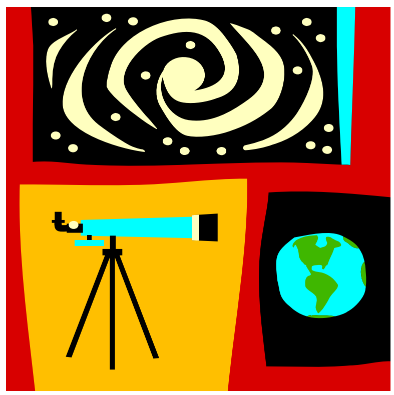
Teaching Scientific Concepts & Problem Solving



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Contents

I. USING THE BLACKBOARD

1. How to write on the board

A. Both words and diagrams should be large and clear. Try using big soft chalk if the room is large and/or you tend to write too small.

B. Use colored chalk as much as possible.

C. Use diagrams as well as words (see below).

D. Erase carefully.

(1). When you have filled up the board, erase a large area thoroughly before continuing. Don't keep writing in the corners and edges of your old, filled up board.

(2). When you need space, try to erase the oldest writing, not the most recent. You and the students may want to refer back to the most recent writing, so leave it up for a while.

2. Using Diagrams

Diagrams and pictures are very helpful, both to you and to the students. A diagram helps the students because it can convey relationships that are almost impossible to put into words. (see 4 below) It helps you, because you can refer to it over and over. Once you have the picture on the board, you can point to it and avoid using the technical terms or you can point and use the terms at the same time as reinforcement. So draw as much as you can. Artistic talent is not required, but remember the colored chalk and draw big, clear pictures.

To put it another way, drawing allows you to show what you mean in pictures at the same time that you say what you mean in words. So drawing a diagram and explaining it as you go along makes the best use of the board. It is much better than just writing down the words that you say.

3. What to write

Don't write everything you say on the board. It is good to write all the important points and terms on the board, but it is not necessary to write down all the details. It usually works best to write a term or draw a picture and then explain verbally.

4. Showing relationships

When you write down the important points or terms, try to write them in a way that shows their relationships. Suppose you are explaining terms or concepts A, B, & C. Suppose B and C are subcategories of A. (Example: A is transport, and B and C are types of transport. Or A is a structure made of two parts, B & C.) Then a simple diagram like the one below shows the relationship between A, B & C, and is much more informative that just writing a list with A, B & C (or writing A, B & C in random order).

$$\begin{tikzcd} & A \arrow[dl] \arrow[dr] & \\ B & & C \end{tikzcd}$$

5. Timing

Drawing carefully, writing clearly, and erasing properly all take time. Don't worry about wasting time. A pause is usually welcome if the general pace is lively. Remember that the students are writing things down, and that they usually are writing more than you are, since they are copying your lists and pictures and taking notes on your explanations. So they sometimes need a pause in order to catch up with you.

6. Avoiding "blackboard carpentry"

Many problems in science involve comparing two very similar situations -- normal vs mutant, before drug added vs after drug added, with oxygen vs without, etc., **or** explaining a sequence of events. In these situations it is very tempting to draw the picture for the first case or step, and then to alter the picture by erasing or adding a little here or there (that's the carpentry) to convert the picture into the next case or step. It is usually much better to draw each case or step separately. (Do a "story board.") It does take time, but it's worth it. Why bother to draw each situation individually?

(1) If you have both pictures on the board at the same time it is much easier to compare and contrast the two stages. If you modify the first stage to get the second, the first one is gone! You can't go back and point to the critical differences or show how the two cases compare. You can say it, but you no longer have the two pictures in front of the students.

(2) It is much easier for the students to take notes if you redraw the pictures. If the students are trying to take notes so they can capture the essence of your explanation, they can't keep modifying the picture (using pen and paper) the way you can on the board (with chalk and eraser). They have to keep drawing it over again, and they can't get all the details straight or keep up with the speed of your changes. (See "timing" above.)

If the picture you are drawing is complex, and you want to be sure the students can follow, you might consider providing a handout with the main steps or features. (It's hard to copy drawings – harder than getting down words.) It's best if the handout does not have all the details – that way the students are more likely to pay attention so they can label and/or annotate the picture as you explain. (See "Bag of Tricks" below.)

7. Planning Ahead & Using other Media.

If you are going to explain something complex, you should think through your presentation carefully before you do it. You need to consider what you will write or draw, where on the board you will draw it, what steps to include, etc. It helps to think it through as carefully as if you were making overheads or preparing a Power Point presentation. If you don't think it through in advance, you may find yourself without room to complete your diagram, trying to compare things on boards that are at opposite ends of the room, erasing things you need to refer to later, etc.

If you feel the subject is complex enough, or requires better drawing ability than you have, then you might consider using PP or overheads instead of the board. However, using the black board gives you much more flexibility, and makes it easier to pace yourself so students can take notes. Presentations with PP or overheads look prettier, but they easily become too static or "canned," especially if you have to turn the lights out. It is also very easy to go too quickly and explain too little if you use prepared materials. So if you use overheads or PP remember that it isn't enough to show the pictures – you have to slow down and explain them even if they look completely self explanatory.

What ever medium you decide to use, be sure to adjust the pace and level to your audience. You might want to provide the students with a handout lacking some of the details, as explained above.

8. Miscellaneous Advice on Using the Blackboard

A. When you are facing the blackboard, stop talking. In other words, don't talk into the blackboard.

B. When you write an important point or term, and then explain, don't stand in front of what you have just written.

C. If your English pronunciation is poor, draw and write more on the board.

II. TIPS ON EXPLAINING

1. Improving Clarity: Avoid pronouns and use nouns instead.

Don't say "it" -- say "mRNA" or "gene" or whatever. You should be careful not to use too many pronouns yourself and you shouldn't let the students do it either. For example, suppose a student says "The gene is transcribed and then it goes to the cytoplasm and it is translated which uses tRNA and mRNA." Now the student may or may not understand how genes are expressed, but you can't tell whether s/he knows or not, because "it" could mean gene or mRNA and "which" could mean transcription or translation. In this example, the student may know the correct answer and just be using poor English by accident, or the student may not know and be using unclear language on purpose to hide his or her confusion. Alternatively, the student may not even realize that s/he is unclear in his or her own mind. So if you want to express yourself clearly, and you want to be sure that your students have everything straight, use as many nouns and as few pronouns as possible, even if it sounds a little repetitious. And make the students talk in nouns too.

2. If you don't know the answer, what should you do?

A. Go look it up for next time, or look it up right on the spot if you have the right book and can figure it out right away. You aren't expected to know everything, but you are expected to be able to figure everything out eventually.

B. If you start to explain, and realize half way through that you are stuck, it usually pays to stop and admit it. It doesn't pay to continue, unless you are one of the rare people who can think well enough in public to get untangled in front of the class. The best strategy is usually to stop before you get in even deeper, and to go home and figure it out. (But be sure to tell the students the answer when you finish.)

C. The fact that you have to look things up has its bright side. It's useful for students to see that learning is a continuous project that doesn't end when you finish the course or when you graduate. It also helps to build up their interest and enthusiasm when they see you "get hooked" and go running after the information.

3. Provide a road map. What is coming, and why? Set up a "frame" for what you are going to say.

Before you attempt to explain anything, say, in advance: (a) what you are about to explain, and (b) why you are bothering to explain it.

Why (a)? Listeners feel much more comfortable when they know what is coming and approximately how you are going to get there. What is the major point, and how are you going to address it? It is much easier to pay attention and to follow the argument when you know what the "destination" is, and when you know something about the route. (First you say "Let me explain how to get to Brooklyn – it will take 3 trains." Then you go into the details of which you take first, where you transfer, etc)

Why (b)? Listeners will be much more willing to concentrate on details if they know why they matter. Why are you talking about this apparently obscure case or example? Why is it important? What does it illustrate? Why are we going to this destination and/or why are we taking this detour to get there? In the context of the class, how does this issue fit in to what has already happened? How does this relate to what will come next? Why do you need to explain it *now*? (Why do we want to go to Brooklyn in the first place? Why go now?)

4. Look Out for Potential Sources of Confusion

When you explain things, it is often worth while to draw attention to certain issues or concepts that are easily confused with others, or mistakes that are easily made. ("When you get to Times Square, be sure to take the 2, not the 3.") Foreseeable problems may arise from difficult concepts, but they often come from problems of terminology or inconsistent use of symbols. For example, what does C → Y mean? Signal C goes to structure Y? Compound C turns into compound Y? Structure C makes Y? C donates electrons to Y? In biology it can mean any of these. See "Famous Difficulties & Misunderstandings" for confusion that arises from problems of terminology.

Note: It is sometimes necessary to get the students to see the problem first on their own before you can straighten them out. In other words, some mistakes have to be made, and corrected – they can't be avoided. But many common errors can be circumvented

III. HOW TO EXPLAIN AT THE RIGHT LEVEL & HOW TO FIND THE RIGHT LEVEL

1. General Principle -- try to think like a student, not like a professor. Remember that they probably haven't taken a lot of advanced classes or worked in a lab. So they are lacking in both basic facts and general background. (You are explaining how to make scrambled eggs to someone who has never cooked. Or maybe never even seen an egg.)

2. Probe First. Before you start to explain a topic or problem, try find out exactly where the student is stuck. Don't just start at the beginning of the problem or topic and plow through to the end. When the student asks you to explain problem 2, ask the student something like, "Where did you get stuck? Or what is the part you don't understand?" This probing for the exact nature of the student's problem may seem to take a long time, but it pays in the end. It will save you from wasting time and energy explaining things that are clear and allow you to zero in on the real problem.

3. Explain in Small Bites. Explain a short piece of a problem at a time, and then don't go on until

(a) you are sure that everyone understands what you explained, and

(b) you are sure that you need to explain the rest.

For part (a) asking "Does everyone understand?" doesn't usually get a satisfactory answer. You have to look at the students' faces or ask a specific question about what you have just said in order to find out if they understand. (If you are using personal response devices, aka clickers, they are good for asking these types of questions. See below at * for an example.)

For part (b) you may discover that you don't have to explain the whole thing because the part you just explained was the only hard part and the student has now come "unstuck." (See previous point.)

*An example of a specific question (for a molecular biologist): Suppose you have just been explaining the conventions for writing out DNA – 5' end goes on the left, two strands are antiparallel, etc. Now you write out a single strand, horizontally, left to right. Then you ask "Which end is the 3' end?" You label it after they respond. Then you write in the second strand to make a double stranded DNA molecule. Then you ask, "Which end is the 5' end?"

4. Don't Start too Far Back. When a student asks a specific question, try to answer it without going over a lot of background material. If a student asks you to explain hydrophobic bonds, don't start with atomic structure. Assume s/he knows what electrons and covalent bonds are, and proceed from there. If there is any question about where to start explaining, ask the student. (See above.)

5. Don't assume too much. Remember that your students don't have as much background as you do, so you will probably have to explain things that seem obvious to you. (Of course this contradicts #4 – you don't want to overdo it in either direction.) Some ways to figure out what they know are described below. Also see "Famous Difficulties and Misunderstandings."

See next page for more ways to find 'the right level' – how to find out where the students are.

6. Ways to get the students to tell you what they need to know – How to figure out where they are at:

A. Collect Questions

Ask the students for specific questions or topics that they want you to go over. Write the questions &/or topics on the board. Do not answer the questions as they are asked. Keep collecting questions until you have a reasonably long list. Once you have the list of questions/topics on the board, you can look at the list and decide what to do first. You can go over the questions in order of importance, or logical order, or the order they were covered in class. Do whatever seems sensible to you. As you cover each question, check it off the list.

The first few times you do this, it may be very difficult to get the students to speak up. So be patient and give them plenty of time to come up with questions. If they don't seem to have any questions, suggest that they look through their notes or text to find points that were unclear. Wait until you have a decent length list before you start answering the questions.

This method works best if you can look at the list and see instantly what topics need to be discussed. So be sure your list is self explanatory. If the student says "Do problem 5," don't just write "#5" on the board -- add a few words so you and the students can remember what problem 5 is about. For example, write "#5 -- crossing over" or "#5 -- protein synthesis" or whatever. If the student asks a long question, you don't have to write it out word for word -- just write enough on the board so everyone can remember what the question is about. For example, you don't have to write "Why is the maximum value for recombination frequency 50%?" You can just write "Max RF" or "why RF < 50%?"

B. The Old Card Trick

Ask each student to come to class with at least one question written on a 3 X 5 card. Collect the cards at the beginning of class and use the questions to organize the session. One way to proceed is to spend a few minutes reading the questions silently. Then you can write the good questions on the board, as above, or read them out loud. Another way to start is simply to shuffle the cards and read one out loud at random. Once you have picked the question(s) to go over, you can answer the questions yourself, or you can let the students answer each other's questions.

An electronic variation – ask the students to email you the questions the night before. This gives you more time to compose your thoughts, decide which questions to use, and look up the answers.

*C. Ask **Them** a Question*

Ask the students a question, preferably about an experimental situation. (See below for an example. If you have clickers, you can use them to ask the question.) After you pose the question, you can then ask the students:

(1) What do you know that's relevant to this question/situation?

(2) What do you need to measure or find out?

After you have discussed what information you need, you can then go over how to use the information to get the answer. This sort of exercise will reveal what level of knowledge the students have (what facts they know) and their level of insight (how good they are at applying the facts). It will also allow any misconceptions or uncertainties the students have to surface.

A sample question from Biology:

Suppose you find a one foot black and white sphere in Riverside Park and you suspect it is a new organism.

(a) If it really is alive and not an abandoned soccer ball, then is it more likely to be a prokaryote or a eukaryote?**

(b) How can you decide (experimentally) if your answer to (a) is correct?

**Note for the nonbiologists: eukaryotes and prokaryotes are the two major types of organisms &/or cells – virtually any introductory biology class goes over the differences and similarities on the first day.

IV. TIPS ON TEACHING PROBLEM SOLVING

1. What's the Point? Before you try to explain a problem, ask yourself "What is the point of this problem or experiment?" Is it to show how to use a formula? Get certain facts or relationships straight? Gain familiarity with a concept or procedure? Make certain distinctions clear? Once the answer is clear in your own mind, it will be much easier to explain the problem and much easier for you and the students to see what is important and what is trivial.

2. Preparation: When you go over a problem in preparation for class, you should understand

(a) the general principles on which the specific problem is based, not just the answer to that particular problem, and

(b) how to get the answer. The process of getting there is just as important as the result. Remember you are trying to teach the students how to solve problems for themselves. (See below.)

3. How do I solve it? A common response to a complicated problem is, "How the *?#*#*! am I supposed to answer/solve this?" In other words, "How do I get the answer?" as opposed to "What is the answer?" You may need to explain one or both of the following:

(a) What information is needed to solve the problem -- including how you figured this out.

(b) How you use the information to solve the problem.

You may be tempted to assume that (a) is obvious and to skip right to (b). However (a) may be the major stumbling block. It is often very difficult for students to figure out what the real question is, and/or what info is needed to solve it. Students often know the right information but they know so much irrelevant information that they can't pick out the right pieces. So before you attack (b), be sure to go over how you figure out the answer to (a) – in other words, "What do I know (or need to look up) that's relevant?" See topic 5 for more suggestions on how to do this.

Once you have shown the students what information they need, go over how to use the information to get the solution (if necessary). Once you explain (a), you may not need to explain (b) at all, as the students are no longer stuck. On the other hand, even if (a) IS obvious, students may not know how to use the information to solve the problem.

It is important to realize that explaining <u>how</u> you get the solution is <u>different</u> from explaining the solution itself.

4. Estimate first and calculate later (if necessary)

Encourage students to estimate and use their heads instead of relying solely on their calculators. You will undoubtedly have a mixture of math whizzes and math phobics in your class. Estimating makes the math seem less formal and intimidating to some of the nonmathematical, and it discourages the overly mathematical from plugging blindly into formulas. In other words, using estimates often helps keep the focus on the science instead of the math. Also, if students learn to estimate, they can often avoid gross errors that lead to absurd results.

More Tips on Teaching Problem Solving -- Especially useful if your class does "Classic Word Problems"

Important: These are things the student should learn to do. You may demonstrate them the first time, but the student should learn to do them for him/her self.

5. Cracking a Complex Problem -- Additional tips to pass on (&/or demonstrate) about how to decode and tackle a complicated question.

A. Draw a picture or diagram whenever possible. (You may draw the picture for the student the first time. But the goal is to get the student to learn how to draw his/her own picture.) The relationships between the various parts and pieces of information are often not readily apparent until you get the words translated into pictures. Once you understand the relationships between the terms, facts, steps, etc., you will find the individual pieces are much easier to remember and recall. If a picture isn't appropriate, try a chart or diagram.

B. If at first you don't succeed, try, try again. If you have a complex problem to solve, don't try and get it in one shot. Read it through, and make an intelligent guess at the answer. Then go back and see if your solution explains all the data given. If it does, fine. If it doesn't, refine/adjust your solution and try again.

C. If one approach doesn't work, try another one. The following list comes from a math class, and duplicates some of the suggestions above, but is a useful list of problem solving approaches to keep in mind for any scientific discipline:

Guess & check
Draw a picture
Look for a pattern
Make a model
Act it out
Use easier numbers
Write a number sentence
Make an organized list
Make a table or chart
Use logic
Work backwards

V. FAMOUS DIFFICULTIES & MISUNDERSTANDINGS -- *Problems of terminology*

1. Confusing technical meanings and ordinary meanings of words.

Some scientific terms have technical meanings that are very different from their commonsense meanings. For example "spontaneously" in chemistry does not mean "very quickly" or "all by itself" -- it means "without net input of energy." Unfortunately, in common English, spontaneously means "all by itself" and often also "very quickly." So students think spontaneous reactions occur rapidly &/or without an enzyme. This type of difference between technical and ordinary meanings often leads to a lot of confusion, because the TA, book or lecturer is using the term in the technical sense, while the student is using the same term in its non-technical, commonsense meaning. Even when the student tries to use the term correctly, s/he is often confused by the connotations that the word has in common usage.

Another example: The teacher asks "Does burning destroy matter?" and the student says "Yes." The teacher groans and thinks the student is an idiot. But the student is not -- s/he is using the term "destroy" in its ordinary English sense, and the teacher is using it in its technical physics sense. If the teacher's house burns down, the house will certainly be destroyed (in the English sense), even though the atoms that were in the house have not been altered.

2. Using words that have technical meanings and not even realizing it.

Some ordinary English words are used as technical terms, as explained above, but experienced scientists (such as graduate students and lecturers) are so used to using these words that they often forget that these words have special meanings. So the scientists don't define the terms and are surprised when the students don't know what they mean. For example, what is a "strain" of bacteria? Do all bacteria of the same strain have the same genes &/or alleles? Are the genes in the same order? Are all bacteria of one strain of the same sex? A graduate student who works with bacteria will consider these questions so obvious that s/he will not realize that the answers are not common knowledge.

3. Getting confused between similar but not identical terms.

Certain terms seem to be difficult to get straight, for example, gene vs allele and chromosome vs chromatid. There are many such pairs of terms that are very similar in meaning and that are often used sloppily even in scientific writing (and speech). To make it worse, some of these terms are synonyms in common speech, such as "inhibition" and "repression." A good way to clear up confusion is to "compare and contrast" -- compare what is similar between the two terms and contrast what is different.

Note: If you are explaining a topic in your own field, you have to watch out especially for problem 2 above. If you are discussing an area outside your field, you have to beware of problem 3 – you are likely to find the terms confusing, just like the students. The good news is that you can understand the students’ confusion; the bad news is that you have to go to extra effort to get the terminology sorted out before you can conduct recitation.

VI. Short List of What NOT to Do

1. Draw/show a confusing diagram like: HT → TRH → Ant. Pit → TSH → thyroid → TH. → target cells

> *What's wrong with this?* HT, Ant. Pit, thyroid are glands. TRH, TSH & TH are hormones. The distinction is almost impossible to see when the diagram is written as above. The arrows also mean two different things – some arrows mean "releases" and some arrows mean "goes to." (This is a real example from a real prof.) *How to fix it?* One possibility is to put the glands/targets in boxes or circles so it is clear what's released and what's a tissue. Alternatively, draw a longer arrow from each tissue to the next, and write the names of the hormones over the arrows.

2. Do some blackboard carpentry. Draw a picture that shows a normal, baseline situation. Then erase and alter your picture to fit a new situation – more oxygen? with drug? next step in pathway? Don't redraw, just alter the original picture. (*What should you do instead?* Make a story board -- draw each case or step separately.)

3. Stand in front of what you wrote.

4. Face the board as you talk.

5. Write in corners of board or wherever there is space.

6. Use jargon, abbreviations. (Verbally and on board.)

7. Erase what you just wrote before everyone has finished copying it down. (When there is plenty of other old stuff you could have erased.)

8. Skip important steps. Start explaining in the middle.

9. Take a lot of time explaining the obvious.

10. Write too small or in unintelligible handwriting.

11. Show a slide and wave the laser pointer over it. (But don't explain what's on the slide.)

12. Mumble.

13. Talk too fast.

14. Stare at the floor.

15. Say something very complex (like the pathway above or a description of a complex structure) and write nothing on the board.

16. Insult the students – make fun of them (or their ignorance) when they ask questions, and berate them when they don't speak up.

17. Explain how stupid, worthless, lazy, pampered etc. students are nowadays. Not like when I was a student.

I don't include making actual mistakes as something NOT to do – everyone does that! (But it's okay if you admit it.)

VII. MY BAG OF TRICKS

These are things that work very well for me, but they may not work for everyone

1. Analogies. I compare the situation to something that is familiar to the students. For a complex process I use cooking or an assembly line. (Try to vary your analogies so that students of all stripes can relate. Don't do all sports or all sewing.) For DNA vs RNA I talk about reference works vs. Xerox copies. For tRNA vs mRNA I talk about hardware vs. software.

2. Models. I use simple 3D models made of common objects. I use pre-school toys, tissue boxes, wire left by the repairmen, Velcro strips, bread, etc, . A bagel is a great way to demonstrate a donut shaped hole in a membrane and a tissue box makes a great cell to show where the bagel goes. Giant, pre-school pop beads are an easy way to demonstrate many of the features of polymers. These models are low cost, easily replaceable, easy to see, and have great "wake 'em up" value. They don't have a lot of detail, which makes it easier to demonstrate your point. Thinking about constructing a useful model or working through a good analogy helps me to see the important features that I am trying to explain – it helps clarify things for me as well as the students.

3. Using the Blackboard. I prefer chalk to Power Point or overheads, especially in a small group setting such as a lab or discussion session. This is partially an aversion to technology that doesn't always work and/or requires equipment that isn't always provided. (I am not morally opposed to either one, and I have colleagues who do a great job with them. But I think they are both hard to use properly in classroom situations.) I think that chalk gives you much more flexibility in explaining things. You can vary the order, go into more or less detail, explain things that you never thought would need it, skip what doesn't seem to need explaining, etc. You can do all these things with prepared media, but it's much harder to vary the script. I also find it's easier for students to take notes if I have to write it all on the board. It's also more animated -- somehow a chalk talk is more "live" than any of the other options, and therefore more interesting. PP is great in the right hands, but so is chalk. I solve the problem of presenting complex structures and processes by using handouts.

4. Handouts. I give out several different kinds of handouts – the first type is to help with note taking. I found out early in my teaching career that students have a hard time copying diagrams. It's also difficult for me to draw them perfectly. So I give out handouts – 1 or 2 pp usually per class, with the basic structures and/or processes drawn the way I plan to draw them on the board. I deliberately leave off some of the labels and details. I draw the same picture on the board, and explain (and annotate) as I go. To help me do it right, I make a special annotated copy of the handout for myself. It has the major points and details on it, often in numbered order. The handout helps the students follow and take notes without getting lost. It also helps me as well as the students -- if I make a minor mistake on the board, the students still have the correct structure on their handout. (You could show an overhead or PP slide instead, but it's easier to add details on the board.)

I also make handouts that summarize large areas or compare and contrast related phenomena. I use them to frame the class discussion – in class I "blow up" each area of the picture, and fill in the details. I constantly refer back to the overall hand out to show how the details fit into the big picture. (See tips on explaining.)

More information on teaching and being a TA

There is additional information (see the "How To Collection") on how to grade papers, how to analyze the literature, etc., and a manual for TAs at http://www.columbia.edu/cu/biology/faculty-data/deborah-mowshowitz/faculty.html

If you find any of the information here or on the web site helpful, or would like to add additional topics, please let me know. (dbm2@columbia.edu).

Good Luck!!