ACTIVE LEARNING IN THE ADVANCED CLASSROOM

LAUREN TOMPKINS
MECHANICS:

Prior to Class:
• Students complete targeted reading
• Take reading quiz

In Class:
• Group (3-4 students) activities in worksheet form interspersed with ~five minute mini-lectures
• Teaching staff circulate to guide inquiry

Homeworks used to deepen knowledge with longer exercises
Exams test if learning goals have been met
MINDSET:
TEACHING AS MENTORING
MINDSET: SHIFTING FROM "WHAT DO I NEED TO TELL THEM" TO "WHAT DO THEY NEED TO DO SO THAT THEY WILL UNDERSTAND THIS"
MINDSET:
TEACHING TO THE ENTIRE CLASS
MINDSET:
THINKING IN TERMS OF EXPERT VS NOVICE KNOWLEDGE
IMPORTANCE OF:
LEARNING GOALS
1. Units and scales. Converse in the units and scales used by particle physicists, for example, GeV, barns, fermi.
   (a) Convert between mass, energy and wavelength of a particle, keeping in mind that very often \( c = 1 \) and/or \( h = 1 \).
   (b) Know references that connect units to familiar scales.
       For example, \( \frac{m_p}{c^2} \approx 1 \text{ GeV} \), \( 1 \text{ ns} \approx 1 \text{ ft} \), \( \tau_p \approx 1 \mu s \).
   (c) Explain why particle accelerators are a useful tool for particle discovery.

2. Standard Model particles and interactions. Classify all fundamental particles by how they interact with other particles.
   (a) Describe the nature of all particles as quanta of fields.
   (b) Differentiate between force carrier particles (gauge bosons) and matter particles.
   (c) Know and explain the conservation laws of the Standard Model and when they hold.
   (d) Identify which quantities are conserved in a given interaction, for example, charge, isospin, angular momentum, quark flavor, color.
   (e) Differentiate the three fundamental forces by how they interact with the known particles.
   (f) Give examples of parity or charge conserving and violating interactions.
   (g) Qualitatively describe the energy (or scale) dependence of the three Standard Model interactions. What are some measurable consequences at high and low energies?

3. Feynman diagrams. Draw and interpret Feynman diagrams for a given hadron decay or scattering, for example, \( n \rightarrow p + e^- + \bar{\nu}_e \).
   (a) Know which interactions are allowed in the Standard Model.
   (b) After finding one possible diagram for a given reaction, determine if there are any other allowed diagrams with the same number of vertices.
   (c) Classify the contribution of a diagram to a particle interaction rate by its number of vertices.
   (d) Explain the difference between real and virtual particles.

4. Relativistic kinematics. Formulate relativistic problems mathematically in four-vector notation, including:
   (a) Identify invariant quantities and determine the validity of a quantity in a given frame.
   (b) Calculate the invariant mass given decay four-vectors.
   (c) Calculate the decay kinematics given a set of measurements.
   (d) Use energy and momentum laws in the correct reference frame.
   (e) Show that handedness is not an invariant quantity.

5. Decays and scattering.
   (a) Build a decay equation including phase space factors and matrix element for a given particle decay.
   (b) Evaluate the relative rates between two known particle decays that differ by quark content at a single vertex.
   (c) Requires ability to draw Feynman diagrams (see above).
   (d) Use the CKM matrix to determine relative coupling strengths.

   (a) Use addition of isospin, spin and angular momentum quantum numbers to combine quarks into baryons and mesons.
   (b) Construct possible particle states based on constituent spin and orbital angular momentum numbers.
   (c) Explain the internal structure of the proton and how we know about it.

7. Symmetries.
   (a) Describe the relationship between symmetries and conservation laws.
   (b) Explain the symmetries giving rise to the Standard Model conservation laws.
   (c) Explain why CP is violated in weak decays.
   (d) Distinguish between an internal and non-internal symmetry
   (e) Operate on interactions with charge and parity operators.

8. Lagrangians and Particle Interactions
   (a) Be able to identify components of a Lagrangian and build corresponding Feynman diagrams
   (b) Describe what is gauge invariance and how it gives rise to forces
IMPORTANCE OF:
NORM SETTING
SYLLABUS
FIRST DAY
Class Climate:
Fear of asking questions can be a pernicious impediment to learning. In our active-learning classroom, the most valuable contributions to learning can be questions like “I don’t understand why we can come to that conclusion... can we discuss it further?” or “how did that step work? can we go over it again?” or “I don’t recall seeing that terminology/symbol/notation before, can we review the precise definition?”

Strongly encouraging questions in your active-learning groups benefits not only the person asking the question, but also benefits the students responding. Our understanding of concepts can be quite muddled until we attempt to articulate them verbally or in writing. If you ask a question and receive a response from a classmate that doesn’t bring complete clarity, try responding with “Is this what you are saying?” and then describe your interpretation of the explanation in your own words. Everyone at your table can listen and give input to bring further clarity.

To facilitate the most effective and inclusive learning environment by promoting deliberate exploration of what we don’t know, we have just a couple of “social rules”:

1. Please resist acting surprised when people say they don’t know something. Feigning surprise has no social or educational benefit.

2. Avoid subtle racism, sexism, homophobia, transphobia, and other kinds of bias. ”Subtle-isms” are small things that make others feel uncomfortable. For example, saying ”It’s so easy my grandmother could do it” is a subtle-ism.

If you find yourself breaking one of these rules, please apologize, use it as a learning experience, and then move on. If you see repeated feigned surprise, or hear a subtle-ism, you can point it out to the relevant person, either publicly or privately, or you can ask a member of the teaching team to say something. After this, we ask that further discussion move off public channels. The “subtle” in “subtle-isms” means that it may not be immediately obvious to everyone what was wrong with the comment. Please use it as a teachable moment, and then assume the message was received.
BENEFITS:
CONSTANT FEEDBACK LETS YOU MONITOR STUDENT LEARNING
BENEFITS: Students like learning this way
BENEFITS:
RESEARCH SHOWS IT’S BETTER

Transforming a 4th year Modern Optics Course Using a Deliberate Practice Framework

David J. Jones, Kirk W. Madison, Carl E. Wieman

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We present a study of active learning pedagogies in an upper division physics course. This work was guided by the principle of deliberate practice for the development of expertise, and this principle was used in the design of the materials and the orchestration of the classroom activities of the students. We present our process for efficiently converting a traditional lecture course based on instructor notes into activities for such a course with active learning methods. Ninety percent of the same material was covered and scores on common exam problems showed a 15% improvement with an effect size greater than 1 after the transformation. We observe that the improvement and the associated effect size is sustained after handing off the materials to a second instructor. Because the improvement on exam questions was independent of specific problem topics and because the material tested was so mathematically advanced and broad (including linear algebra, Fourier Transforms, partial differential equations, vector calculus), we expect the transformation process could be applied to most upper division physics courses having a similar mathematical base.
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<th>What’s its name?</th>
<th>Bra-ket</th>
<th>Matrix</th>
<th>Function</th>
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<td>\alpha\rangle$</td>
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<td>2. a different state vector</td>
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<td>8.</td>
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<td>$\hat{H}\psi(x) = E\psi(x)$</td>
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