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ABSTRACT

This document is written to encourage college faculty to use a student-centered, activity-related, approach to science instruction. Suggestions are provided for methods that can be used by faculty and administrators to develop alternatives to lecturing. The major sections of this document include the following: (1) Is There an Alternative to Lecture? (2) Labs: The Place To Experiment; (3) The Doubts; and (4) How To Get Some of These Changes Moving. The following alternatives to lecture are described: question asking, hiding the textbook, putting the students in the center of the class, letting students do experimental analysis, and using projects. (PR)

# KEYWORDS FOR SCIENCE EDUCATION:

# ALIVE AND ACTIVE

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**Keywords for Science Education: Alive and Active**

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## Introduction

*Science is a verb.* (No, I know the dictionary doesn't agree with that, but I think the dictionary is wrong.)

Science is a dynamic, continuous process. Too often it becomes a static encyclopedia presented via monologues and laboratory "exercises" with predictable outcomes. The national dialogue on science education has reached a consensus: active learning and participatory science should be the goals of science education. The need for change is real - and obvious- to any thoughtful observer. Sheila Tobias[1] (a sociologist) has thoroughly investigated the classroom atmosphere, the pedagogical style and the coverage-driven pace of introductory science classes. Even those who do not agree with her cannot argue with the disappointing results of today's college-level science education: 45-50% of college freshmen who begin with a major in science leave the science field altogether. In many cases there is no difference in the SAT scores or GPA's of those who leave and those who stay.

I hope to provide some useful ideas for faculty to apply. I also hope to show administrators and faculty that change is feasible, even in times of tight budgets. Administrative support does not always mean money only.

## Is there an alternative to lecture?

All faculty enter the classroom or laboratory with preconceived ideas of what should happen - based on their own undergraduate experiences. They often feel constrained by their own preconceptions or by the attitudes of colleagues. Unfortunately, these role models all too often used a monotonous, information-dense lecture style. A prime requisite for passing a standard organic chemistry course is a course in speedwriting organic structural formulae. 1000+ page textbooks are the norm in all introductory science courses. Whether the lecturer is as uncharismatic as Paul Tsongas or as flamboyant as a television evangelist, the process is the same: a passive learning environment characterized by frantic scribbling of dozens (or hundreds) of students.

*What to do? Simple: stop talking. Make the students the center of the class rather than the audience.*

* <u>How many questions do you ask in a normal class?</u> In too many of the classes that I sit through as an evaluator there may be none- or only a handful of rhetorical "are there any questions?" or " do you understand?".

* <u>Hide the textbook</u>. Use original research papers, wide-audience targeted reviews, popular science press articles, newspaper articles (Science, Nature, American Scientist, Discover, etc.) as a source for articles which address current developments or applications of science - and which often have built into them some review of the basics. Assign the articles as reading, along with study questions. Then- an in-class discussion centered on the article will actually cover the same ground as a formal lecture. But, instead of you talking to a class of freshmen stenographers they have become active participants- answering the discussion questions, explaining the underlying concepts. One of the things that convinced me to change my lecture-only approach was the number of times that I would stop in the middle of a long lecture to ask

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1. Tobias, Sheila. *They're not dumb, they're different.* Research Corporation, Tucson, AZ. 1990.

a question, only to have the student look up from writing and ask me "what was the question?". They were not processing any information; they were just writing. The first time I actually did this, I used two articles about AIDS. By the time the students were done, one of them actually said "we really did learn everything in the chapter on the immune system - and more. I'm amazed." I try to use at least one paper per week in my advanced placement freshman class and one every 10 days or so in my standard freshman class. When I surveyed my students from last semester they were generally pleased with this aspect of the course. They liked the idea of using current material. I always was sure to connect the research to something with which they could identify and they liked that. This was despite the fact that many of them found the original papers to be challenging and difficult to understand.

* <u>Put the students at the center of the class</u>. I often warn the students that, when we talk about a particular topic that they will be the experts- then I follow through. Protein synthesis is a good example of where students can play roles: I assign one to be the DNA, another the mRNA, another the ribosomes, and so on. Each has to pop up at the appropriate time and describe what their role in protein synthesis is. This makes for a good demonstration of the wide "cast of characters" required for this fundamental but complex process.

* <u>Let the students do the experimental analysis</u>: Experimentation is the basic methodology of science...so do some experiments. Or, more accurately, present some experimental scenarios and data and let the students draw some conclusions. I find that when I presented the experimental basis for a particular concept as part of the lecture, it is just generated more frantic notetaking so I stopped. Instead, I give the students the basic information, then break them up into groups (4-5 students) and let them have 10-15 minutes to work through the information. The group element is important: it avoids the problem of the student who truly just does not "connect" with a particular problem and gets them involved in the group learning process, as the other group members suggest ideas. Once someone in the group makes any suggestion, even the weakest student can then get a glimpse of what is going on. To make this work, I often have the students spread out a bit- they may spill over into an adjacent classroom or the lobby area, or wherever there is an appropriate empty spot. Then I call them all back and have some of them present their answers.

I try to be neutral about the acceptability of the answer of the first group, asking if anyone else in the class agrees/disagrees. Often there are very different opinions and often these are for very good reasons. Other times, the students let their preconceptions cloud their analysis. For example, when given a data set that demonstrates that flowering plants actually do pick their mates, some students have a hard time accepting the data and they work out ways to interpret the data to support their own belief. The students often think of variables that are not clearly described or controlled in the scenario that I give them- and which would generate very different results than those that are the "correct" answer.

* <u>Paradigms: Ideas and People</u>. One of the problems of science education is that, despite the experimental basis and the ever changing frontiers, science is all too often presented as a static body of "truth". In reality, much of science is fluid. Ideas come and go all the time. The simple certainty of the atom that I (and probably most of you) grew up with (protons, electrons, neutrons) has long since disappeared into a welter of subatomic particles: quarks, leptons, gluons, muons, - with properties as elusive as "color" and "charm". What this means, in essence, is that the physicists can't tell us what the "stuff" that we (and the entire universe) are actually made of- that's a little unsettling, isn't it?

A related problem is that this static approach to science as fact divorces science from the really important fact: people do science; people change science; people are what count. A freshman science student is overwhelmed by the thousands of "factoids". It is hard to imagine how this incredibly complex construct of today's science got put together- or how they, as potential future scientists- will ever have a significant voice. So, each semester I divide the students into groups and assign each group a scientist and a paradigm. The assignment is to follow the career of this scientist and the development of this paradigm. The paradigm may be one that is destroyed by the work of the scientist or it may be one that is developed by the scientist. The important thing is, that for a significant period of time, the paradigm must be the accepted "truth" that appears in textbooks, etc. So- ask about William Keeton and how pigeons find their way home; ask about E. W. Sutherland and how hormones affect their target cells; about William Dart and the evolution of the first hominids; about Salvador Luria and whether viruses are actually just a normal part of every organisms' own DNA.

These projects take some time. I assign them to groups and give them a month or more to do the work. They are expected to locate the earliest published works of their assigned scientist (on the assigned topic) and then find the latest work of that person on the same topic. I usually try to find scientists still alive or only recently deceased. If the scientists has been dead five years or more, then the students must find current papers on the topic and use that information as well. They trace the rise and/or fall of a paradigm, write a paper and deliver a presentation to the class (copies of the paper are put on reserve and all students are held accountable). To do this task, the students have to master a specific field, often one that they have not yet covered in class (since this is a freshman course). They also, by the way, need some introductory training in how to do the library research- most have never used Bioabstracts, etc. Our library staff puts together discipline-specific minicourses for classes.

The poster and a "closed end" project: The poster is becoming a dominant mode of presentation of ideas among the scientific community, replacing many "single speaker with audience" sessions (by the way, you are right to ask why I am, indeed, presenting my ideas this way. I am afraid the answer is simple: it takes more time to organize a non-lecture presentation). So, assigning poster projects is good training in a skill that students will need as a practicing scientist- or in basic communications skills regardless of their eventual career. In our General Biology lab, every student is assigned an organism. They are expected to develop a poster about that organism, including illustrations and text that define the organism, explain its physiology, ecology, morphology, etc. The students make a short presentation based on their poster. The posters are then displayed in the hallways for the rest of the semester. The results range from grade-school quality to ones that I would be pleased to take to a meeting with my name on them.

What do the students gain: an in depth involvement with a slice of biology instead of a mind-numbing effort to memorize thousands of factoids about the classification of organisms that will all be forgotten the day after the final exam (remember, this is general biology). At the same time, they get an awareness of the diversity of life by listening to others' presentations.

The poster and "open end" project: One of our Physics faculty who teaches our general education Physics courses (such as astronomy, earth science, etc.) assigns semester length student projects. The students work with him to select a topic, then go off to do their work- which may be anything from "an investigative report on over use of national parks" (complete with phone interviews with park service personnel) to construction of a model of the effects of glaciation, to design and carrying out of an experiment. Note that one of the weaknesses of this is that we do not have the lab facilities to make this a formal lab course, so these students really are doing much of the work outside of a formal structure. The instructor demands weekly progress reports to try to avoid disasters both of both procrastination and collapse of a grand idea on the shoals of reality.

The students must develop a poster based on their project. They bring in the posters at the end of the semester and make brief (very brief) presentations; then the entire class is given poster evaluation forms and they roam around the room, examining and evaluating the posters on display. Again, the results range from amazingly impressive to embarrassingly simplistic.

## Labs: the place to experiment

That sounds like it is self-evident, but it is not always what happens. Science is based on verifiable, reproducible experimentation. But...there is a funny thing about experiments: they do not always "work" (to use the students' vocabulary; in faculty terms, they may just produce "anomalous results"). Also, in a real experiment, the experimenter does not know what the outcome will really be. What has happened is that, all too often, the labs became places for simple observation or for reproducing data from the textbook. The "classic experiments" became, in truth, nothing more than self-done demonstrations of the already known. Also, there are many of these "classic" experiments, so the lab became a fixed curriculum within many departments. You know you are in trouble when an experimentally based science is taught in a course where the so-called experiments never change!

What to do? There is now a growing movement to get the experimentation back into the labs. For example, the first lab in our Intro Chemistry course used to be "how to bend glass...". Now during the first week, the students receive an organic compound and are told to identify it. (The compound is known to be from a limited list...since there are millions of organic compounds, this would be beyond freshman capabilities). They characterize their own compound via physical and chemical properties (density, freezing point, boiling point, solubility, chromatography, pH, etc.). The rest of the semester has similar, more open ended experiments. General Biology does not spend a lot of time peering through microscopes at preserved slides (actually, our Biology department has not done a lot of that in our freshman course for 20 years). Instead they are tracing the genetics of biochemical pathways, or developing biomechanical models that let them compute weight and size of an animal (themselves) from footprints (stride length). They can then use the model to determine size of prehistoric animals, based on footprints in fossil rocks.

One thing that marks many of these experimental approaches is that they are "sloppy" and time intensive. They do not always fit neatly within a 3 or 4 hour period. At various times in the semester, our Biology students may have 3 different experiments in various stages of progress-bacterial clones, fruit flies and seedlings may all be growing or incubating. The length of the experiments also means that something has to go: there is not room to do as many different kinds of experiments. Our Endocrinology class (a senior level course) has changed dramatically in this aspect. I (and a colleague) used to teach it as the "hormone of the week". The goal was to introduce the students to as many different hormonal effects on as many different types of organisms as possible. Now, the class runs, essentially, one long experiment. The animals are manipulated the first week of the course, then they are treated with different protocols and the various parameters are monitored over an extensive period of time. The final result is a wealth of data that the students then analyze and interpret. Another colleague plans on introducing a neurobiology lab that spends the entire 15 weeks on various aspects of the neural system of the leech. Why: because it lets students concentrate on the science rather than on learning new manipulative skills each week. (When it takes a student an hour to anesthetize an animal and then 3 more hours to prepare the animal for the experimental treatment...there is not much time left in a 4 hour lab to do the actual experiment.)

<u>Putting experiments into non-lab courses</u>: You do not need a lot of expensive equipment to do some true experiments even with large classes. Again, one of the problems we face at Siena is that we do not have enough lab space to offer a lab-based course for our general education courses (although our majors' curriculum is very strongly lab-based). I have seen this issue handled in various ways. Astronomy and earth science, for example, use the biggest laboratories around: the earth and the sky. By having students make a series of simple observations over a period of weeks, you can get the data needed to make some general conclusions about the orbit paths of the planet, about weather cycles, etc. One faculty starts one class each week by using student data to do weather prediction by correlating local weather data (from the students) with weather information from remote sites, over time.

I teach a nutrition class...but I want it to be a science class, not a "diet of the week" class. I will put the students on various diets for a week or so, then measure the result- e.g. put them on a low salt diet, then do simple taste tastes to see if their ability to taste salt is altered, as compared to a control group. Or, since I always schedule my classes first thing in the morning, I can get my students to show up in a fasting state and then feed them a variety of foods. This lets me do things such as find out if it is true that cornflakes actually raise blood sugar more than ice cream (all this takes are a couple of the blood glucose monitors now sold for home use by diabetics). Probably the toughest thing here is to convince the students to show up a little early so that we have enough time to collect blood samples over 90 minutes.

The students then are expected to grapple with the data set, do the statistics, read some background literature and prepare a report- just like scientists do. This is a real challenge for non-scientists. We spend quite a bit of time in class going over statistical tools; talking about what a scientific research paper should contain; how it is structures (very different from an essay on Shakespeare or an accountant's double entry ledger: there is no place in accounting practice for "standard deviations" and "statistically significant"). This is not an esoteric, meaningless enterprise. The scientific paper is **the** paradigm for how science is done. The best way to teach the "scientific method" is to do it.

**The doubts...**

Ok, so what have I done? I have told you that we should throw out some- or maybe even a lot- of content. What replaces it? The opportunity to study fewer topics but in more depth. The opportunity to have the students participate in the learning process while in the class or lab, with the assistance of the faculty. This is very different mode for the faculty. I still feel like I am not earning my pay when I simply wander around the classroom as the student groups grapple with a problem (although I do interact with them, asking and answering questions and clarifying issues).

Fortunately, I am in a position where I can control my class however I want to. That is not always the case; many of the Physics examples that I have talked about were done by a temporary faculty; he took a lot of pressure from older faculty. Some was subtle some was direct and hostile, especially when he was teaching science majors. He went out of his way to keep me informed of his efforts and get my support. The Chemistry department was cleanly divided between the old and the young on the issue of revamping the introductory labs. In other words, be aware that the greatest of ideas may not be universally loved by everyone.

The other little issue: while some of these ideas do not cost a lot (or even any) money- they do cost time. I still have to admit that when pressed for time, I can still walk into a class and do 80 minutes of non-stop lecture with much less preparation time. Finding appropriate readings, developing study questions, developing new experiments, making sure that the correct pieces of equipment and chemicals are ready, that the organisms are available and at the right stage of growth takes much lead time and constant care. Being in a lab where every question can easily bring up an "unknown" is more stressful than when the questions are "where can I find the next slide"? (It is also more fun.)

**How to get some of these changes moving?**

- Find the right person(s) to start (respected faculty; preferably tenured; or maybe one of your departments is ripe for change).
- The science community is full of these efforts. A good example is Project Kaleidoscope[2], a

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2. Project Kaleidoscope. Ms. Jeanne Narum, Director. ICO, Suite 1205, 1730 Rhode Island Avenue NW, Washington, DC 20036

project of the Independent Colleges Office, funded by NSF and others (they have a two volume set out now that describes the problem, what to do about it, is filled with resources). Discovery Chemistry at Holy Cross (Joe Ricci) is a good example, as is Workshop Physics at Dickinson (Priscilla Laws). Learn about them. The unknown is never as frightening when you share it with someone else.

- Get a group of faculty together to talk about the issues on a continuing basis. The discussions, believe me, will be lively and spirited.
- Each individual faculty is different (I'm sure that is obvious to all of us!). Let each of them start with something that they are comfortable with and can execute well. Diversity is crucial! No one faculty can or wants to do everything described in my presentation, but a large percentage can incorporate one or more of these ideas.