**Motivation**

Students take the plurality of their physics classes in undergraduate, but often don't really deeply understand physics until graduate school.

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**Approach**

Four immersive projects

- Quantum Computing Simulator
- Renormalization Group on the Ising Model
- Topological Insulators
- Machine Learning

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**Project 1: Quantum computing simulator**

*Language: python*

Students write code to take a quantum circuit description:

```
using a universal set of gates (i.e. Hadamard, Phase, CNOT)
```

and output the quantum state produced from the circuit.

They then figure out how to make gates not in their universal set which they turn into a simple quantum compiler.

Students proceed to write code to generate quantum circuits for arbitrary phase estimation.

```
and use phase estimation to factor numbers.
```

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**Project 2: Renormalization Group**

*Language: C++*

Students write code to simulate Ising models on arbitrary graphs via Markov Chain Monte Carlo.

```
and using block-spin decimation
```

with ideas about the renormalization group.

```
computes the RG flow of the coupling constant J → J′
```

They identify the phases and critical points by fixed points of the RG flow and compute critical exponents.

**Bonus:** Simulated Annealing + Parallel Tempering

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**Project 3: Machine Learning**

*Language: C++*

Students write a Hopfield network to measure the energy landscape and empirically determined its memory capacity.

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Students write a Restricted Boltzmann machine
```

and discover it's just an Ising Model.

```
They then use it in an unsupervised capacity to learn digits.
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**Project 4: Topological Insulators**

*Language: python*

Students implement a tight-binding model of graphene, and empirically determined its memory capacity.

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see that there are multiple ways to gap out the Dirac cones,
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and find that some of them have a Chern number and edge modes.

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**Course website:** https://courses.physics.illinois.edu/phys498cmp/