CAE IN CYBERSECURITY COMMUNITY

Quintet: An experiential Learning Platform for Quantum Education

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Introduction

- Quantum communications and Networking presents a high barrier for entry
  - Interdisciplinary nature of the field requires expertise across various domains
  - Educators need to manually compile and curate materials from diverse sources
  - Scarcity of quantum computing equipment and infrastructure hinders hands-on experiences

Quintet Platform Overview

- QUINTET is an advanced experiential learning platform designed to address the challenges
  - Includes: Interactive course modules
  - Learning Objects Repository (LOR) with various learning objects
  - Curricular materials developed using Kolb's experiential learning model

Quintet Interface

QUINTET HOME SCREEN

Let us know if already know below topics:

- [ ] Complex Numbers
- [ ] Operations on Complex Num...
- [ ] Properties of Complex Numb...
- [ ] Modulus and Conjugation
- [ ] Cartesian Representation of C...
- [ ] Polar Representation of Comp...
- [ ] Complex Vector Spaces
- [ ] Operations with Complex Vec...
- [ ] Matrices and Complex Vector...
- [ ] Properties of Transpose, Conj...
- [ ] Matrix Multiplication and Prop...
- [ ] Linear Dependence and Indep...
- [ ] Basis and Dimension
- [ ] Transition Matrices
- [ ] Inner Product and Properties
- [ ] Norm of a Vector
- [ ] Orthogonal Vectors
- [ ] Eigenvalues and Eigenvectors
- [ ] Hermitian Matrices
- [ ] Unitary Matrices
- [ ] Implications of Unitary Transf...
- [ ] Tensor Product
- [ ] Tensor Product Matrices

▸ **The Basics of Complex Numbers**

▸ **Properties of Complex Numbers**

▸ **Complex Numbers on a Plane**

▸ **Complex Vector Spaces**

▸ **Complex Vector Spaces Linear Combination, Independence, Basis and Dimensions**

▸ **Properties and Operations on Vectors and Matrices in Complex Vector Spaces**

▸ **Advanced Concepts in Complex Vector Spaces**

▸ **Overview of Tensor Analysis**

Estimated Time: Estimated Time

- [ ] Hermitian Matrices
- [ ] Unitary Matrices
- [ ] Implications of Unitary Transf...
- [ ] Tensor Product
- [ ] Tensor Product Matrices

▸ **The Basics of Complex Numbers**

▾ **Properties of Complex Numbers**

Concepts

Students will be able to represent complex numbers as ordered pairs.
Students will know some of the basic properties of complex numbers and operations on them.
Students will be able to compute the modulus and conjugate of complex numbers.
Students will be able to prove basic properties of modulus and conjugate operations.
Students will be able to implement programs to divide two complex numbers, compute the modulus and conjugate.

▸ **Complex Numbers on a Plane**

▸ **Complex Vector Spaces**

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▸ **Properties and Operations on Vectors and Matrices in Complex Vector Spaces**

▸ **Advanced Concepts in Complex Vector Spaces**

▸ **Overview of Tensor Analysis**

Estimated Time: Estimated Time

QUINTET Learning Objects

- QUINTET learning objects are categorized into:
  - Foundational Knowledge Units (FKUs)
  - Bridge Knowledge Units (BKUs)
  - Interdisciplinary Knowledge Units (IKUs)
- Learning objects have various attributes like learning choice, learning objective, prerequisite, and completion
  - Metadata example next slide

METADATA EXAMPLE

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        "cell_interactive": "false",
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            "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": [
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        ],
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        "cell_type": [
            "text"
        ],
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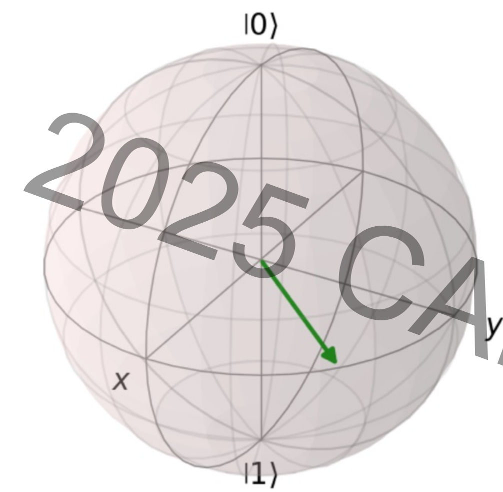
            "Master the concept of complex number representations",
            "Perform basic additive and multiplicative operations on complex numbers",
            "Implement Python programs for addition and multiplication on complex numbers"
        ],
        "module_prereqs": [
            "Algebra",
```

Learning Object Representations

- QUINTET learning objects are available in multiple representations:
  - Text, visual (image), symbolic example, numerical example, widgets, interactive/non-interactive simulations, code-IDE, code-IDE with tests
- Enables learning through various modalities
  - Screenshots show the interface and several features of QUINTET

Example Learning Objects

azimuth –60
elevation 30



Enter number of initial qubits

100

Eve is not active

Click to activate

Enter Alice's bias for diagnal basis over standard basis (0-100)

50

Enter Bob's bias for diagnal basis over standard basis (0-100)

50

Enter Eve's bias for diagnal basis over standard basis (0-100)

50

After setting the parameters you may either:

- Run each of the following cells one at a time in order or

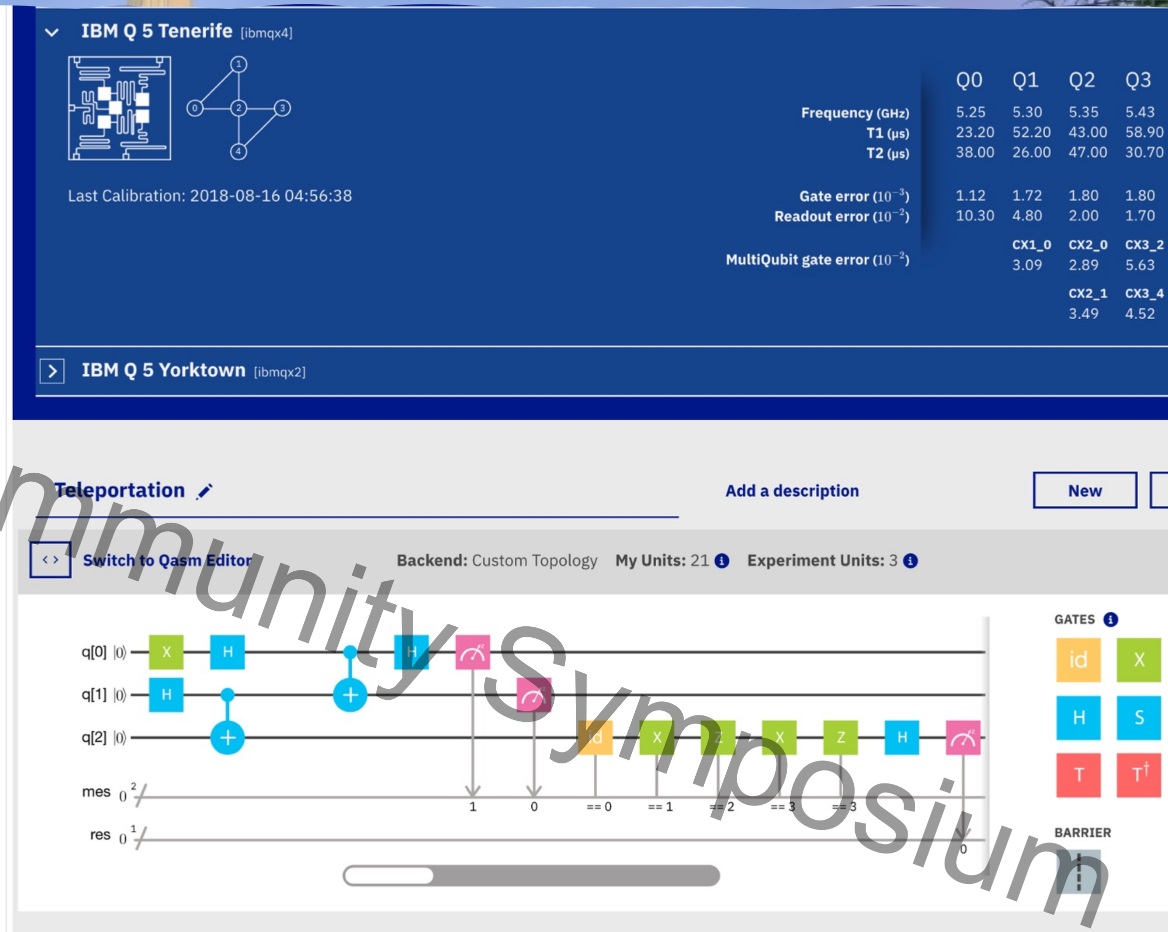


Figure 1. IBM quantum computer interface shown along with circuit for quantum teleportation.

Real

Real= 1.01181714 Imaginary= 0.9877358

✓ Clear

▾ Exercise 1

Is the following a superposition with respect to the standard basis?

$$\frac{1+i}{2}|1\rangle - \frac{1-i}{2}|0\rangle$$

Yes.

No.

Solution ✓ Check 1/7

▸ Exercise 1 (solutions)

Alice's bit	0	1	1	0	1	0	1	1
Alice's basis	+	×	+	×	×	+	+	+
Alice's polarization	↑	↖	→	↗	↖	↑	→	→
Bob's basis	×	×	×	+	×	×	×	+
Bob's measurement	↗	↖	↗	→	↖	↗	↗	→
Public discussion	Alice and Bob Compare Basis							
Secret key	?	1	?	?	1	?	?	1

8

Restart Randomise All

Quiz 3.1 Self Assessment Quiz

Maybe used for in-class hands-on practice.

1. Convert the following into polar representations.

a. $c = 1+i$

$\rho=$ 1.414 , $\theta=$ 44.3 ✓ Graph It

b. $c = 21+48i$

$\rho=$ 52.39 , $\theta=$ 29.0 ✓ Graph It

c. $c = 3-45i$

$\rho=$ 0 , $\theta=$ 0.0 ✓ Graph It

2. Convert the following polar representations into cartesian representations.

a. $\rho = 25$ and $\theta = 60°$

(0 , 0) ✓ Graph It ✗ Incorrect

b. $\rho = 15$ and $\theta = 45°$

(0 , 0) ✓ Graph It ✗ Incorrect

c. $\rho = 45$ and $\theta = 30°$

(0 , 0) ✓ Graph It ✗ Incorrect

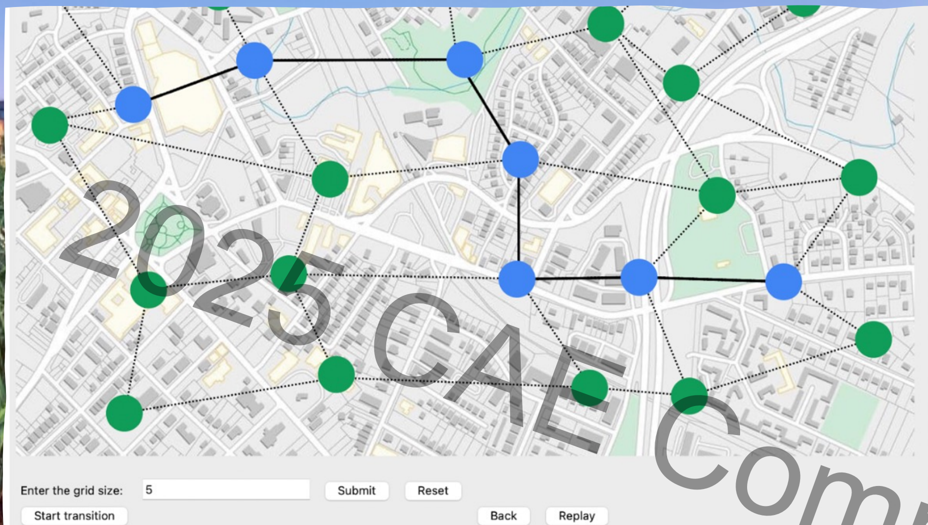
3. Multiply the following using polar representations.

a. $c_1 = 1+2i$ and $c_2 = 4i$

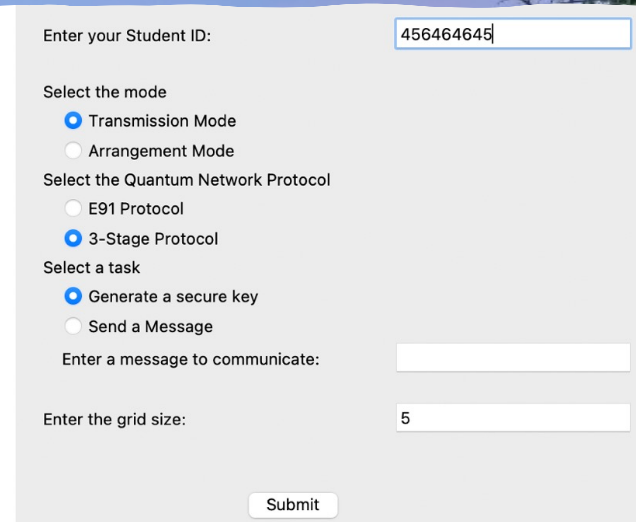
$\rho=$ 0 , $\theta=$ 0.0 ✓ Graph It

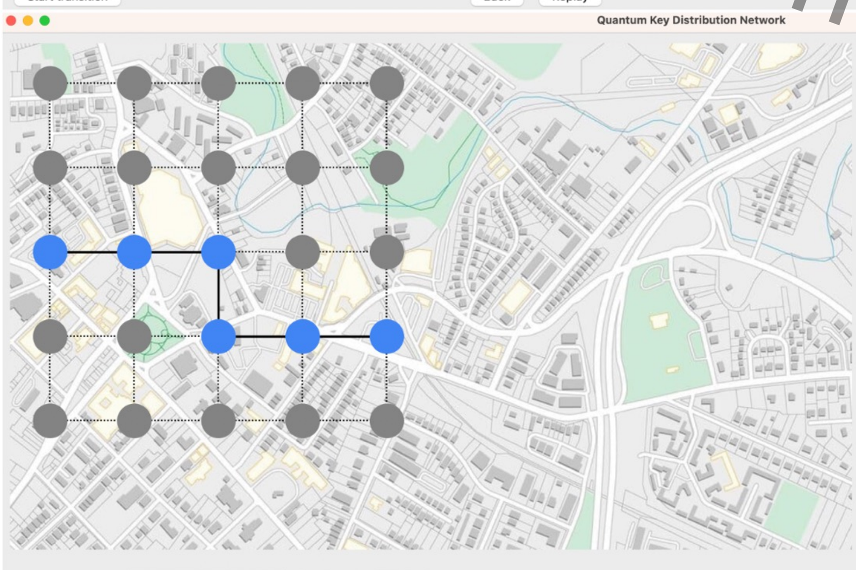
b. $c_1 = 2-4i$ and $c_2 = 3-2i$

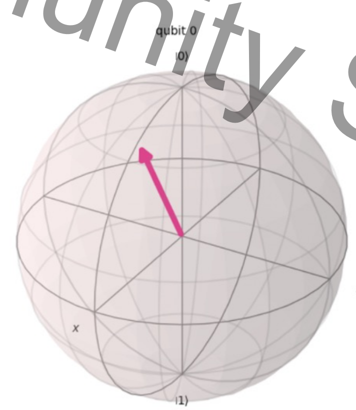
$\rho=$ 0 , $\theta=$ 0.0 ✓ Graph It

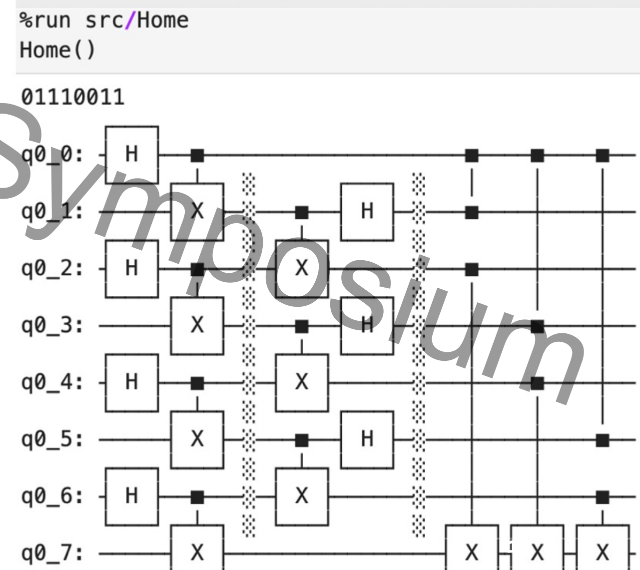


Network Simulator









Experiential Learning in QUINTET

- QUINTET supports experiential learning through:
  - Concrete Experimentation Phase: Interactive simulations, code-IDE with tests, self-graded exercises
  - Reflection Phase: Interactive simulations to replay actions and observe outcomes
  - Conceptualization Phase: Interactive audio-visual scenarios and coding tasks
  - Active Experimentation Phase: Assessment learning objects to test understanding

Lesson Generation using Fractional Knapsack

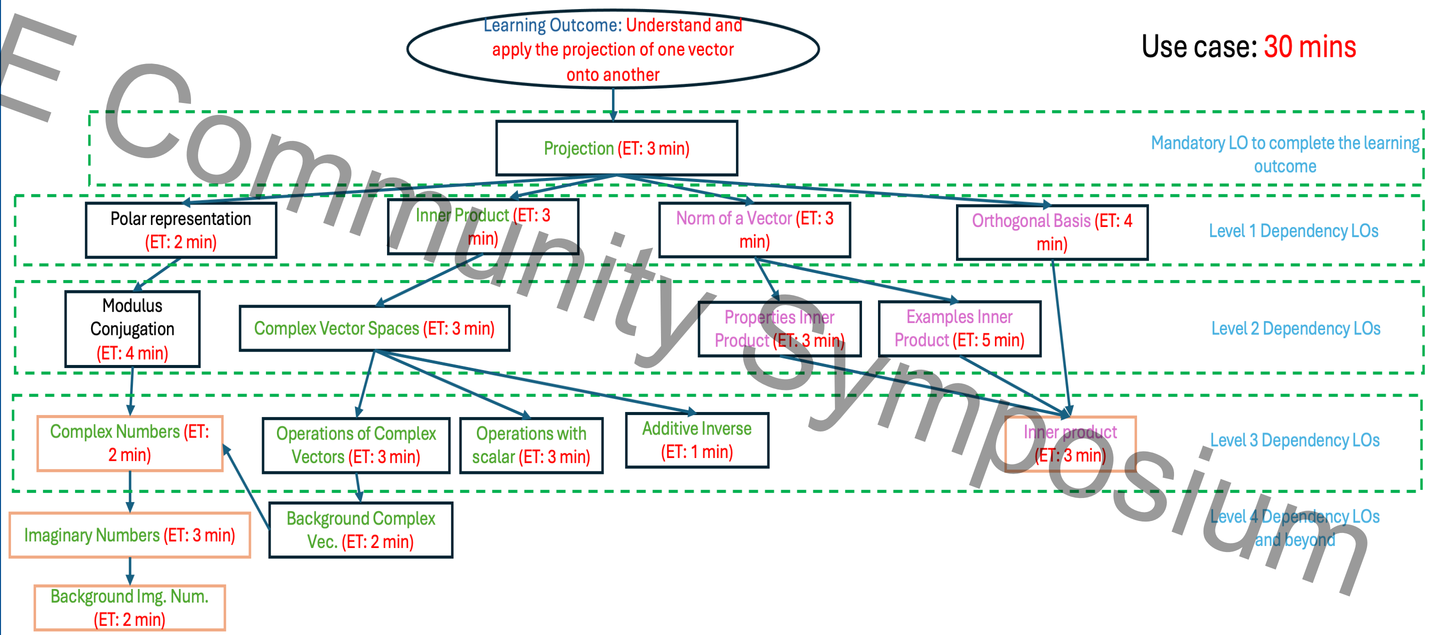
- QUINTET uses a fractional knapsack algorithm to generate lessons
- Maximizes educational value while respecting time constraints and achieving target learning outcomes
- Explanation of the fractional knapsack problem formulation and algorithm implementation

Fractional Knapsack Algorithm

- High-level steps of the fractional knapsack algorithm:
  - Initialize a dynamic programming (DP) table
  - Fill the DP table by sorting and processing learning objects
  - Backtrack from the end of the DP table to determine selected learning objects
  - Calculate the completion fraction of each module
  - Verify if the target learning outcome is achieved

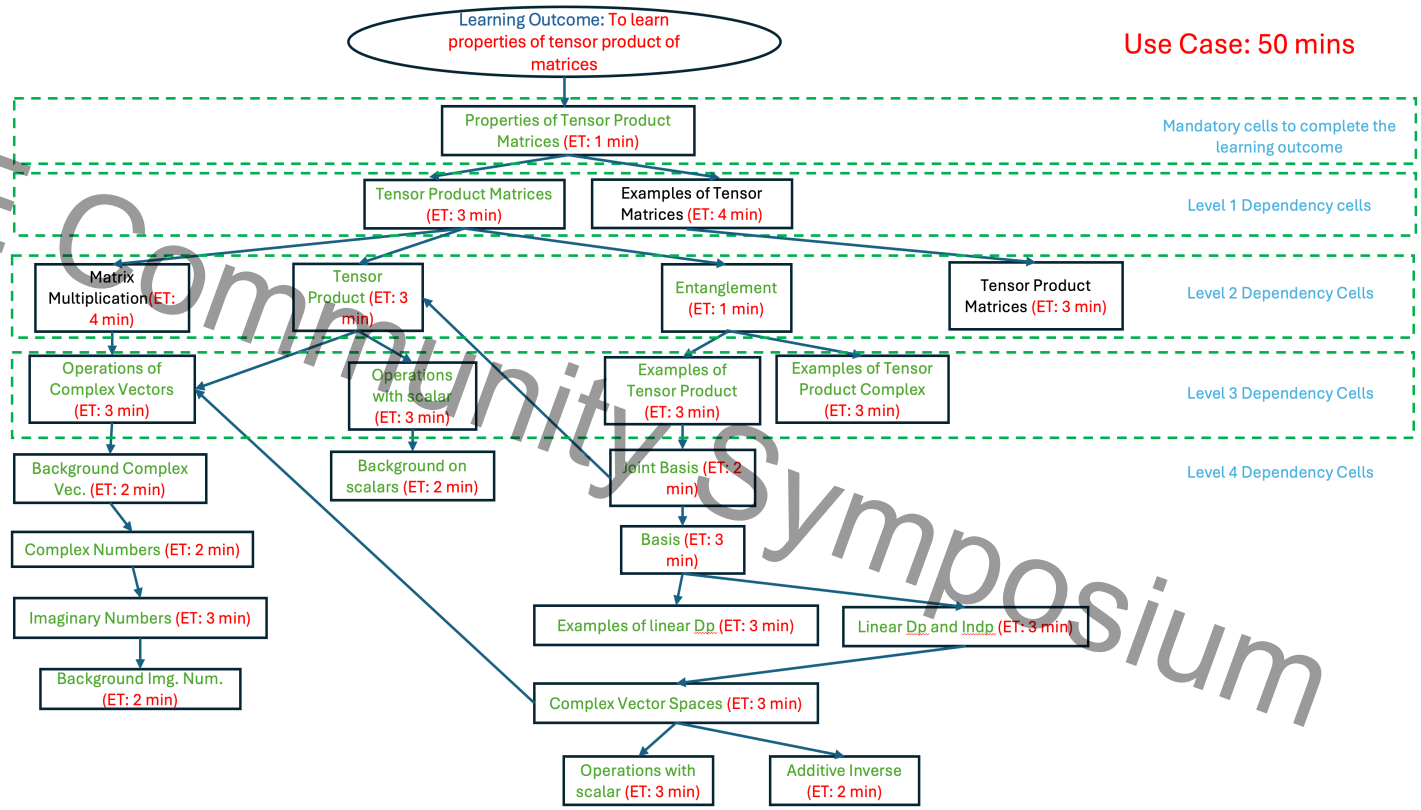
Use Case 1: Single Learning Outcome and Time Constraint

- Explanation of how the algorithm generates the lesson within the given time constraint



Use Case 2: Time Constraint of 50 Minutes

Use Case: 50 mins



Advantages of QUINTET

- Addresses the unique challenges in quantum education through an experiential learning approach
- Automatically generates lessons that align with specified learning outcomes and time constraints
- Provides hands-on virtual network experimentation and supports multiple representations of learning objects

Future Work and Conclusions

- Future work involves developing more learning objects and supporting additional constraints
- QUINTET introduces a novel experiential learning platform for quantum education

Thank you!

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