cell\_outcomes": [

"Compute the product of complex numbers in cartesian representation",

"Numerically verify the distributive property of multiplication over addition with complex numbers",

"Compute division of complex numbers in cartesian representation"

],

"cell\_prereqs": ["m2-properties","m2-propertiesContd",],

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"cell\_estimated\_time": "10",

"cell\_alternates": ["m2-quiz-2.1-interactive"],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-quiz-2.1-interactive",

"cell\_concepts": ["Complex Numbers", "Cartesian Representation", "Multiplication", "Verification"],

"cell\_outcomes": [

"Compute the product of complex numbers in cartesian representation",

"Numerically verify the distributive property of multiplication over addition with complex numbers",

"Compute division of complex numbers in cartesian representation"

],

"cell\_prereqs": ["m2-properties","m2-propertiesContd",],

"cell\_type": ["quiz", “text”],

"cell\_interactive": "false",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m2-quiz-2.1"],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-modulusConjugation",

"cell\_concepts": ["Complex Numbers", "Modulus", "Conjugate"],

"cell\_outcomes": [

"Understand the concept of modulus of a complex number",

"Compute the modulus of complex numbers",

"Understand the concept of conjugate of a complex number",

"Compute the conjugate of complex numbers"

],

"cell\_prereqs": ["m1-complexNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-quiz-2.2",

"cell\_concepts": ["Complex Numbers", "Modulus", "Conjugate"],

"cell\_outcomes": [

"Compute the modulus of given complex numbers",

"Compute the conjugate of given complex numbers"

],

"cell\_prereqs": ["m2-modulusConjugation"],

"cell\_type": ["quiz"],

"cell\_interactive": "false",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m2-quiz-2.2-interactive"],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-quiz-2.2-interactive",

"cell\_concepts": ["Complex Numbers", "Modulus", "Conjugate"],

"cell\_outcomes": [

"Compute the modulus of given complex numbers",

"Compute the conjugate of given complex numbers"

],

"cell\_prereqs": ["m2-modulusConjugation"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m2-quiz-2.2-interactive"],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-summary",

"cell\_concepts": ["Complex Numbers", "Addition", "Multiplication", "Distributive Property", "Negation", "Subtraction", "Division", "Modulus", "Conjugate"],

"cell\_outcomes": [

"Summarize the properties and basic operations on complex numbers"

],

"cell\_prereqs": ["Introduction to Complex Numbers", "Operations on Complex Numbers", "Modulus and Conjugation"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Properties of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Understand and apply basic properties of complex numbers",

"Perform operations like addition, multiplication, division on complex numbers",

"Compute modulus and conjugate of complex numbers",

"Implement Python programs for complex number operations including addition, multiplication, division, computing modulus, and conjugate"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m2-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

M3 – Complex Numbers on a Plane

{

"cell\_ID": "m3-learningOutcomes",

"cell\_concepts": ["Complex Numbers", "Cartesian Coordinates", "Polar Representation", "Conversion", "Plotting", "Python Programming"],

"cell\_outcomes": [

"Know the outcomes of learning module complex numbers on a plane",

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Implement Python programs for representation and conversion of complex numbers"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-cartesianRepresentation",

"cell\_concepts": ["Complex Numbers", "Cartesian Representation", "Complex Plane", "Argand Plane", "Modulus", "Vector Representation"],

"cell\_outcomes": [

"Understand the Cartesian representation of complex numbers",

"Plot complex numbers on the Argand (complex) plane",

"Compute the modulus of complex numbers using Cartesian representation"

],

"cell\_prereqs": ["m2-modulusConjugation"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Implement Python programs for representation and conversion of complex numbers"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-polarRepresentation",

"cell\_concepts": ["Complex Numbers", "Polar Representation", "Magnitude (Modulus)", "Angle (Theta)", "Vector Projections", "Cartesian Conversion"],

"cell\_outcomes": [

"Understand the polar representation of complex numbers",

"Convert complex numbers from Cartesian to polar representation and vice versa",

"Compute the magnitude and angle of complex numbers in polar representation"

],

"cell\_prereqs": ["m2-modulusConjugation"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Implement Python programs for representation and conversion of complex numbers"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-polarRepresentationExample",

"cell\_concepts": ["Complex Numbers", "Polar Representation", "Magnitude (Modulus)", "Angle (Theta)", "Vector Projections", "Cartesian Conversion"],

"cell\_outcomes": [

"Understand the polar representation of complex numbers",

"Convert complex numbers from Cartesian to polar representation and vice versa",

"Compute the magnitude and angle of complex numbers in polar representation"

],

"cell\_prereqs": ["m3-polarRepresentation"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Implement Python programs for representation and conversion of complex numbers"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-multiplicationPolar",

"cell\_concepts": ["Complex Numbers", "Polar Coordinates", "Multiplication"],

"cell\_outcomes": [

"Understand the process of multiplying complex numbers in polar coordinates",

"Perform multiplication of complex numbers using polar coordinates",

],

"cell\_prereqs": ["m3-polarRepresentation"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Simplify complex number operations using polar coordinates",

"Implement Python programs for representation and conversion of complex numbers, including multiplication in polar coordinates"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-quiz-3.1",

"cell\_concepts": ["Complex Numbers", "Polar Representation", "Cartesian Representation", "Conversion", "Multiplication"],

"cell\_outcomes": [

"Convert complex numbers from Cartesian to polar representations",

"Convert complex numbers from polar to Cartesian representations",

"Multiply complex numbers using polar representations"

],

"cell\_prereqs": ["m3-multiplicationPolar", "m3-polarRepresentation", "m3-cartesianRepresentation"],

"cell\_type": ["quiz"],

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"cell\_estimated\_time": "15",

"cell\_alternates": ["m3-quiz-3.1-interactive"],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Simplify complex number operations using polar coordinates",

"Implement Python programs for representation and conversion of complex numbers, including multiplication in polar coordinates"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-quiz-3.1-interactive",

"cell\_concepts": ["Complex Numbers", "Polar Representation", "Cartesian Representation", "Conversion", "Multiplication"],

"cell\_outcomes": [

"Convert complex numbers from Cartesian to polar representations",

"Convert complex numbers from polar to Cartesian representations",

"Multiply complex numbers using polar representations"

],

"cell\_prereqs": ["m3-multiplicationPolar", "m3-polarRepresentation", "m3-cartesianRepresentation"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "15",

"cell\_alternates": ["m3-quiz-3.1"],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Simplify complex number operations using polar coordinates",

"Implement Python programs for representation and conversion of complex numbers, including multiplication in polar coordinates"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-conclusions",

"cell\_concepts": ["Complex Numbers", "Modulus", "Complex Conjugate", "Cartesian Representation", "Polar Representation", "Conversion"],

"cell\_outcomes": [

"Summarize the key concepts and operations related to complex numbers",

"Understand the transition between Cartesian and polar representations"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Numbers on a Plane"],

"module\_outcomes": [

"Understand the geometric representation of complex numbers",

"Learn to represent complex numbers in Cartesian and polar coordinates",

"Convert between Cartesian and polar representations of complex numbers",

"Simplify complex number operations using polar coordinates",

"Implement Python programs for representation and conversion of complex numbers, including multiplication in polar coordinates"

],

"module\_prereqs": ["Algebra", "Trigonometry", "Introduction to Programming", "Python Basics", "The Basics of Complex Numbers"]

}

{

"cell\_ID": "m3-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

M4 - Complex Vector Spaces

{

"cell\_ID": "m4-LearningOutcomes",

"cell\_concepts": ["Complex Vector Spaces", "Basic Operations", "Properties", "Matrix Operations", "Programming", "Addition", "Multiplication", "Transpose", "Conjugate", "Dagger Operations"],

"cell\_outcomes": [

"Know the outcomes of learning Complex Vector Spaces",

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Background",

"cell\_concepts": ["Complex Vector Spaces", "Quantum Systems", "Dimensions", "Complex Vectors"],

"cell\_outcomes": [

"Understand the concept of complex vector spaces",

"Identify examples of complex vectors in different dimensions"

],

"cell\_prereqs": ["m1-complexNumbers"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-OperationsComplexVectors",

"cell\_concepts": ["Complex Vector Spaces", "Vector Addition", "Commutative Property", "Associative Property"],

"cell\_outcomes": [

"Understand and perform addition of complex vectors",

"Apply commutative and associative properties in vector addition"

],

"cell\_prereqs": ["m4-Background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-OperationsScalar",

"cell\_concepts": ["Complex Vector Spaces", "Vector Addition", "Commutative Property", "Associative Property"],

"cell\_outcomes": [

"Understand and perform addition of complex vectors as a scalar"

],

"cell\_prereqs": ["m4-Background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-AdditiveIdentityInverse",

"cell\_concepts": ["Complex Vector Spaces", "Additive Identity", "Additive Inverse", "Zero Vector", "Transpose"],

"cell\_outcomes": [

"Understand the concept of additive identity and additive inverse in complex vector spaces",

"Compute the additive inverse of complex vectors"

],

"cell\_prereqs": ["m4-Background"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-quiz-4.1",

"cell\_concepts": ["Complex Vector Spaces", "Vector Addition", "Vector Subtraction", "Scalar Multiplication", "Numerical Verification", "Properties"],

"cell\_outcomes": [

"Compute addition and subtraction of complex vectors",

"Perform scalar multiplication on complex vectors",

"Verify properties of complex vector spaces numerically"

],

"cell\_prereqs":[ "m4-OperationsComplexVectors", "m4-AdditiveIdentityInverse","m4-OperationsScalar"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m4-quiz-4.1-interactive"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-quiz-4.1-interactive",

"cell\_concepts": ["Complex Vector Spaces", "Vector Addition", "Vector Subtraction", "Scalar Multiplication", "Numerical Verification", "Properties"],

"cell\_outcomes": [

"Compute addition and subtraction of complex vectors",

"Perform scalar multiplication on complex vectors",

"Verify properties of complex vector spaces numerically"

],

"cell\_prereqs": [ "m4-OperationsComplexVectors", "m4-AdditiveIdentityInverse","m4-OperationsScalar"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m4-quiz-4.1"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-ComplexVectorSpaces",

"cell\_concepts": ["Complex Vector Spaces", "Vector Addition", "Negation", "Scalar Multiplication", "Zero Vector", "Properties"],

"cell\_outcomes": [

"Understand the definition of complex vector spaces",

"Identify operations and properties in complex vector spaces"

],

"cell\_prereqs": [ "m4-OperationsComplexVectors", "m4-AdditiveIdentityInverse","m4-OperationsScalar"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-MatricesComplexVectorSpaces",

"cell\_concepts": ["Complex Vector Spaces", "Matrices", "Transpose", "Conjugate", "Dagger Operation", "Adjoint"],

"cell\_outcomes": [

"Understand matrices as complex vector spaces",

"Identify and perform additional operations for matrices: transpose, conjugate, and dagger"

],

"cell\_prereqs": ["m4-Background", "m4-ComplexVectorSpaces" ],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "4",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-PropertiesTransposeConjugateDagger",

"cell\_concepts": ["Complex Vector Spaces", "Transpose", "Conjugate", "Dagger Operation", "Properties", "Idempotent", "Scalar Multiplication", "Addition"],

"cell\_outcomes": [

"Understand the properties of transpose, conjugate, and dagger operations",

"Apply properties of these operations to complex matrices",

],

"cell\_prereqs": ["m4-MatricesComplexVectorSpaces"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "4",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Quiz-4.2",

"cell\_concepts": ["Complex Vector Spaces", "Transpose", "Conjugate", "Dagger Operation", "Numerical Verification", "Properties"],

"cell\_outcomes": [

"Numerically verify the properties of transpose, conjugate, and dagger operations for complex matrices"

],

"cell\_prereqs": ["m4-ComplexVectorSpaces", "m4-MatricesComplexVectorSpaces","m4-PropertiesTransposeConjugateDagger"],

"cell\_type": ["quiz"],

"cell\_interactive": "false",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m4-Quiz-4.2-interactive"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Quiz-4.2-interactive",

"cell\_concepts": ["Complex Vector Spaces", "Transpose", "Conjugate", "Dagger Operation", "Numerical Verification", "Properties"],

"cell\_outcomes": [

"Numerically verify the properties of transpose, conjugate, and dagger operations for complex matrices"

],

"cell\_prereqs": ["m4-ComplexVectorSpaces", "m4-MatricesComplexVectorSpaces","m4-PropertiesTransposeConjugateDagger"],

"cell\_type": ["quiz"],

"cell\_interactive": "false",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m4-Quiz-4.2"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-MatrixMultiplication",

"cell\_concepts": ["Complex Vector Spaces", "Matrix Multiplication", "Non-commutativity"],

"cell\_outcomes": [

"Understand and perform matrix multiplication in complex vector spaces",

"Recognize the non-commutative nature of matrix multiplication",

],

"cell\_prereqs": ["m4-OperationsComplexVectors"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "4",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-IdentityMatrix",

"cell\_concepts": ["Complex Vector Spaces", "Identity Matrix", "Multiplicative Identity"],

"cell\_outcomes": [

"Understand the role of the identity matrix in matrix multiplication",

"Identify the identity matrix and its properties within complex vector spaces"

],

"cell\_prereqs": ["m4-MatrixMultiplication"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-PropertiesMatrixMultiplication",

"cell\_concepts": ["Complex Vector Spaces", "Matrix Multiplication", "Properties", "Associativity", "Identity", "Distributivity", "Scalar Multiplication", "Transpose", "Conjugation", "Adjoint"],

"cell\_outcomes": [

"Understand and apply the properties of matrix multiplication within complex vector spaces"

],

"cell\_prereqs": ["m4-MatrixMultiplication", "m4-IdentityMatrix"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "4",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Quiz-4.3",

"cell\_concepts": ["Complex Vector Spaces", "Matrix Multiplication", "Properties", "Associativity", "Distributivity", "Scalar Multiplication", "Numerical Verification"],

"cell\_outcomes": [

"Numerically verify the properties of matrix multiplication within complex vector spaces"

],

"cell\_prereqs": ["m4-MatrixMultiplication", "m4-IdentityMatrix","m4-PropertiesMatrixMultiplication"],

"cell\_type": ["quiz"],

"cell\_interactive": "false",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m4-Quiz-4.3-interactive"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Quiz-4.3-interactive",

"cell\_concepts": ["Complex Vector Spaces", "Matrix Multiplication", "Properties", "Associativity", "Distributivity", "Scalar Multiplication", "Numerical Verification"],

"cell\_outcomes": [

"Numerically verify the properties of matrix multiplication within complex vector spaces"

],

"cell\_prereqs": ["m4-MatrixMultiplication", "m4-IdentityMatrix","m4-PropertiesMatrixMultiplication"],

"cell\_type": ["quiz"],

"cell\_interactive": "false",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m4-Quiz-4.3"],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-Conclusions",

"cell\_concepts": ["Complex Vector Spaces", "Operations", "Properties", "Linear Independence", "Basis"],

"cell\_outcomes": [

"Summarize the concepts of complex vector spaces and their operations",

"Prepare for the upcoming lessons on linear independence and basis for complex vector spaces"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces"],

"module\_outcomes": [

"Understand the concept of vector spaces in the context of complex numbers",

"Learn basic operations within Complex Vector Spaces",

"Understand and apply matrix operations in Complex Vector Spaces",

"Develop programming skills for operations on complex vectors and matrices"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m4-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["The Basics of Complex Numbers"],

"module\_outcomes": [

"Master the concept of complex number representations",

"Perform basic additive and multiplicative operations on complex numbers",

"Implement Python programs for addition and multiplication on complex numbers"

],

"module\_prereqs": ["Algebra", "Introduction to Programming", "Python Basics"]

}

M5 - Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions

{

"cell\_ID": "m5-LearningOutcomes",

"cell\_concepts": ["Complex Vector Spaces", "Linear Independence", "Basis", "Dimension"],

"cell\_outcomes": [

"Understand and apply the concept of linear independence in complex vector spaces",

"Understand and apply the concept of basis and dimension of a complex vector space"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-LinearDependenceIndependence",

"cell\_concepts": ["Complex Vector Spaces", "Linear Combination", "Linear Independence", "Complex Coefficients"],

"cell\_outcomes": [

"Understand the concepts of linear combination and linear independence in complex vector spaces",

"Apply these concepts to analyze the structure of complex vector spaces"

],

"cell\_prereqs": ["m4-ComplexVectorSpaces"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-ExamplesLinearDependenceIndependence",

"cell\_concepts": ["Complex Vector Spaces", "Linear Dependence", "Linear Independence", "Examples"],

"cell\_outcomes": [

"Identify examples of linearly dependent and independent sets of vectors",

"Apply criteria to determine linear dependence and independence"

],

"cell\_prereqs": ["m5-LinearDependenceIndependence"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.1",

"cell\_concepts": ["Complex Vector Spaces", "Linear Independence", "Problem Solving"],

"cell\_outcomes": [

"Show that a given set of vectors is not linearly independent",

"Apply the concept of linear independence to specific examples"

],

"cell\_prereqs": ["m5-ExamplesLinearDependenceIndependence"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m5-Quiz-5.1-interactive"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.1-interative",

"cell\_concepts": ["Complex Vector Spaces", "Linear Independence", "Problem Solving"],

"cell\_outcomes": [

"Show that a given set of vectors is not linearly independent",

"Apply the concept of linear independence to specific examples"

],

"cell\_prereqs": ["m5-ExamplesLinearDependenceIndependence"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m5-Quiz-5.1"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Basis",

"cell\_concepts": ["Complex Vector Spaces", "Basis", "Linearly Independent Vectors", "Orthonormal Bases"],

"cell\_outcomes": [

"Understand the concept of a basis in complex vector spaces",

"Identify examples of basis sets, including orthonormal bases"

],

"cell\_prereqs": ["m5-ExamplesLinearDependenceIndependence"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Dimension",

"cell\_concepts": ["Complex Vector Spaces", "Dimension", "Basis"],

"cell\_outcomes": [

"Understand the concept of the dimension of a complex vector space",

"Relate the dimension to the number of vectors in a basis set"

],

"cell\_prereqs": ["m5-Basis"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.2",

"cell\_concepts": ["Complex Vector Spaces", "Basis", "Verification", "ℂ2"],

"cell\_outcomes": [

"Verify that given sets are basis for ℂ2"

],

"cell\_prereqs": ["m5-Basis", "m5-Dimension"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m5-Quiz-5.2-interactive"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.2-interactive",

"cell\_concepts": ["Complex Vector Spaces", "Basis", "Verification", "ℂ2"],

"cell\_outcomes": [

"Verify that given sets are basis for ℂ2"

],

"cell\_prereqs": ["m5-Basis", "m5-Dimension"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "20",

"cell\_alternates": ["m5-Quiz-5.2"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-TransitionMatrices",

"cell\_concepts": ["Complex Vector Spaces", "Transition Matrix", "Basis", "Hadamard Matrix", "Quantum Computing"],

"cell\_outcomes": [

"Understand the concept of transition matrices and their application in changing basis of vectors",

"Identify the role of Hadamard matrix in quantum computing for basis conversion",

],

"cell\_prereqs": ["m4-MatrixMultiplication", "m5-Basis", "m5-Dimension"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts",

"Learn the application of transition matrices in the context of quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.3",

"cell\_concepts": ["Complex Vector Spaces", "Hadamard Basis", "Vector Representation", "Hadamard Matrix", "Inverse"],

"cell\_outcomes": [

"Represent vectors in the Hadamard basis",

"Prove that the Hadamard matrix is its own inverse"

],

"cell\_prereqs": [ "m5-TransitionMatrices", "m5-Basis", "m5-Dimension"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m5-Quiz-5.3-interactive"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts",

"Learn the application of transition matrices in the context of quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Quiz-5.3-interactive",

"cell\_concepts": ["Complex Vector Spaces", "Hadamard Basis", "Vector Representation", "Hadamard Matrix", "Inverse"],

"cell\_outcomes": [

"Represent vectors in the Hadamard basis",

"Prove that the Hadamard matrix is its own inverse"

],

"cell\_prereqs": [ "m5-TransitionMatrices", "m5-Basis", "m5-Dimension"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m5-Quiz-5.3"],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts",

"Learn the application of transition matrices in the context of quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-Conclusions",

"cell\_concepts": ["Complex Vector Spaces", "Linear Dependence", "Linear Independence", "Basis", "Dimension", "Transition Matrices", "Inner Product", "Norm", "Orthogonal Vectors", "Projections"],

"cell\_outcomes": [

"Summarize the concepts of linear dependence and independence, basis, dimension, and transition matrices in complex vector spaces",

"Prepare for the upcoming lessons on inner product, norm, orthogonal vectors, and projections"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "2",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts",

"Learn the application of transition matrices in the context of quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m5-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"module\_outcomes": [

"Understand advanced concepts in complex vector spaces including linear combinations, independence, basis, and dimensions",

"Develop the ability to analyze complex vector spaces in terms of these advanced concepts",

"Learn the application of transition matrices in the context of quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

M6 – Properties and Operations on Vectors and Matrices in Complex Vector Spaces

{

"cell\_ID": "m6-LearningOutcomes",

"cell\_concepts": ["Inner Product", "Norm of a Vector", "Orthogonal Vectors", "Orthonormal Basis", "Vector Representation", "Vector Projection", "Python Programming"],

"cell\_outcomes": [

"Understand the definition and properties of inner product",

"Compute the inner product of vectors and matrices",

"Compute the norm of a vector",

"Understand and apply the concept of orthogonal/orthonormal vectors and basis",

"Represent a vector using a given basis set",

"Understand and apply the concept of projection of one vector onto another",

"Write Python programs to determine the norm and inner product"

],

"cell\_prereqs": ["Complex Vector Spaces: Linear Combination, Independence, Basis and Dimensions"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-InnerProduct",

"cell\_concepts": ["Inner Product", "Complex Vector Spaces", "Dot Product", "Scalar Product", "Adjoint Operation", "Transpose", "Trace"],

"cell\_outcomes": [

"Understand the definition of inner product for complex vector spaces",

"Distinguish the inner product calculation for vectors and matrices"

],

"cell\_prereqs":[ "m4-ComplexVectorSpaces"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-PropertiesInnerProduct",

"cell\_concepts": ["Inner Product", "Properties", "Complex Vector Spaces", "Non-negativity", "Linearity", "Conjugate Symmetry"],

"cell\_outcomes": [

"Understand and apply the properties of inner product in complex vector spaces"

],

"cell\_prereqs": ["m6-InnerProduct"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-ExamplesInnerProduct",

"cell\_concepts": ["Inner Product", "Examples", "Complex Vector Spaces", "Vector Calculation", "Matrix Calculation"],

"cell\_outcomes": [

"Calculate the inner product for given vector and matrix examples"

],

"cell\_prereqs": [ "m6-PropertiesInnerProduct"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "5",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-Quiz-6.1",

"cell\_concepts": ["Inner Product", "Complex Vector Spaces", "Computation", "Properties Verification"],

"cell\_outcomes": [

"Compute the inner product for given vectors and matrices",

"Prove specific properties of the inner product"

],

"cell\_prereqs": ["m6-ExamplesInnerProduct"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m6-Quiz-6.1-interactive"],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-Quiz-6.1-interactive",

"cell\_concepts": ["Inner Product", "Complex Vector Spaces", "Computation", "Properties Verification"],

"cell\_outcomes": [

"Compute the inner product for given vectors and matrices",

"Prove specific properties of the inner product"

],

"cell\_prereqs": ["m6-ExamplesInnerProduct"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m6-Quiz-6.1"],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-NormVector",

"cell\_concepts": ["Norm of a Vector", "Vector Length", "Inner Product", "Complex Vector Spaces"],

"cell\_outcomes": [

"Understand and compute the norm of a vector using the inner product",

"Apply the concept of norm to determine the length of vectors in complex vector spaces"

],

"cell\_prereqs": ["m6-ExamplesInnerProduct"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-Quiz-6.2",

"cell\_concepts": ["Norm of a Vector", "Vector Addition", "Scalar Multiplication", "Numerical Verification", "Inequality", "Complex Vector Spaces"],

"cell\_outcomes": [

"Numerically verify the norm properties for given vectors",

"Apply the concepts of vector addition and scalar multiplication to verify norm properties"

],

"cell\_prereqs": ["m6-NormVector", "m6-InnerProduct"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m6-Quiz-6.2-interactive"],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-Quiz-6.2-interactive",

"cell\_concepts": ["Norm of a Vector", "Vector Addition", "Scalar Multiplication", "Numerical Verification", "Inequality", "Complex Vector Spaces"],

"cell\_outcomes": [

"Numerically verify the norm properties for given vectors",

"Apply the concepts of vector addition and scalar multiplication to verify norm properties"

],

"cell\_prereqs": ["m6-NormVector", "m6-InnerProduct"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m6-Quiz-6.2"],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-OrthogonalVectors",

"cell\_concepts": ["Orthogonal Vectors", "Inner Product", "Complex Vector Spaces", "Perpendicularity"],

"cell\_outcomes": [

"Understand the concept of orthogonal vectors and their characteristics",

"Identify orthogonal vectors through inner product calculations"

],

"cell\_prereqs": ["m6-InnerProduct"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-OrthogonalBasis",

"cell\_concepts": ["Orthogonal Basis", "Orthonormal Basis", "Complex Vector Spaces", "Inner Product"],

"cell\_outcomes": [

"Understand the concept of orthogonal and orthonormal basis in complex vector spaces",

"Identify basis sets that are orthogonal and/or orthonormal"

],

"cell\_prereqs": ["m6-OrthogonalVectors"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-Projection",

"cell\_concepts": ["Projection", "Trigonometry", "Inner Product", "Complex Vector Spaces", "Vector Length", "Cosine Theta"],

"cell\_outcomes": [

"Understand the concept of projection in the context of inner product and vector spaces",

"Apply the inner product to calculate the projection of one vector onto another"

],

"cell\_prereqs": ["m3-polarRepresentation","m6-InnerProduct", "m6-NormVector","m6-OrthogonalBasis"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m6-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Properties and Operations on Vectors and Matrices in Complex Vector Spaces"],

"module\_outcomes": [

"Master the operations on vectors and matrices in complex vector spaces",

"Develop the skills to apply these operations in practical scenarios"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

M7- Advanced Concepts in Complex Vector Spaces

{

"cell\_ID": "m7-LearningOutcomes",

"cell\_concepts": ["Eigenvalues", "Eigenvectors", "Hermitian Matrices", "Unitary Matrices", "Quantum Computing", "Python Programming"],

"cell\_outcomes": [

"Understand eigenvalues and eigenvectors and compute them",

"Prove properties of Hermitian and unitary matrices",

"Verify properties of unitary and Hermitian matrices",

"Understand the implication of unitary matrices in quantum computing",

"Implement Python programs to check for Hermitian or unitary matrices"

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-EigenvaluesEigenvectors",

"cell\_concepts": ["Eigenvalues", "Eigenvectors", "Matrix Operations", "Vector Scaling"],

"cell\_outcomes": [

"Understand the concept of eigenvalues and eigenvectors",

"Identify examples of eigenvalues and eigenvectors",

],

"cell\_prereqs": ["m4-OperationsScalar", "m4-MatrixMultiplication"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-DefinitionEigenvectorsEigenvalues",

"cell\_concepts": ["Eigenvectors", "Eigenvalues", "Complex Matrix", "Complex Vector", "Matrix Operations"],

"cell\_outcomes": [

"Define eigenvectors and eigenvalues and understand their relationship to complex matrices",

"Identify examples of eigenvectors and eigenvalues"

],

"cell\_prereqs": ["m7-EigenvaluesEigenvectors"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-HermitianMatrices",

"cell\_concepts": ["Hermitian Matrices", "Symmetric Matrix", "Adjoint", "Complex Matrix", "Matrix Properties"],

"cell\_outcomes": [

"Understand the definition and properties of Hermitian matrices",

"Identify examples of Hermitian matrices"

],

"cell\_prereqs": ["m4-MatricesComplexVectorSpaces"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-Quiz-7.1",

"cell\_concepts": ["Eigenvectors", "Eigenvalues", "Hermitian Matrices", "Matrix Operations", "Verification"],

"cell\_outcomes": [

"Compute eigenvectors and eigenvalues for given matrices",

"Verify Hermitian property for given matrices"

],

"cell\_prereqs": ["m7-HermitianMatrices","m7-DefinitionEigenvectorsEigenvalues"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m7-Quiz-7.1-interactive"],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-Quiz-7.1-interactive",

"cell\_concepts": ["Eigenvectors", "Eigenvalues", "Hermitian Matrices", "Matrix Operations", "Verification"],

"cell\_outcomes": [

"Compute eigenvectors and eigenvalues for given matrices",

"Verify Hermitian property for given matrices"

],

"cell\_prereqs": ["m7-HermitianMatrices","m7-DefinitionEigenvectorsEigenvalues"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m7-Quiz-7.1"],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-UnitaryMatrices",

"cell\_concepts": ["Unitary Matrices", "Invertible Matrices", "Matrix Operations", "Identity Matrix", "Adjoint"],

"cell\_outcomes": [

"Understand the definition and properties of unitary matrices",

"Identify examples of unitary matrices"

],

"cell\_prereqs": ["m7-HermitianMatrices"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-ImplicationUnitaryTransformations",

"cell\_concepts": ["Unitary Transformations", "Quantum Systems", "Reversible Systems", "Vector Space Geometry"],

"cell\_outcomes": [

"Understand the implications of unitary transformations on quantum systems",

"Apply the concept of reversibility to quantum state operations"

],

"cell\_prereqs": ["m7-UnitaryMatrices"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "3",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-Quiz-7.2",

"cell\_concepts": ["Unitary Matrices", "Matrix Verification", "Inner Product", "Complex Vector Spaces"],

"cell\_outcomes": [

"Verify unitary property for given matrices",

"Prove preservation of inner product under unitary transformation"

],

"cell\_prereqs": ["m7-ImplicationUnitaryTransformations"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m7-Quiz-7.2-interactive"],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-Quiz-7.2-interactive",

"cell\_concepts": ["Unitary Matrices", "Matrix Verification", "Inner Product", "Complex Vector Spaces"],

"cell\_outcomes": [

"Verify unitary property for given matrices",

"Prove preservation of inner product under unitary transformation",

],

"cell\_prereqs": ["m7-ImplicationUnitaryTransformations"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "25",

"cell\_alternates": ["m7-Quiz-7.2"],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

{

"cell\_ID": "m7-finalQuiz-information",

"cell\_concepts": [],

"cell\_outcomes": [

"Know the information about the final Quiz of this module"],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Advanced Concepts in Complex Vector Spaces"],

"module\_outcomes": [

"Master advanced concepts in complex vector spaces",

"Develop the ability to analyze and apply advanced mathematical concepts in practical scenarios, particularly in quantum computing"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics", "Complex Vector Spaces"]

}

M8 – Overview of Tensor Analysis

{

"cell\_ID": "m8-LearningOutcomes",

"cell\_concepts": ["Tensor Products", "Matrices", "Vectors"],

"cell\_outcomes": [

"Prove properties of tensor products of matrices and vectors",

"Compute tensor products",

"Implement a program to compute the tensor product of two matrices",

],

"cell\_prereqs": [],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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{

"cell\_ID": "m8-TensorProduct",

"cell\_concepts": ["Tensor Products", "Quantum Systems", "Vectors", "Scalar Multiplication", "Addition"],

"cell\_outcomes": [

"Understand the use of tensor products in describing joint states of quantum systems",

"Identify the components and structure of a tensor product",

"Learn the properties of tensor products, including distribution over addition and respect for scalar multiplication",

],

"cell\_prereqs": ["m4-OperationsComplexVectors", "m4-OperationsScalar"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

{

"cell\_ID": "m8-JointBasis",

"cell\_concepts": ["Joint Basis", "Basis Vectors", "Tensor Products", "Vector Spaces", "Dimension"],

"cell\_outcomes": [

"Understand the concept of a joint basis for tensor product spaces",

"Determine the basis for the tensor product of two vector spaces",

"Comprehend how the dimension of the tensor product space is calculated"

],

"cell\_prereqs": ["m5-Basis","m8-TensorProduct"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

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"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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{

"cell\_ID": "m8-ExampleTensorProduct",

"cell\_concepts": ["Tensor Product", "Vectors", "Examples", "Vector Multiplication"],

"cell\_outcomes": [

"Demonstrate the calculation of tensor products through examples",

"Apply the concept of tensor products to vectors",

"Visualize the structure of a tensor product of two vectors",

],

"cell\_prereqs": ["m8-TensorProduct","m8-JointBasis"],

"cell\_type": ["text"],

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"cell\_estimated\_time": "1",

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"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

}

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"cell\_ID": "m8-ExampleTensorProductComplex",

"cell\_concepts": ["Tensor Product", "Complex Vectors", "Vector Multiplication", "Examples"],

"cell\_outcomes": [

"Calculate the tensor product of complex vectors",

"Understand the effect of complex numbers in tensor product calculations",

"Visualize the result of a tensor product involving complex vectors"

],

"cell\_prereqs": ["m8-TensorProduct","m8-JointBasis"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts, including those involving complex numbers"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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{

"cell\_ID": "m8-Quiz-8.1",

"cell\_concepts": ["Tensor Product", "Vectors", "Complex Numbers", "Self Assessment", "Quiz"],

"cell\_outcomes": [

"Calculate tensor products involving both real and complex vectors",

"Apply knowledge of vector operations to solve tensor product problems",

"Self-assess understanding of tensor products and their properties"

],

"cell\_prereqs": ["m8-ExampleTensorProductComplex", "m8-ExampleTensorProduct"],

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"cell\_interactive": "true",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m8-Quiz-8.1-interactive"],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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"cell\_ID": "m8-Quiz-8.1-interactive",

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"cell\_outcomes": [

"Calculate tensor products involving both real and complex vectors",

"Apply knowledge of vector operations to solve tensor product problems",

"Self-assess understanding of tensor products and their properties"

],

"cell\_prereqs": ["m8-ExampleTensorProductComplex", "m8-ExampleTensorProduct"],

"cell\_type": ["quiz"],

"cell\_interactive": "true",

"cell\_estimated\_time": "10",

"cell\_alternates": ["m8-Quiz-8.1"],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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"cell\_ID": "m8-Entanglement",

"cell\_concepts": ["Entanglement", "Inseparability", "Tensor Product", "Quantum Systems"],

"cell\_outcomes": [

"Understand the concept of entanglement in the context of tensor products",

"Identify systems that cannot be decomposed into tensor products of smaller vectors",

"Recognize the implications of entanglement for quantum systems"

],

"cell\_prereqs": ["m8-ExampleTensorProductComplex", "m8-ExampleTensorProduct"],

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"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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{

"cell\_ID": "m8-TensorProductMatrices",

"cell\_concepts": ["Tensor Product", "Matrices", "Operators", "Joint System States"],

"cell\_outcomes": [

"Extend the concept of tensor products to matrices",

"Construct operators for joint system states using tensor products",

"Understand how to perform tensor product operations on matrices"

],

"cell\_prereqs": ["m4-MatrixMultiplication", "m8-Entanglement"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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{

"cell\_ID": "m8-ExamplesTensorProductMatrices",

"cell\_concepts": ["Tensor Product", "Matrices", "Complex Numbers", "Examples"],

"cell\_outcomes": [

"Demonstrate the calculation of tensor products of matrices including complex numbers",

"Visualize the process of scalar multiplying a matrix by each element of another matrix in the context of tensor products",

"Apply the concept of tensor products to complex matrices",

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"cell\_prereqs": ["m8-TensorProductMatrices"],

"cell\_type": ["text"],

"cell\_interactive": "false",

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"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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"cell\_ID": "m8-PropertiesTensorProductMatrices",

"cell\_concepts": ["Tensor Product", "Matrices", "Associativity", "Adjoint Operation", "Properties"],

"cell\_outcomes": [

"Understand and apply the associativity property of tensor products of matrices",

"Learn how the tensor product respects the adjoint operation",

"Identify key properties of tensor products in the context of matrix operations"

],

"cell\_prereqs": ["m8-TensorProductMatrices"],

"cell\_type": ["text"],

"cell\_interactive": "false",

"cell\_estimated\_time": "1",

"cell\_alternates": [],

"module\_title": ["Overview of Tensor Analysis"],

"module\_outcomes": [

"Gain a foundational understanding of tensor analysis",

"Develop the ability to work with tensor products in mathematical and computational contexts"

],

"module\_prereqs": ["Linear Algebra", "Complex Numbers", "Introduction to Programming", "Python Basics"]

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