1di.a.logue or di.a.log \ 'di-ê-,lòg, -,läg\ n [ME, fr. OF, fr. L dialogus, fr. Gk dialogos, fr. dialegesthai to converse, fr. dia- + legein to speak] 1: a written composition in which two or more characters are represented as conversing 2 a: a conversation between two or more persons; also: a similar exchange between a person and something else (as a computer) b: an exchange of ideas and opinions.

D·I·A·L·O·G·U·E

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Involving Undergraduates in Research

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Undergraduate education in research universities requires renewed emphasis on a point strongly made by John Dewey almost a century ago: learning is based on discovery guided by mentoring rather that on the transmission of information. Inherent in inquiry-based learning is an element of reciprocity: faculty can learn from students as students are learning from faculty. (Boyer Commission Report on Reinventing Undergraduate Education)

Introduction

There has been a chorus of appeals recently to involve undergraduate students in research. The Council on Undergraduate Research was created specifically to promote undergraduate involvement in research and publishes a quarterly journal devoted to the topic. Undergraduate research is a key component in the mission statements of funding agencies such as the National Science Foundation, the Keck Foundation and the M.J. Murdock Charitable Trust. Not only are state and national learning standards calling for students to be versed in the art of scientific investigation, some graduate school science departments, such as the Geology Department at the University of Chicago, now only consider applicants who have completed a senior research project. The National Science Education Standards has called for professional development programs that: "Involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding." In addition to rigorous content and skill standards, the Washington State Essential Academic Learning Requirements state that students will: "…understand the nature of scientific inquiry" and "develop abilities necessary to do scientific inquiry."

What is research?

In the most restrictive sense research is original discovery that creates new knowledge. Most peer-reviewed science papers involve original discovery. The term research is also applied to the rediscovery of existing knowledge. The literature search that we do in preparation for writing a scientific article or "research" for a term paper fall into this category. True research (involving original discovery) is open-ended, i.e. the researcher addresses a question for which there is no generally agreed upon answer.

Why Research?

A research-based course is also an excellent way to achieve the affective outcomes that most of us want for our students. For example, when I picture in my mind the ideal student (or research assistant or colleague), I see someone who is not just knowledgeable about facts, but also asks critical questions, evaluates data, communicates well, handles data quantitatively and assesses its statistical significance. Moreover, an ideal student (or assistant or colleague) knows how to use a computer, works well with others or alone, does not need constant supervision, keeps objectives in mind, meets deadlines and enjoys what they do.

Last fall, on the first day of my upper division paleontology class (a GUR composed of science and non-science majors), I asked the students what they wanted to be like after they got their degree, i.e. what are the attributes of an educated person? On page two, their list, my list, and a list generated by Fortune 500 companies can be compared.

There is a startling and gratifying similarity. All stress a wide range of skills centered on solving problems and communicating. Lecture courses, however, stress only the transfer of knowledge, devoting little, if any, time to the other attributes listed above. On the other hand, I would like to teach in a manner designed to achieve *all* of my learning objectives, and centering a class on solving research questions is an excellent way to do this. Research is an active learning process that develops critical thinking and problem solving skills; it is a natural vehicle for group work and development of communication skills. Moreover, research is much more effective at teaching *content*. Research provides a *context* for content, making it more relevant and meaningful.

How is research taught in universities?

Based on my experiences at several universities and at countless scientific conferences where I attend both technical and science education symposia, I think a general dichotomy exists in academia between "educators" and "scientists" and how they involve research in the curriculum.

Educators are academics with education degrees. They have studied how people learn and have received practice and feedback in teaching. Educators enjoy the teaching process, i.e. how to find information, how to write, how to think critically. The are usually less concerned with content, feeling that a student with the proper skills can get the content on their own. Educators favor active learning because research shows that active learning is more effective than passive learning modes. To an educator, research in the curriculum usually means "rediscovery".

Scientists have degrees in science and they practice science. Even though all professors are paid to teach, freshly-minted scientists have received little if any training in *teaching*, and are therefore amateurs at the job. As a result, they tend to teach as they were taught, usually reverting to a passive lecture-style format. Although with time they often become skilled at teaching, scientists as teachers tend to focus on content, with an implicit goal of producing other scientists. This is exemplified in their surprise that most students don't like science as much as they do and that they are happiest when inspiring a student to become a scientist like them. To a scientist, research in the curriculum is "original discovery," never "rediscovery," and occurs only in senior theses and graduate studies.

Yet whether an "educator" or "scientist," teaching styles form a continuum arranged along a gradient of "open-endedness." (This continuum is graphically represented on page four.)

Lectures tend to deliver information, which the student receives in class and repeats on exams ("gulp and puke" is my favorite analogy). This is quintessential passive learning, where the student simply listens or, if a multimedia presentation, watches. **Active learning** is a general term for a wide variety of learning styles that make the student a part of the learning process. "Hands-on" active learning may be as simple as taking the students to a rock outcrop as part of a lecture on geology. In this situation the student sees real-life examples of the subject being taught and *can ask questions when they see something that doesn't fit their mental construct from the lecture*. **Inquiry-based learning**, **collaborative learning**, and **constuctivism** are more advanced forms of active learning in which the student uses an investigative process to "discover" (rediscover) knowledge. They employ much of the process of genuine research but the result is still "fixed", e.g. the instructor knows what the reaction will be when substance A is mixed with substance B. Even though the outcomes are known, active learning is more open-ended than lecture because the student is exposed to ambiguities and variation in the natural world, e.g. the reaction may be a little different if substance A is heated before mixing it with B. In true research, the same

Thor's Ideal Student	Skills desired by Fortune 500 Companies	What Students Want For Themselves
Can think critically	Creative thinking	Wide scientific background
Can write and speak well	Critical reading	To write and speak well
Can think quantitatively	Oral communication	Relevant skills
Can use a computer	Analytical writing	Leadership ability
Works well in teams and independently	Computation	Ability to solve novel problems
Can start and finish a project	Team work	A degree
Enjoys discovery and learning	Organizational effectiveness	To be employable
Has knowledge in field	Problem solving	To work well with others

investigative process is used as in discovery-based active learning styles, but it is less programmed and more hit-and-miss. In research you often search blindly for an answer and end up with more new questions than answers. It is ironic that scientists, who innately strive to produce more scientists, generally teach by lecture, arguably the worst way to accomplish their goal.

Why should we strive to involve students in genuine research?

I argue that the ability to enter into a new situation (or question or problem) for which there is no known solution, and figure out how to cope with it (or answer it or solve it), is one of the most important goals of education. In the process of true research, there is a time in which the student is groping, searching data for correlations and connections. The student must bring all of his or her knowledge and resources to bear on the problem of interpreting the data, reaching a conclusion and defending it. He or she cannot go to the back of the book and see if the answer is right. In the process of true research students apply concepts and techniques they have learned and develop intellectual self-reliance. This kind of experience is only achieved by doing open-ended investigative activities.

Educators	Scientists
Know how people learn	Know how to do science
Are student centered	Are discipline centered
Are process oriented	Are knowledge oriented
Focus on outcomes	Focus on content
Prefer active learning	Teach as taught
GOAL: to produce life-long learners	GOAL: to produce scientists

How do you teach research?

Once a year I teach an upper division class in paleontology. The class averages 15-25 students. A few years ago, I made the decision to conduct the entire class in a research-based format. About the same time, I attended the Third Annual Teaching, Learning and Assessment Colloquy in Leavenworth Washington, which featured discussions and demonstrations of Collaborative Learning Models. Lectures are de-emphasized in collaborative learning. Instead, teams of students work on projects designed to impart critical skills and knowledge. Inspired by the presentations, I completely revamped my paleontology class to follow a collaborative learning model focused on research. I wanted the students to address a real research question, the results of which would be potentially publishable, so I came up with a problem that could reasonably be answered by a class of 20 in the space of a quarter. I divided the class into teams, letting them choose their own partners, and gave them small projects designed to develop their research skills. After we had discussed the objectives of the main research question, each team was given a small part of the research project. At the end of the quarter the parts that each group had researched were assembled to answer the question. Class and lab periods (both taught in the same room) were devoted to project work and I gave information (mini-lectures) only when needed by the students. As a result, the class resembled one long lab session with student teams working continuously on projects while I provided guidance and support.

In order to assess this class I kept a daily diary in which I recorded student comments and my evaluations of their performance and attitudes. Coursework consisted of multiple written assignments, including reports, a mock grant proposal and a written capstone project. I performed mid- and end-course student evaluations. The reports and grant proposal underwent multiple drafts that were commented upon by myself and a university writing fellow. During the first half of the course I “held their hands” and guided them through the research process. In the latter half I gave them greater independence, basically leaving them alone on the capstone project, so I could use it to assess what they had learned.

How Did the Class Turn Out? For one, I received the *lowest* teaching evaluations I’ve had since I started teaching in 1978. Here are some excerpts from my diary about the students:

“...students are frustrated, not engaged;”

“...they are unable to formulate an hypothesis;”

“...ask what results I want them to get;” and towards the end of the course:

“...students still don’t understand objectives of the project.”

Abysmal, too, were the mock grant proposals, which had as objectives getting them to think about 1) what they were trying to do, 2) why it was scientifically significant, and 3) exactly how they were going to do it (the specific procedure). They wrote their proposals after much discussion in class on all three of these points. Upon reading their proposals, it was clear they understood neither the objectives nor why they were doing the project, nor were their proposed procedures appropriate to the objectives.

In the capstone report, as well, the students were not creative in comparing and contrasting data sets, i.e. they went no farther than my suggestions. Nor could they interpret results in light of the research question, e.g.:

Results: "The sample contained 60% mollusks and 40% arthropods."

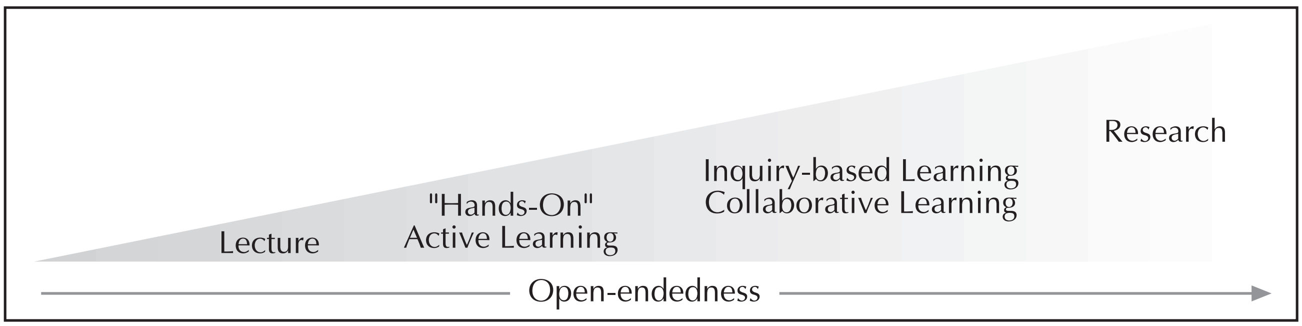
Discussion: "The sample had mostly mollusks and arthropods in it."

Conclusion: "The sample was dominated by mollusks and arthropods."

hypothesis even though the data they acquired falsified it. All of these reactions seem characteristic of a mindset used to "cookbook" activities where there is one right answer and the student can tell "where the professor is trying to go." In addition, the students did not feel ownership of the projects and resented having to do what they thought was my research.

Problems and solutions:

- **The students were not ready to enter into research.** They were used to lecture courses and I had taken them directly to a much higher cognitive level, essentially skipping the whole active learning process (refer to figure below). In addition, the project on which they worked involved too much tedious sample processing; a necessary step in genuine research but inappropriate for a quarter-length course.



Course evaluations indicated that students did not understand the objectives of the course, felt they were doing my research (for my benefit), and did not enjoy discovery and learning

Outcomes: Basically the students were not prepared by previous coursework to engage in open-ended research. While used to processing information, they were not good at asking questions or attacking problems. For example, they could not formulate an hypothesis or construct an experimental procedure that was appropriate to test the hypothesis. Once embarked on a project, they had difficulty staying focused on the objectives and kept checking with me to make sure they were getting the "right results". Many of the students did not understand that the results might not match the predictions of the hypothesis (i.e. that the hypothesis may be false) and they ignored data that did not conform to the predictions of the hypothesis. As a result their conclusions tended to confirm their original

Solution: Students need projects that begin with baby steps in research and progressively build, with increasing point values assigned to the projects as the quarter progresses. I also quit trying to make the results publishable. In essence I backed away from pure research and climbed down the ladder to collaborative learning (refer to figure above). I designed the projects more around the critical concepts I wanted them to learn and less around a real scientific problem. This allowed shortcuts in procedure, which omitted some of the tedious processing and gave them more time for data analysis. However, I was careful to maintain the "open-endedness" of the projects so that results were not predictable. With this modification, the course becomes a good stepping stone to a true research project such as a senior thesis.

- **Bad attitude.** This was a combination of things, including loss of focus, poor inter-group interactions and lack of project ownership. In order to improve the situation, I consulted with Judith Kjellman of

Skagit Valley Community College (who has employed collaborative learning for more than a decade and was one of the presenters at the Third Annual Assessment Colloquy on Collaborative Learning) both before and during the next time I taught the class.

Solutions: I assigned the membership of the teams and changed it randomly with each new project to improve overall class cohesion. I involved the students more in the design of the projects. Basically I gave them a question to answer—which they had a hand in defining—and then left it up to them as to *how* they were going to answer it. The only caveat was that the whole class had to follow the same protocol so that data could be shared and compared between teams. I also explicitly discussed the objectives of the course. When each project was handed in, I acknowledged their progress and reiterated the objectives so that the students could see how they were progressing towards the class goals. All of this helped the students keep their focus, develop ownership of the projects and take responsibility for their learning.

- **Lack of a research space—with computers and lab equipment—where students could work as a team on all aspects of the project under my guidance.** This caused frustration at critical moments. For example, once a member of a student team asked if he could go to a computer lab to enter data. I said no, I wanted them all here during class time so that we could work together and suggested he go to the computer lab in the evening. The next day I asked how things had gone in the computer lab. He said he wasted two hours, one waiting for a computer and one trying to log onto the directory where they accessed programs for the course. He finally gave up. If we had had a research facility with computers, there would have been immediate access and I could have solved his log-on problem in seconds.

  Solution: Through the student technology fee we received money to construct a small networked computer lab (10 work stations plus printers, scanners and digitizing table) connected to an existing general purpose lab room. The lab was also stocked with a small reference library. This allowed all of the team's work, with the exception of library research, to be conducted in one space. This allowed me to look over their shoulders and guide them and it increased communication between the groups.

A Comment about the Corrective Measures: While several of the solutions above lower the frustration level of the students—e.g. reducing the tedium of sample processing or alleviating computer glitches—aren't these issues also a part of research? Shouldn't the students experience the pains as well as the rewards? Well, yes and no. Part of being capable of discovery is that the student becomes comfortable with entering the unknown: dealing with ambiguous results, formulating new hypotheses, adjusting procedures when the current ones don't work. Towards this end I initially give the students plenty of leeway in the design of their projects and let them make mistakes. At this point my crucial role is to serve as a sounding board and a resource for how to get out of trouble and get their project back on track. I distinguish between critical learning moments during intellectual crisis versus unproductive frustration because the student incorrectly copied the address of a website.

Results of Second and Third Iterations: I have run the course twice since implementing the above changes and the results have been excellent. Students were highly motivated and there was full attendance. When I entered the classroom each day I was greeted by a room full of busy students, entering data, peering through microscopes, excited and talking about the projects. I noted excellent teamwork both within and between teams. Students became confident and skilled at approaching a problem, comfortable with scientific method. Critical thinking skills improved, as did the ability to evaluate sources of information. Students learned to support an argument, and became comfortable with ambiguity. Writing skills improved, as did data interpretation. Students seemed to have fun.

Tradeoffs of Teaching Research

What are the costs of a research-based approach to teaching? Small class size is important in order to provide close guidance and rapid feedback to students, so this model does not work for larger numbers of students. Less breadth of coverage for greater depth is another tradeoff. Many faculty feel that *all* the material in their course is indispensable, yet studies consistently show that most material learned in lecture-based courses is forgotten soon after exams. On the other hand, material covered in an inquiry-based course is not only better understood and retained than in a traditional lecture-based format, students can *apply* these concepts to a much greater degree. So the question becomes, how much of the material that you teach do you want them to retain and be able to use? In addition, lecture-based courses do not appreciably improve affective skills such as critical thinking and communication.

The initial switch to a research-based model of teaching may require some difficult adjustments for both the professor and the student. Many students have been "institutionalized" to efficiently receive and repeat information but have little practice in thinking. They are accustomed to lectures and may resent an approach that seems like more work for them. My experience has been that, when properly presented, students prefer the research-based approach. After my first crash and burn experience, my teaching evaluations in my research course are as good as or better than ever. Of course I am a tenured full Professor (and department chair to boot!) so it was easier for me to weather this transition in teaching styles than it would be for an untenured assistant professor. My advice here is to keep your colleagues and chair informed about what you are doing in your classes and why. Risky changes in teaching strategies are easier in a supportive environment.

Does inquiry or research-based teaching require more time? Yes, although not prohibitively so. It is also a lot more fun. For instance, in the lecture format I typically spend the hour or so prior to class in preparation; reviewing my notes, organizing overheads and slides and "getting up" in order to present a well-organized and inspiring lecture. I put much energy into the preparation and delivery of the lecture and I feel drained afterwards and need time to rest. In the research-based class, I do not prepare before class. I may show up early to help students who are already there working on their projects. During class, I will guide them or give an impromptu "mini-lecture" (at their request) on a topic crucial to their research. After class, I may stay to help some students who remain to work on their projects. When I return to my office, I am energized by the give and take with the students and the interesting leads they have developed. Rather than lose energy, I gain it.

The Moral of the Story

To paraphrase Claude Raines in the movie *Casablanca*, I was shocked (shocked!) to find that students coming into my upper division class had virtually no skills in critical thinking, problem solving or communicating in a scientific context. I was delighted to find that I achieved measurable improvement in these skills when I changed my class to a collaborative research-based mode. I also found that my experience in this class changed the way I teach my introductory classes. Now I embed all of my lower division courses with activities that develop critical thinking and problem solving. University-wide, fusing the experience and knowledge of the "educator" and "scientist" cultures can produce a research-based curriculum that achieves *all* the cognitive and affective outcomes we want for our students, and would would improve the transition from lectures into investigative modes of learning.

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