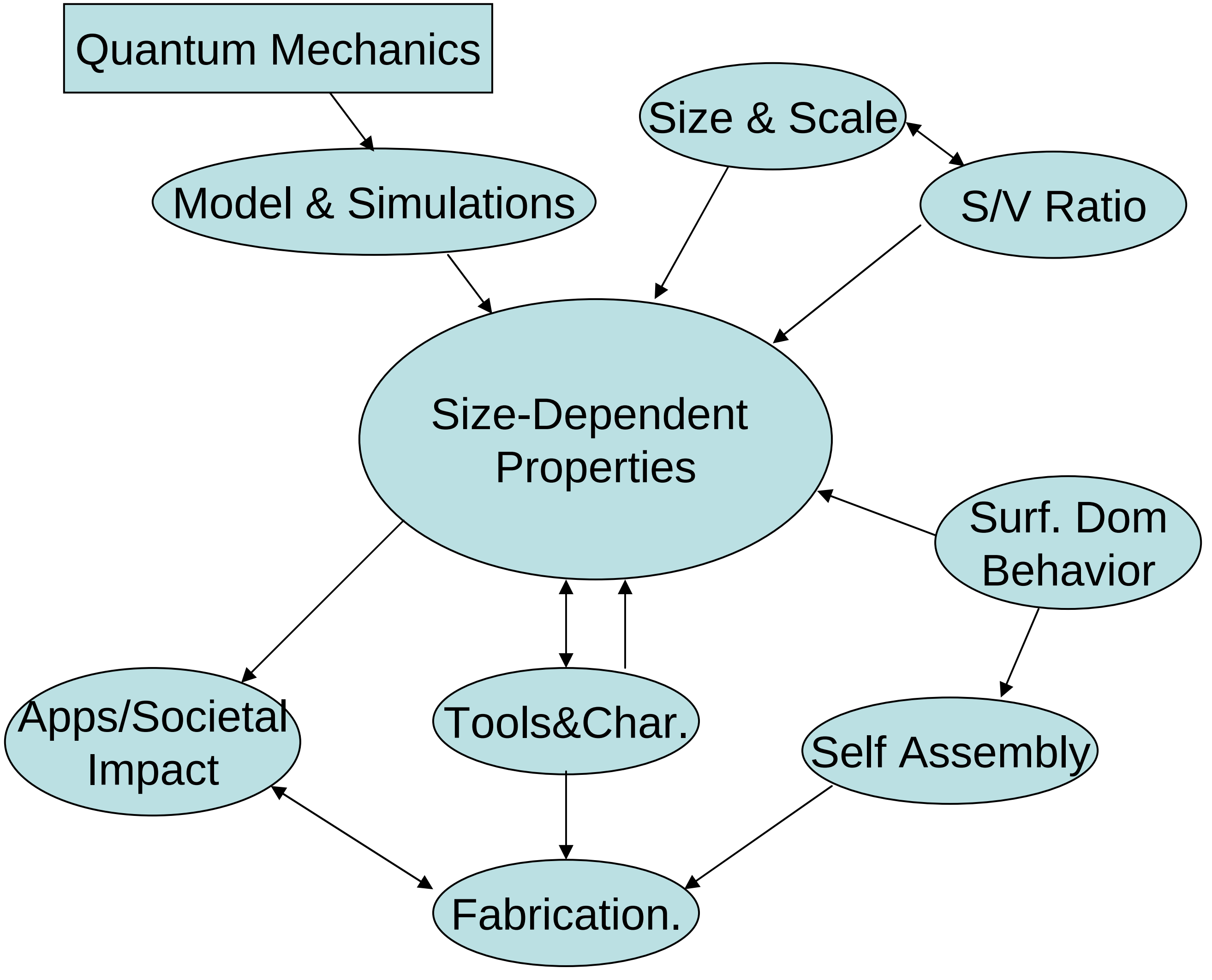
Quantum Mechanics
Size & Scale
Model & Simulations
S/V Ratio
Size-Dependent Properties
Surf. Dom Behavior
Apps/Societal Impact
Tools&Char.
Self Assembly
Fabrication.

Big Idea: Size Dependent Properties taught through Quantum Mechanics

Critical Concept: Tunneling

Level: freshman undergraduates

Course: general introductory course

Concepts (Science content)

- Distance Dependent
- Energy Dependent
- Material Dependence
- Probability:
  - The probability will increase as the size decreases (probability increases)
  - We can also consider a thinner wall (thinner barrier) (careful with misconceptions)
- Explain as a particle in well and not mention QM

Potential student difficulties

Quantum mechanics is just difficult

- We do not live in a quantum world, so quantum effects are not intuitive and are necessarily abstract.
- not consistent with student experiences

Students may struggle with probabilistic models

Students have difficulty connecting the need to use QM to explain the behavior of matter with scale

Logarithmic scales and relationships

Prerequisite knowledge/ assumed prior knowledge

- What is an electron? (high school chemistry)
- Voltage, current
- Energetic barriers
- What materials are conductors and insulators
- Algebra
- Graphing (logarithmic scales)
- Basic concept of probability

Learning Outcomes

1. Student will be able to use the relationships between relevant parameters (i.e., size, energy, distance and materials) to explain when tunneling might occur.
2. Given a simple equation and a set of parameters, students will be able to calculate the probability of tunneling in relation to distance; from these findings, they will be able to graphically define the relationship between probability and distance.
3. Student will be able to explain how a scanning tunneling microscope works

- **Learning outcome 1:**
  - Student will be able to use the relationships between relevant parameters (i.e., size, energy, distance and materials) to explain when tunneling might occur.
- **Evidence:**
  - Qualitative relationship between probability and:
    - size
    - energy
    - distance
    - materials
- **Tasks:**
  - Comparison and justification of relative tunneling probability given diagrams of potential wells with varied height, width, particle energy.
  - Predict if tunneling might occur for given physical scenarios (e.g. materials/separations/energy)

- **Learning outcome 2:**
  - Given a simple equation and a set of parameters, students will be able to calculate the probability of tunneling in relation to distance; from these findings, they will be able to graphically define the relationship between probability and distance.
- **Evidence**
  - interpretation of distance dependence of tunneling probability. Definition of axes and recognition of exponential dependence at small separation and negligible probability at large separation distance
- **Tasks:**
  - Calculate probability for range of separation values
  - Graph the probabilities and describe how the probability varies with with distance.

- **Learning outcome 3:**
  - Students will be able to explain how a scanning tunneling microscope works
- **Evidence**
  - The explanation will include and relate the ideas below:
    - importance of tip/probe and substrate materials
    - dependence of signal detection on distance between tip/probe and surface
    - importance of exponential relationship
    - electrical/energy output requirements
- **Tasks:**
  - Practical/lab with STM, as part of lab write-up explain how STM works.

  OR

  - Project or paper using visuals and/or models to explain how STM works.

- **Activities and phenomena:**
  - Ball against the wall
    - Calculate the probability of tunneling as a function of size without going into a detail explanation
  - Light in a glass fiber--bend it and see the light escape
  - STM lab or activity.
    - Real instrument and/or model

- **Exercises:**
  - Construct a graph from calculations results

Potential Misconceptions/ Alternative Ideas

General:

Must have conductive material to use STM

- *just regular electric current, not tunneling*

Due to their experiences, students may believe that classical mechanics effectively and accurately predicts and describes the behavior of matter under all conditions and scales.

From lessons:

Probability of ball bouncing against/through wall

- *thinner wall just breaks easier*
- *easier for smaller particles to fit through*