Reconceptualizing the nature of science activity for high school learners--
Or:
The quest for "infinitely skilled teachers."

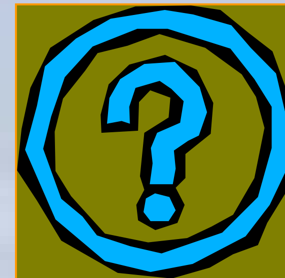
New visions for the laboratory tied to teacher development

Only way to bring teachers to this level is to cultivate them as professionals, intellectuals, and life-long learners.

This requires of teachers a greater repertoire of pedagogical skills, deeper content knowledge, knowledge of student learning.

Standards documents prioritize inquiry-oriented teaching

Shifting conceptions of “Laboratory”



- Not a well-defined activity structure.
- Working with materials can now happen in broad range of instructional circumstances.
- Technology allows new kinds of interactions with science in new types of settings.
- Some teachers move easily between lab work and other forms of instruction--often hybridizing activity structures (demo-based discussion, “just-in-time” presentation during inquiry activities).

Q1. What knowledge and skills required to design and carry out different forms of laboratory activity?

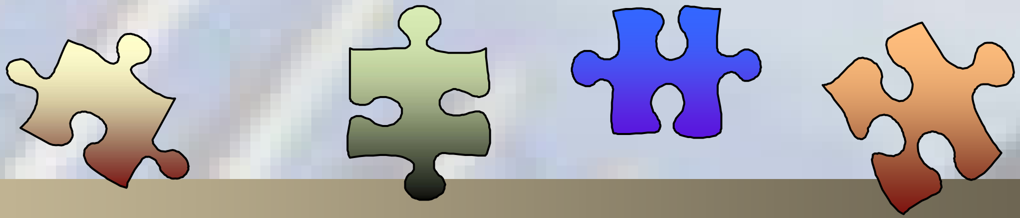
- More scripted
- Short term
- Single concepts

- Demonstrations
- Discovery learning
- Building skills
- Problem solving
- "School science" inquiry
- Authentic forms of inquiry

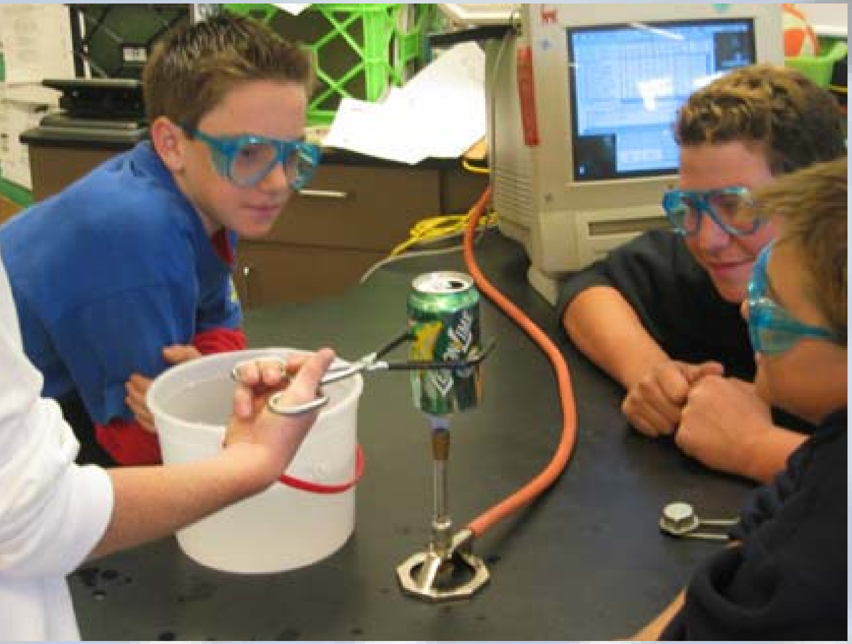
- Less scripted
- Longer term
- Integration of ideas
- Process, judgment emphasized
- Different relationship between teacher and student

Requires view of knowledge that is grounded in literature and responsive to professional development

- General pedagogical knowledge – moderating discussions, designing group work, organizing materials for student use, etc.
- Content knowledge – understanding of domain's concepts, theories, laws, principles, history, classic problems, etc.
- Pedagogical content knowledge –
  - how to select representations, analogies that help learners conceptualize science ideas; recognizing common alternative conceptions students hold, how to scaffold intellectual and procedural skills related to science, etc.
- Disciplinary knowledge –
  - purpose of science inquiry,
  - domain-specific methods of investigation,
  - nature of relationship between theory/models and data,
  - standards for evidence and argument that are held in various fields of science. etc.



Demonstration, skill-building, discovery

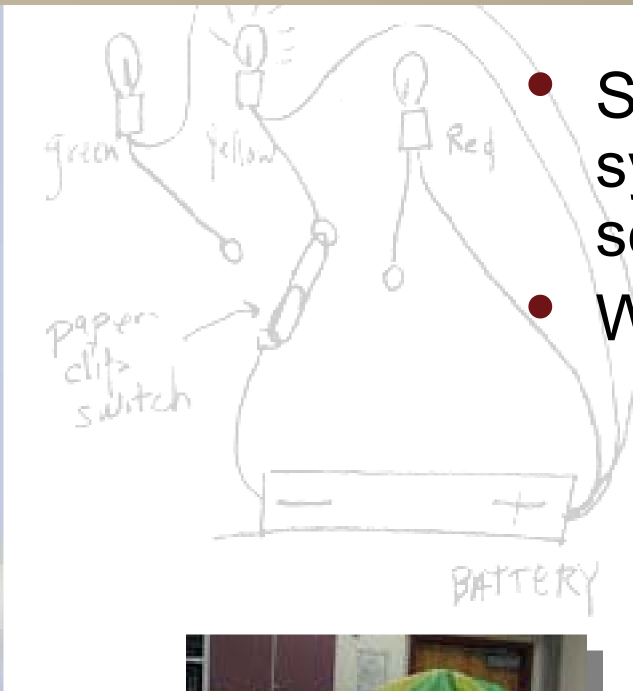


- Demonstration:Teacher illustrates principles (Bernoulli's), concepts (osmosis), or laws (Newton's Law of Cooling)
- Discovery learning: Students work in prescribed ways with materials to "discover" or confirm an idea (using pulleys, ropes, and masses to explore mechanical advantage).
- Skill-building: Students engage in manipulative activity (assembling distillation apparatus), follow procedures (collecting data on cricket behavior), or practice intellectual skills (transforming table data into graphical representations).

Demonstration, skill-building, discovery

General pedagogical knowledge	How to organize phases of activity. How to organize and manage material use by students.
Content knowledge	Surface level familiarity of target concept or skill required. Preferably knowledge of phenomena at the theoretical level. Knows examples and counterexamples of target concepts. Understands how key ideas related to others in domain. Understanding nature of observation versus inference.
Pedagogical content knowledge	Understands: how to elicit students' existing conceptions which type or sequence of interactions with materials most likely to promote unambiguous conceptions of target ideas. which representations/activities will avoid generating alternative conceptions. how to scaffold students' generalizations of the focal idea to related contexts. how to scaffold students' integration of focal idea with other ideas in domain. how to bring students to proficient performances with important skills. how to recognize flaws in students' thinking about concepts, skills. how to help students recognize under what circumstances these skills should be used. how to combine these forms of instruction with others for the most effective learning experience. how to assess students' knowledge and skills.
Disciplinary knowledge	Conceivably none. Preferably knowledge of how skills and ideas might fit within larger context of an investigation. Knows historical context of development of idea.

Problem-solving



- Students use understandings of concepts, systems, instruments, procedures to solve self-defined or teacher-defined problems.
- Wide range of complexity, could be:
  - determining a definitive answer ("puzzle solving", e.g. Identify the mystery chemical),
  - technological construction (creating a working circuit system for a set of model traffic lights), or,
  - solving ill-defined problems in authentic contexts (e.g. How does run-off from agricultural land affect local aquatic ecosystems?).

Problem-solving

General pedagogical knowledge	Understanding: how to strategically improvise sequences of instructional moves based on ill-structured problem-solving contingencies. how to organize and manage materials.
Content knowledge	Ranges from surface level to in-depth understandings of phenomena and how it is manifested in various contexts. Knowledge of problem-solving skills, process skills, etc. Knowledge of how different science ideas inter-relate with one another. Knowledge of instrumentation and other technologies, knowledge of materials.
Pedagogical content knowledge	How to scaffold the problem-posing and problem-solving activities of students to bring them to proficient performances. Knowing the timescale of potential investigations. Knowing what background reading is necessary. Knowing how to speak the language of models and modeling with students. How to recognize flaws in students' problem-solving approaches or conceptual thinking. How to get students to monitor their own thinking and regulate their progress in these tasks. How to get students to recognize under what circumstances problem-solving skills should be used. How to promote sense-making discussions during and after the experience that will result in greater understanding of focal phenomena. How to assess students' knowledge and performances.
Disciplinary knowledge	Preferably knowledge of how skills and ideas might fit within larger context of inquiry. In some cases needs to understand how scientists approach/define certain types of problems and employ standards for "what counts" as a solution to a problem.

"School science" inquiry

- Students follow more or less scripted version of "The Scientific Method."
- Questions often based on what is interesting, do-able, but not grounded in theoretical model.
- Are often content-less (e.g.paper towel experiments).
- Determines only how outcomes are related to conditions (e.g whether small crystals of sugar will dissolve faster than large ones). (Chinn & Malhotra, 2002; Driver et al., 1996).
- Underlying theory not addressed.

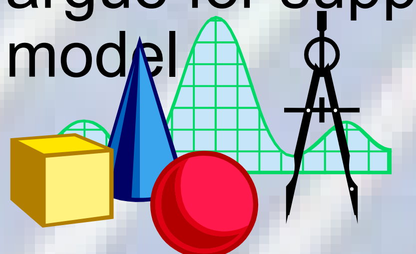
Observe phenomena
↓
Develop question
↓
Create hypothesis
↓
Design experiment
↓
Conduct experiment
↓
Analyze data
↓
Draw conclusions
↓
New questions arise

"School science" inquiry

General pedagogical knowledge	How to organize and manage group work. How to organize and manage materials.
Content knowledge	Knowledge of focal phenomena at the level of observation, not necessarily at the theoretical level. Often content knowledge not needed (paper towel experiment).
Pedagogical content knowledge	Understands: how to organize sequences of events based on ill-structured tasks for learners (becomes PCK because content dependent) what background reading is necessary the timescale of potential investigations what investigative approaches are likely to result in "dead-ends" how to scaffold those students who cannot pose questions based on observations (sic), design control group experiments, analyze data, represent data appropriately, draw conclusions how to promote sense-making discussions during and after the experience that will result in greater understanding of phenomena how to assess whether students understand these skills and how to execute these skills in appropriate contexts
Disciplinary knowledge	Conceivably none needed. Understanding: principles of randomized control group experimental design. In some cases needs to understand how scientists approach/define certain types of problems and employ standards for "what counts" as a solution to a problem.

Authentic forms of inquiry

- Investigations based on questions about models of natural phenomena.
- Questions, investigative procedures are domain specific (e.g. use of spatial data from Geographic Information Systems).
- Not necessarily randomized control group experiments (can include correlational, descriptive studies).
- Hypotheses can shift (as they do in real science).
- Findings are not “ends-in-themselves”, but used to argue for support or revision of explicitly stated model



Begin with model → Conduct investigation → Argue for revision of model

Authentic forms of inquiry

General pedagogical knowledge	How to organize and manage group work. How to organize and manage materials.
Content knowledge	Deep knowledge of phenomena required, how it inter-relates to other key ideas Knowledge in the form of models and theories as well as facts, concepts, principles, etc. Need to understand the distinctions between theoretical explanations and empirical/descriptive accounts of the phenomena.
Pedagogical content knowledge	Understands: how to organize sequences of events based on ill-structured tasks for learners what background reading is necessary the timescale of potential investigations what investigative approaches are likely to result in “dead-ends” how to scaffold those students who cannot pose questions based on observations (sic), design control group experiments, analyze data, represent data appropriately, draw conclusions how to scaffold modeling and argumentation how to promote sense-making discussions during and after the experience that will result in greater understanding of phenomena how to assess whether students understand skills and how to execute skills in appropriate contexts how to get students to monitor their own thinking and regulate their progress in these tasks.
Disciplinary knowledge	Having some domain-specific knowledge of how scientists design questions from models or theory, employ methodological standards for data collection and use arguments around model-based reasoning to link empirical results with theoretical explanations.

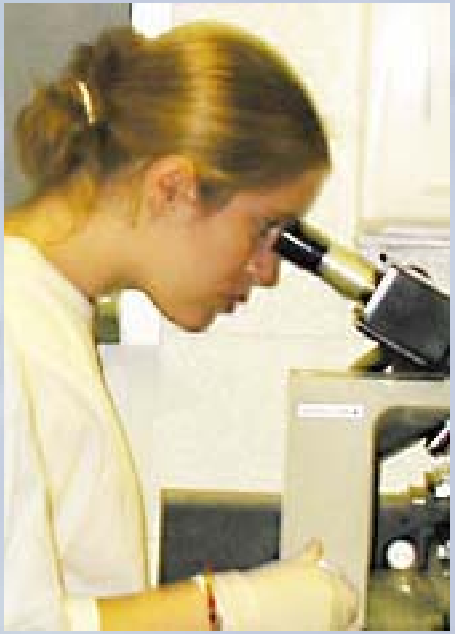
Q2. Do teachers' current preparation and PD provide them with these knowledge and skills?

Undergraduate work

- As undergraduates, generally subjected to models of highly-structured inquiry.
- Lab work not unlike confirmatory laboratory experiences found in high school (Trumbull & Kerr, 1993).
- Rarely exposed to discussions about science as a discipline at college level; do not participate in discussion of how new knowledge is evaluated (Bowen & Roth, 1998; Thorley & Stofflett, 1994, 1996; Wenk & Smith, 2004).
- Have some knowledge of methodology but do not think in terms of models/theory as they attempt scientific investigations (Roth, 1999; Shapiro, 1996;Windschitl, 2004a, 2004b).

Q2. Teachers' current preparation and PD…

- Teacher ed. quality also varies
- My experience… ~100 pre-service teacher case studies.
- Content knowledge in terms of familiarity with facts, concepts, principles is adequate to marginal.
- Over past 8 years, only 20% have reported doing any form of authentic inquiry where they have developed questions, designed own studies.
- For virtually all pre-service teachers, the “scientific method” remains the dominant procedural framework for inquiry
- Pre-service teachers who use inquiry in classrooms are those who have had authentic research experiences.



Professional Development

- Quality varies dramatically
- Many PD providers less than effective:
    - Only short term experiences
    - PD not grounded in the experiences of the teachers, their curriculum, or local instructional context
    - Often focused on “how-to” activities, teacher-proof curricula
    - Does not use students’ thinking as a basis for planning, evaluating and revising instruction
- At best, leads to “additive” learning, rarely achieves “transformative learning” (Thompson & Zeuli, 1999).

Deal-breakers in getting teachers to consider inquiry

- 3 C's and a K

  PD around inquiry-based teaching must directly address teachers concerns about two issues: covering content and controlling kids.

  - Teachers must see images of how inquiry works with kids like theirs.
  - PD around inquiry-based teaching should refute the common notions that kids need to master "the fundamentals"(facts, concepts, lower cognitive demand skills) before attempting inquiry.
  - Inquiry activity too often seen as optional enrichment, not the core of student work.

C
C
C
K

Q3. How should teachers' preparation and professional development be changed?

Undergrad preparation - raising the ceiling as well as the floor

1) Rigorous content courses for teachers that emphasize:
   - a less is more approach to content selection
   - role of modeling in the relevant science domain
   - transparency about how evidence and argument used to adjudicate between rival hypotheses
   - authentic forms of assessment (e.g. students engaged in some form of inquiry during course and given formative feedback as it progresses)
2) Provide multiple opportunities for undergraduates to be mentored through authentic forms of inquiry (as opposed to acting as technicians, data collectors)
3) Coordination between science departments and schools of education about advising undergrads who aspire to be teachers.

Teacher Education

1) Methods instruction should be evaluated against standards.
2) General methods courses should be done away with.
3) Pre-service teachers should be placed in schools with cooperating teachers who are competent with inquiry and meaningful lab work.
4) "Quickie" teacher certification is antithesis to idea of teachers as highly skilled professionals-- totally counterproductive.
5) Inquiry-oriented activities requires teacher skills that can come only from a robust preparation program.
6) Unqualified teachers reproduce the status quo.
7) Better prepared teachers stay in the profession long enough to acquire skills (UW has 80% retention through 8 years).

Professional development

1).Planned by partnerships of scientists, education faculty, and master teachers.

2). Content knowledge enhancement should go hand-in-hand with fostering inquiry-based teaching.

3). PD should focus not only on the "hands-on" of inquiry (running teachers through the activities in a kit), but meaning behind the activities and how they tie together.

Q3. How should teachers' preparation and professional development be changed?

4). PD should consist of strategic combinations of experiences for teachers

e.g. beginning with immersing them in inquiries of their own, then studying their own student work,then engaging in curriculum adaptation.

5). PD should be grounded in the participants' own context, using the participants' curriculum as a starting point.

6). 80 hours minimum.

7). Need a marketable, intellectually honest idea to replace the cultural icon of "The Scientific Method."

Returning to theme of teacher professionalism

Only way to bring teachers to this level is to cultivate them as professionals, intellectuals, and life-long learners.

This requires of teachers a greater repertoire of pedagogical skills, deeper content knowledge, knowledge of student learning.

Standards documents prioritize inquiry-oriented teaching

At the end of the course, Sinda reflected on her inquiry experiences, claiming that she "*was less than a novice at completing full inquiries*" and that she "*had always been given the question to start with*." She said her previous studies had never included assumptions, predictions, argumentation, or initial theories, none required supporting one's claims, presenting to peers, or looking up other studies. She said she had now changed her mental model of inquiry which previously she had "*considered as step-by-step, very orderly*", and that "*one step had to be finished before the next step started*."

Q2. Teachers' current preparation and PD…

An example from a recent 3-study series

- For virtually all pre-service teachers, the “scientific method” remains the dominant procedural framework for inquiry— to the exclusion of considering models/theory as the fundamental grounding for investigate able questions and the object of inquiry’s pursuits.
- Most have a modest familiarity with the idea of scientific models, although at least half do not have the depth of understanding necessary to lead classroom conversations about the nature and function of models.
- Domain subject expertise and past research experiences influence how teachers conceptualize inquiry and the role of models/theory in scientific discourse.
- Expert understanding of the nature and function of models is closely tied to the belief that it is important not only for students to learn about concepts by using models, but to teach about models as intellectual objects of critique and revision.
- Individuals who use inquiry in the classrooms are those who have had authentic research experiences themselves.