Lab Education
to teach
(i.e. to help students learn)
Scientific Thinking Skills

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This powerpoint is a highly condensed summary of ideas (as in an **executive summary** written for busy people) from http://www.asa3.org/ASA/education/teach/dblabs.htm#i .

And many more ideas for you to explore are in a links-page, https://mywebspace.wisc.edu/crusbult/web/labs/ideas.htm .

file options: If you're using http://www.asa3.org/ASA/education/teach/labs-acs.htm (HTML web-page), replace "htm" with "pdf" or "ppt" to get a PDF or PowerPoint file.

The Basic Ideas

A science lab — where students can *do science* and *think about science* — **is an ideal place to learn scientific thinking skills.**

How?

- **Define Goals** for desired outcomes, for the **Ideas-and-Skills** we want students to learn.
- **Design Instruction** with **Thinking Activities** to provide opportunities for experience with these ideas-and-skills, and **Teaching Methods** that help students learn more from their experiences.

Three Comments

• **The Basic Ideas are not original** — they are common strategies for good teachers — so, in order to be useful, **they must be supplemented with important details.**

• **This is a proposal** for potential future work, not a report of what already has been done.

• **The actions** (to get goals & thinking activities & teaching methods) are not sequential steps, they **are modes of thinking-and-action**, so "reverse inspiration" is possible, common, and often very useful for design. For example, goals can inspire activities (**goals ➔ activities**), and activities can inspire goals (**goals ← activities**), as in my page about lab activities for general chemistry, linked-to in https://mywebspace.wisc.edu/crusbult/labs/ideas.htm

Thinking Activities

Thinking Activities (= **Learning Activities**)
provide **opportunities for** high-quality effective **experience** with the ideas-and-skills that are your educational goals.

How can you find thinking / learning activities?

- **Old Labs** — analyze what students are doing now.
- **Old Labs Revised** by adding new activity-experiences, including those outlined in Teaching Methods, and more.
- **New Labs** — invent by self, find in journals & forums, . . .

All searching can be guided by your educational goals.

And with reversed inspiration, activities you find (in old labs, thinking about teaching methods, in journals/forums) can inspire you to expand-and-revise your educational goals.

Teaching Methods

Teaching Methods are just another perspective on **Thinking Activities** (potential **Learning Activities**), when teaching ➔ thinking-and-learning **experiences.**

1. Reflection Activities — when a teacher directs attention to opportunities for learning, thus moving students from only "going through the motions" to active minds-on awareness, which can help students learn more from their experiences.
2. Student Responses — by **talking** and/or **writing**.
3. Evaluation Activities — if responses / actions are graded.
4. Inquiry Activities — when gaps in knowledge (in ideas-and skills) leads to situations where students "don't know what to do" so they must think, and are allowed to think.

1. Reflection Requests

Reflection Requests can be **implicit** (if an activity automatically requires active minds-on attention) or **explicit** (if a teacher directs attention to "what can be learned" during an experience that could otherwise be done with little awareness of a learning opportunity).

Explicit reflection requests can be useful for motivational persuasion that is done to improve **Educational Teamwork** when there is a feeling of "us" due to a combination of goal-directed teaching (by teachers) and goal-directed learning (by students), and our goals match their goals.

We can achieve closer matching of teacher/student goals in two ways: by adjusting our goals to match students' goals, and persuading students to embrace our educational goals. When we try to persuade, we should consider all aspects of total motivation — intrinsic (enjoying an activity), personal (learn ideas/skills to improve our quality of life), interpersonal (impress others), extrinsic (perform for grades) — which are all **internal,** contributing to what a person wants in their whole life as a whole person.

We can try to persuade students of our good intentions (in setting goals that are good for them) and competence (to achieve these goals), with our words (what we say in "pep talks") and actions (what we do),

2. Student Responses

Should we ask students to respond by writing, or talking, or **both**?

pros & cons of writing: students can improve this valuable skill by practicing it and receiving feedback on how to improve; grading can be difficult, unpleasant, time-consuming; feedback for students is delayed.

benefits of talking: can stimulate minds-on awareness during lab (but so can writing); better feedback (immediate & detailed); less tension of “teacher vs judge” (if information is withheld to be fair-to-all for a written response that will be graded, instead of withholding only for pedagogical reasons, to adjust the level of inquiry-difficulty); and compared with grading lab reports, usually discussions are much more fun.

the problem of pacing: students often must wait for discussion, due to supply/demand imbalance with one teacher & many students; solutions (supergroups, student-only discussions, productive waiting, improved instructional design & teaching skill) are only partially successful.

• **Hybrid Labs**, with skillfully coordinated talking and writing, combine the best of both: some scheduled discussions, and some writing.

3. Evaluation Activities

We do evaluations to test students' **working knowledge:**
their **ideas** (what they know) and skills (what they can do).

How ?

by grading the quality of labwork, responses (written or verbal), online assignments, quizzes & exams, . . .

But evaluating higher-level thinking skills can be difficult.

Why ?

Grades are a useful external motivation for most students.

If our evaluations measure appropriate knowledge (the ideas-and-skills we have defined as educational goals, and have been teaching) accurately, we can reward students who excel in achieving these goals; and we get feedback about our instruction — if a significant number of students do not improve their ideas-and-skills enough, we can try to improve our instruction. (and maybe also revise our goals)

4. Inquiry Activities

I think most of us **agree** that

• inquiry activities can be educationally valuable.

• we need to adjust the level of inquiry-difficulty so it's in a range that is "just right", as in a skillfully designed mystery story; we can adjust the *intrinsic difficulty* (what we ask students to do) and the *actual difficulty* (by preparing students before an activity and coaching them during it).

• we should aim for an eclectic blending of direct learning (which can be active-and-meaningful) with inquiry learning.

But there can be **disagreement** about how to use inquiry, about the types of blends that are most educationally effective for achieving different goals (learning ideas, learning skills,...) in different contexts (in labs, lectures, discussions, computer instruction, ...). My ideas for supplementation-and-revision of labs can be used for any approach, for either inquiry labs or "traditional" labs.

When evaluating blends, consider an 80-20 principle (if 80% of the total value comes from 20%) due to diminishing marginal benefits.

I suggest wise moderation in our use of inquiry. (link is in ...ideas.htm)

Integrative Analysis of Instruction

is a strategy-tool, developed and used for my PhD project, that is useful for Understanding the Structure of Instruction:

	Thinking Activities that promote **Student Experiences**									
Educational Goals	A	B	C	D	E	F	G	H	I	evaluated?
1. Observation-Based Logic	yes			yes		yes	yes			yes
2. Hypothetico-Deduction	yes			yes	yes	yes	yes	yes	yes	yes
3. Calibration Logic		yes		yes		yes	yes		yes	yes
4. If-Then Analysis of Errors	yes	yes	yes		yes			yes		yes
5. Analysis of Random Errors	yes	yes	yes		yes		yes	yes		yes
6. Random vs Systematic	yes		yes		yes			yes		yes
7. Does it matter?			yes		yes			yes		yes
8. Designing Experiments	yes		yes	yes		yes	yes	yes	yes	yes

Skillful goal-directed coordination of activities (seeing patterns horizontally, vertically, and in other ways) increases their mutually supportive synergism and effectiveness; some activities prepare students for others, and what they learn in early lab experiences is reinforced later.

The 8 educational goals are illustrated in labs for general chemistry that (in a page linked-to from .../ideas.htm) are described in 4 sections: Thinking Skills using Observation-and-Imagination, and for Data Analysis; The Logic of Science, and The Logical-and-Social Process of Science.

Appendix

Here ➔
is the main
part of my
Poster
Session
for ACS.

You can find
a web-page
with all of the
poster-pages
(these & more),
ENLARGED
so you can see
all of the details,
by using the
ideas.htm page
whose URL is on
the first page of
this powerpoint.

1a

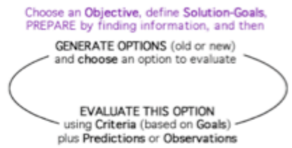
Using Design Method for Problem Solving & Metacognition

Problem = an opportunity to make things better
Problem Solving = moving from NOW-state to desired GOAL-state

Design = solving problems by designing better products, activities, strategies, theories; this **includes almost everything we do in life**.
Design Method = way to improve Understanding & Teaching, to
1. accurately describe the methods used in design & science, thus improving our **UNDERSTANDING**. (achieved? yes)
2. help students improve their thinking skills & thinking methods, thus improving our **TEACHING**. (achieved? potentially yes)

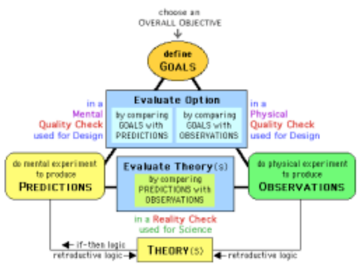
Activities for Instruction — Inquiry & Design
Inquiry = activity where students **explore**, try to **solve problems**:
design-inquiry — if the objective is a product, activity, or strategy;
science-inquiry — if the main objective is a theory (or experiment).
design activities — first-hand experience (students solve problems) & second-hand experience (case studies of other problem solvers) in a wide variety of contexts that can include "almost everything."

Teaching Design Method with a Simple-to-Complex Progression:
1. Two-Step Cycle — **Generate** Options & **Evaluate** an Option,



1b

2. Three Ways to compare Goals, Predictions, Observations:
Quality Check – compare Goals with Predictions or Observations
Reality Check (Theory Check) – Predictions versus Observations



3. in an **optional stage** (a teacher decides how much to explore), **explain the 9 Modes for Improved Thinking-and-Action:**
DEFINE — choose a design-objective, define goals for solution
GENERATE — old info, new options, predictions, observations
EVALUATE — by using Quality Checks & Reality Checks
COORDINATE — by making action-decisions for all 9 Modes

Here are the 9 modes of thinking-and-action used in the process of design:
DEFINITION
1A. CHOOSE AN OVERALL OBJECTIVE (what you want to design) for a design project
1B. DEFINE GOALS (for the desired properties of a satisfactory problem-solution)
GENERATION
2A. FIND (SEARCH for old information about solution-options and relevant theories)
2B. INVENT (to generate ideas for new options, usually by modifying old options)
2C. PREDICT (mental experiments produce predictions that are new information)
2D. OBSERVE (physical experiments produce observations that are new information)
EVALUATION
3A. EVALUATE OPTIONS using QUALITY CHECKS (compare goals with predictions or observations)
3B. EVALUATE THEORIES using REALITY CHECKS (compare predictions with observations)
COORDINATION
4A. EVALUATE THE PROCESS and MAKE ACTION-DECISIONS (for what to do & when in modes 1-4)

1c

In addition to decisions about progressions (especially re: modes), a teacher can also decide how to teach about **optimal blendings** of creative-and-critical thinking & cognition-and-metacognition.

Using Metacognition in Education for Problem Solving:

2a

Education for Thinking Skills & Thinking Methods

My integrative models have **two main goals**, to
A — accurately describe the methods used in design & science, thus improving our **UNDERSTANDING**,
B — help students improve their thinking skills & methods, thus improving our **TEACHING**.

I think "A" has been achieved, and "B" shows promise for:

• **achieving a worthy goal:** We should help students improve their creative-and-critical thinking skills/methods; teaching the methods used in design & science can help us achieve this goal.

• **a wide spiral curriculum** — by using Design Method in a curriculum [mainly K-12?] with **wide scope** (to coordinate diverse subject areas) and **spiral repetitions** (coordination over time). This can help students understand the integration of thinking skills **within** each design experience, and **between** experiences in different areas, for better transfer and synergistic support between areas.

2b

TRANSFER (from Life to Design to Science to Life) is increased by:
• **using ideas many times in different contexts & at different levels**, as in a Wide Spiral Curriculum with wide scope (across many areas) and with spiral repetitions (across time); Design Method is used for almost all we do.
• **teaching ideas in general abstract form**, not domain-lingo; Design Method is generalized: Define, Generate, Evaluate, Coordinate; Predict, Observe,...
• **Learning from the Past** (reaching back); ask "what have I learned in the past that will help me now?" (do self-guidance by prompting memory, giving hints)
• **Learning for the Future** (looking forward); ask "what can I learn now that will help me in the future"; **intentionally learn** for retention-and-transfer; develop **Conditional Knowledge** (about when to use each skill, and why), then match situation (what things need doing) with capability (how to do things).
Learning from Experience — Each time you do a job, do it better than before; always concentrate on quality now, sometimes search past & learn for future.

• We should teach Design before Science: Our designing (of products, activities, strategies, theories) is most of what we do in life, thus:
• diverse areas use design, so (as in "transitive math") we can use Design Method to connect areas in a **wide** spiral curriculum.
• students have used design; it's already in **their past experience** (so we can build on what they know), can be in **their future plans** (so they are motivated to learn skills that will help them achieve their personal goals for life). Therefore, especially in K-12, we should **teach design before science**, and design method before scientific method. Then we build bridges from design to science because reality checks (the foundation of science) are also used in design; and when students know Design Method they already know all of the main skills in Scientific Method, because Science is just a special type of Design in which the main objectives are accurate theories and useful experiments.

2c

Eclectic Instruction: not "if some is good, more is better, all would be best"; instead combine the best features of each approach, with goal of producing "the greatest good for the greatest number of students" for ideas-and-skills.

for Ideas (Conceptual Knowledge), I think the best approach is combining Explanation-Based Instruction with Activities for Application & Extension.

for Skills (Procedural Knowledge), use Inquiry Activities (design-inquiry and science-inquiry) along with explicit teaching of problem-solving strategies that are general (using Design Method) and domain-specific.

2d

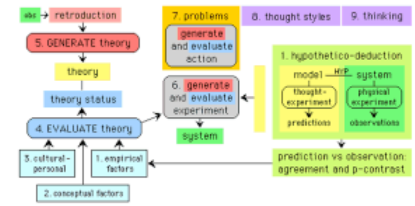
• **improving student motivation:** Educational Teamwork with an "us" feeling requires goal-directed teaching (by us) plus goal-directed learning (by students), with a we-and-they matching of goals. How to match? •We can adjust to student-ideas of what is fun now or will be useful later (to achieve their personal goals for life) and •we can persuade students to change their motives, so our teaching-goals become their learning-goals. How?

Words/Actions, Intentions/Competence: Using **words** (what we say) and **actions** (what we do) we can persuade students of our good **intentions** (we are "on their side") and **competence** (to define worthy goals, and help students achieve these goals). We can try to persuade students that what they are learning is fun now and will be personally useful in their future.

Components of Total Motivation: intrinsic (enjoy interesting activity), personal (learn ideas-and-skills to improve quality of life, now or later), interpersonal (impress others), external (perform well to get good grades). All components of motivation are **internal** because all contribute to how a person thinks about what they want in their whole life as a whole person.

2a

my model to show integrations of thinking-and-action:
Integrated Scientific Method



My models show the **integrated relationships** between mutually supportive aspects of thinking-and-action that coordinate **thinking skills** into a useful **thinking method**.

2b

Color Coding for my diagram of Scientific Method:
RED = Creative Generation (of ideas and actions)
BLUE = Critical Evaluation (of ideas and actions)
PURPLE (red+blue) = Creative-and-Critical Thinking
science is the design (generation+evaluation) of theories & experiments
LIGHT BLUE = 3 Factors in Theory-Evaluations
YELLOW = Theory-Based Logic ➔ Predictions
GREEN = Experimental System ➔ Observations
YELLOW-GREEN = Hypothetico-Deductive Logic
GOLD = Generation-and-Evaluation of Actions

Below is a similar diagram, but it shows more details:

2c