Design of a Nano-Thermodynamics Unit with Group Project for a Sophomore-Level Thermodynamics Course

An example of Construct-Centered Design

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The Big Idea:
"Size-Dependent Behavior"

The properties of matter can change with size and scale. In particular, as the size of a material approaches the nanoscale, it often exhibits unexpected properties that can lead to new functionalities…. Surface-dominated properties result from the increased fraction of atoms on surfaces.

Quoted from "A Rubric for Post-Secondary Degree Programs in Nanoscience and Nanotechnology" by Wansom et al.

Unpacking the Critical Concept:

- Necessary background knowledge:
  - Chemical bonding
  - Basic laws of thermodynamics
  - Surface area-to-volume ratio (SA/V)
- Science Content:
  - The environment/bonding are different at surfaces, and depend upon curvature.
  - The fraction of atoms at surfaces dramatically increases at the nanoscale.
  - Certain properties depend upon this fraction of surface atoms and nano-particles therefore exhibit size-dependent behavior.

Unpacking the Critical Concept:

- Relevant phenomena
  - Melting point reduction of particles at the nanoscale
  - Increased solubility of small vs. large particles
- Student difficulties/misconceptions
  - Since micro- and macro-objects behave similarly, nano-objects will do the same (extrapolation).
  - All surfaces are the same and behave in the same way—a surface is a surface!
  - There is a single melting point for a given material (you can look it up in a handbook!) and there is no deviation from this value.

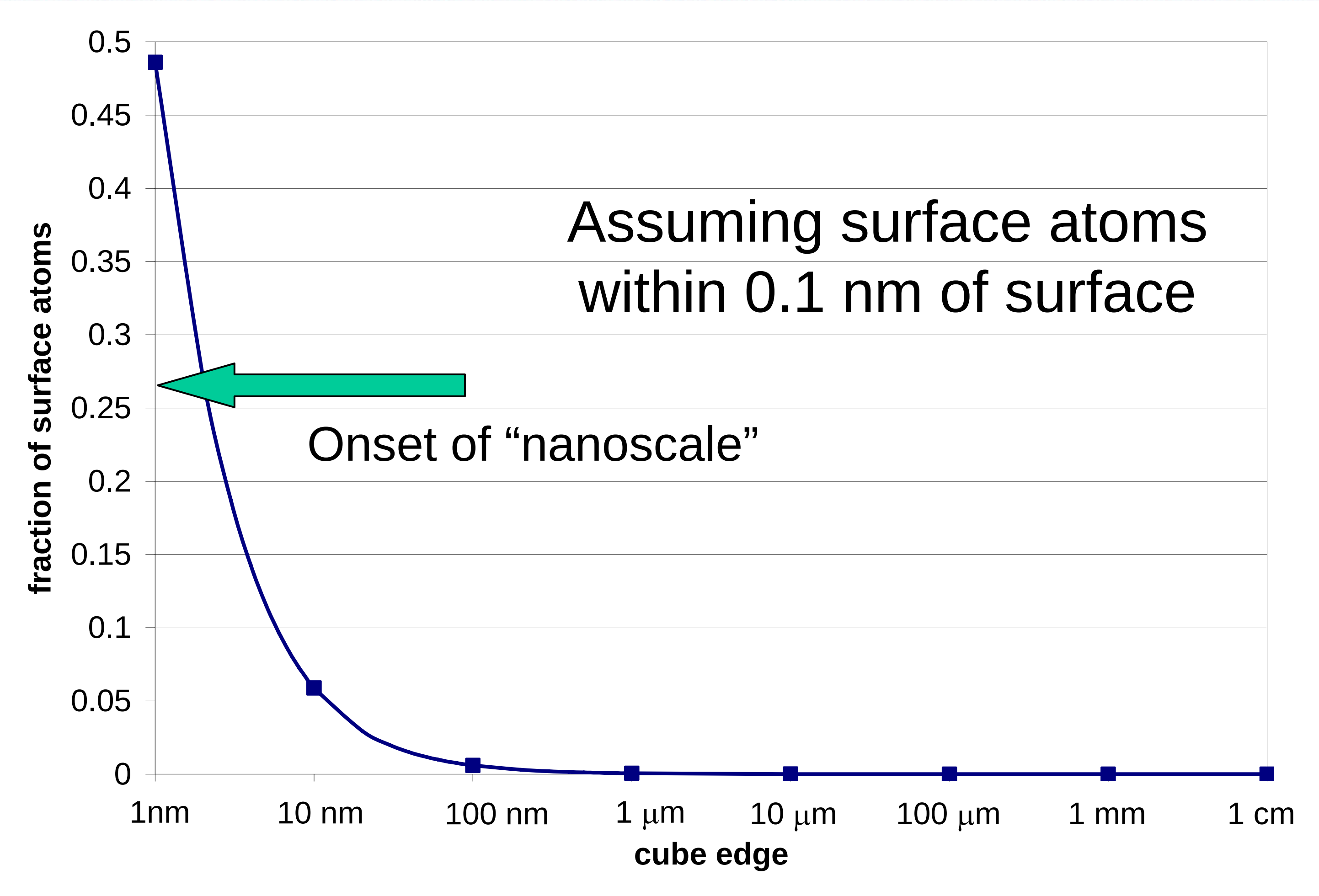
The Critical Concept:

The dramatic increase in the fraction of surface atoms at the nanoscale, with their size-dependent (and curvature-dependent) environment/bonding, can lead to size-dependent thermodynamic properties (e.g., melting point).

Learning Outcomes:

- Upon completion of the Nano-Thermo Unit/Project students will be able to:
  – Explain and quantify how SA/V ratio increases with decreasing particle size
  – Describe and predict how melting temperature decreases with decreasing particle size (increasing curvature)
  – Compare and justify the onset of the so-called “nanoscale regime” in terms of demonstrable changes in SA/V ratio and melting point

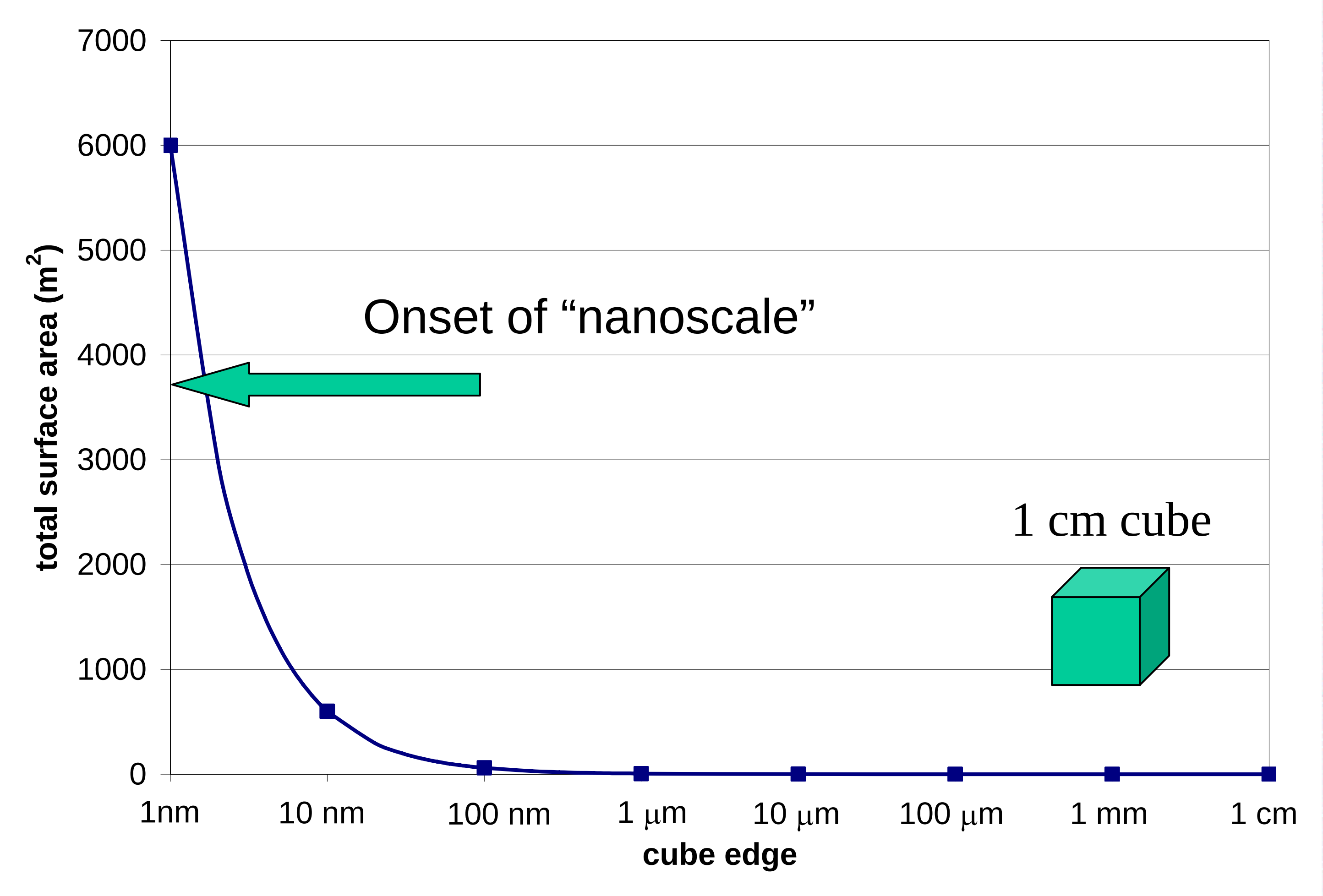
Increasing amounts of surface atoms:



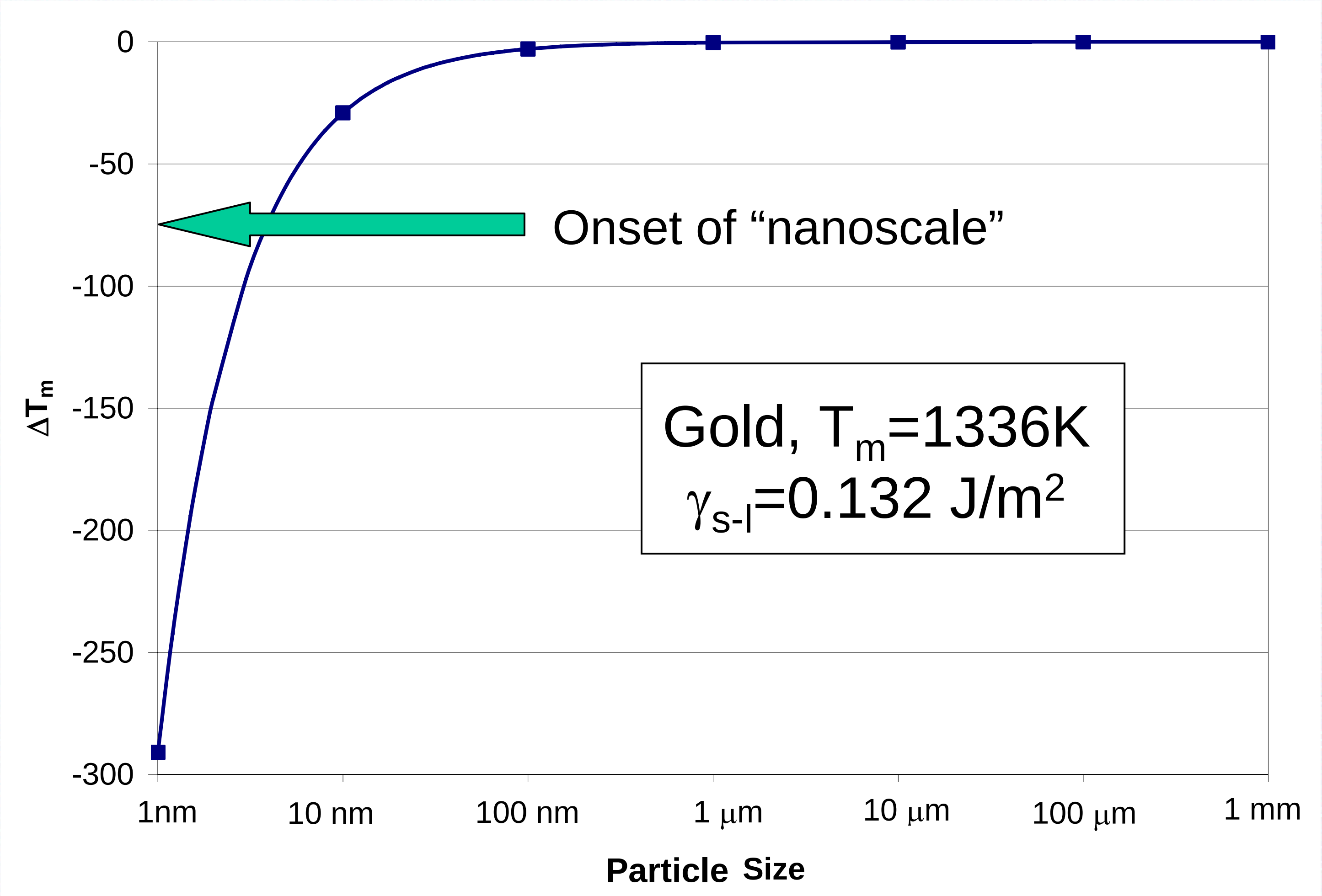
Evidence of Learning Outcomes:

- Construction of computer-generated graphs exhibiting the onset of size-dependent SA/V ratio
- Construction of computer-generated graphs exhibiting the onset of size-dependent (curvature-dependent) thermodynamic behavior (e.g., melting point)
- Effective oral/visual communication of size-dependent SA/V ratio and curvature-dependent thermodynamic behavior (melting point)
- Effective written communication of size-dependent SA/V ratio and curvature-dependent thermodynamic behavior (melting point)

Student Work:



Student Work:



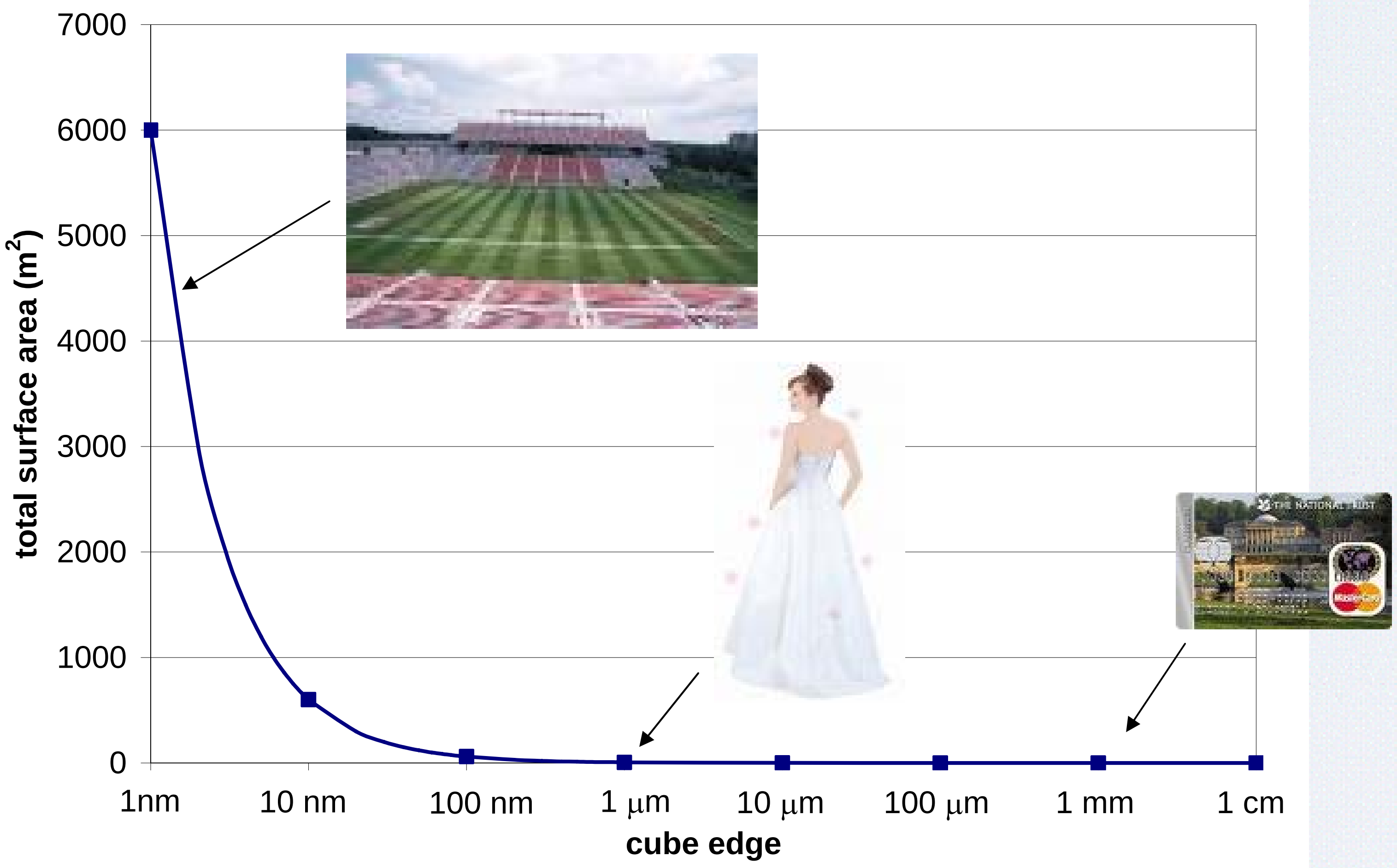
Student Assessment Task(s):

- A Group "Nano-Thermodynamics" Project for use in high school AP science classes. Students are to:
  - Design and implement a stand-alone computer-aided learning tool dealing with:
    - SA/V ratio (nano-to-macro)
    - Melting point changes (nano-to-macro)
  - Develop and write a teacher's guide to provide background and describe how the tool is to be used in the classroom
  - Prepare and deliver a 15-minute Powerpoint presentation to be made as if training high school teachers in using the tool

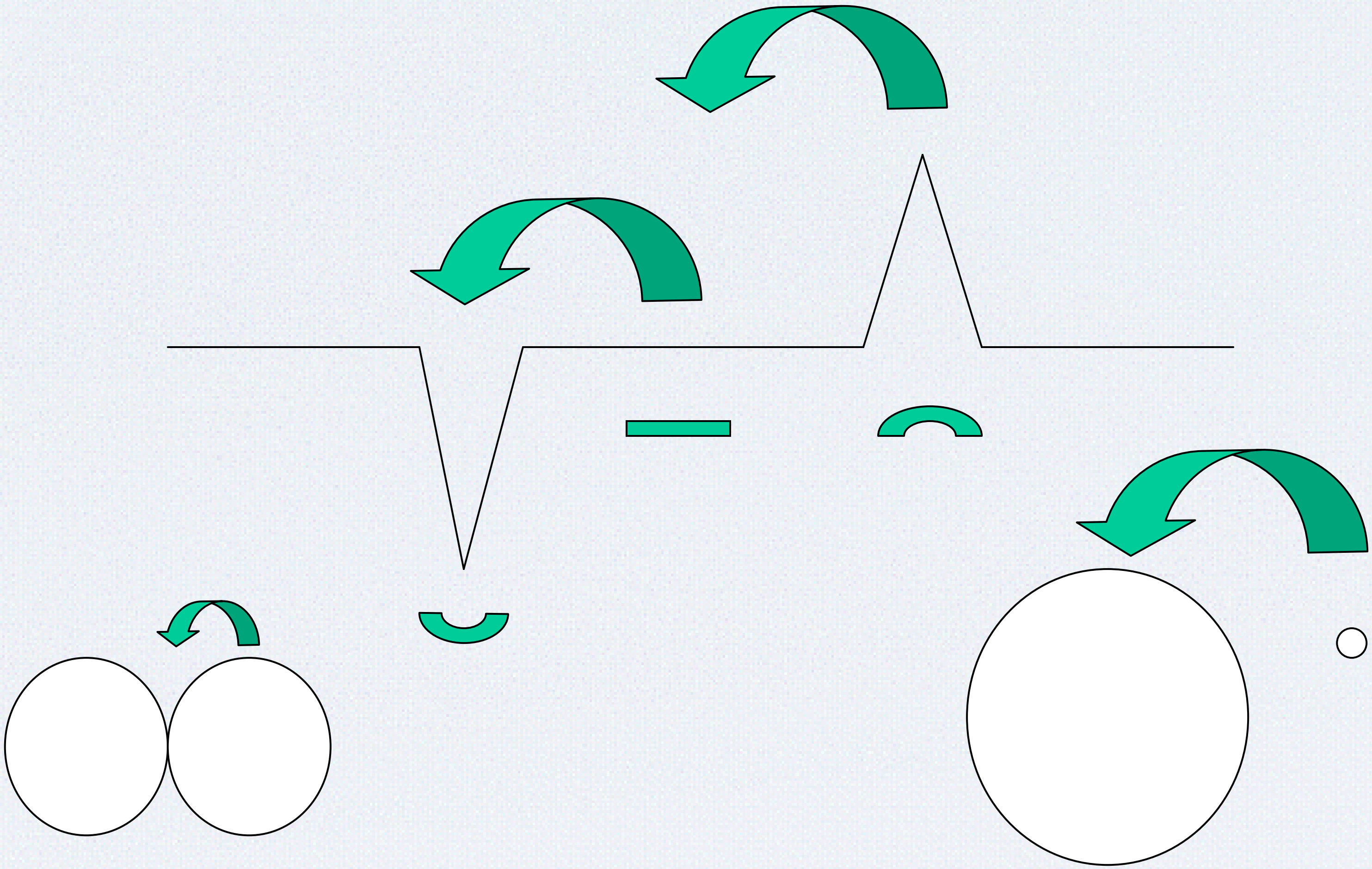
Facilitating the Learning Outcomes:

- Require a Group Project—ask students to develop:
  - Computer simulations
  - Technical writing for non-experts
  - Effective oral communications for non-experts
- Modify lecture content to align with Learning Goals
  - Added visuals
    - Surface area benchmarks
    - Treatment of exaggerated convex, concave surfaces

Lots of surface area!



Chemical potentials at curved surfaces:



Implementation and Evaluation:

- 25 sophomores took MatSci-315 during winter quarter, 2008
  - Lecture content/Powerpoint slides updated
  - Group nano-thermo projects required (4 students/group)
- In-class paper surveys and talk-aloud interviews (by project group)
- Results are currently being analyzed!
- Stay tuned…