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Proposal Cover Sheet

Project Title: Teaching Biology According to How People Learn

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Proposed grant period: 1 May 2006 - 1 May 2007

Type of project. Redesign of Existing Course __

2. Summary

The goal of this proposal is redesign a lecture-based course called Biology of Human Development into one based on active learning principals espoused in the National Academy of Sciences report *How People Learn*.

The existing course integrates concepts of cell biology, molecular biology, and genetics by concentrating on processes that regulate the first few weeks of embryonic development. It emphasizes learning about critical experiments as a way to understand scientific reasoning and how scientific inquiry is similar to and different from other ways of knowing. The current course is based on traditional lectures but its focus on interpreting experimental and understanding scientific thinking makes it better suited for an approach that emphasizes active learning.

The objectives of this proposal are to 1) create a resource base of readings and multimedia for students to study before they come to class 2) create a set of interactive classroom questions and exercises and assessments that make full use of a computerized classroom response system. 3) create a set of exploratory lab exercises that elicit scientific reasoning. I expect that these changes will help students to be able to understand the evidence for some of our current concepts of human development and to be able to apply scientific thinking to a range of problems in human development and in other areas of science.

3. Description

Goals and objectives

The two most important goals I have for my students are that they learn a few scientific concepts well, and that they learn to think scientifically. The goal of this proposal is to redesign a course in Biology of Human Development (BHD) to incorporate pedagogical approaches based on results from cognitive science. There are four specific objectives. 1) create a portfolio of resources about background information in genetics, cellular, and molecular biology, and embryonic anatomy 2) create a progressive series of interactive classroom exercises for lecture and laboratory using a classroom communication system, 3) develop laboratory experiences that elicit scientific reasoning.

Background and significance

Good teaching is an art, but maybe it should not be so much. Why can it not be based more on a solid theoretical understanding of how people learn? In particular, it seems odd to me that so many science educators are unfamiliar with or ignore the insights provided by cognitive science, and that we fail to systematically test our teaching "experiments." With this proposal I hope to begin to put my own teaching on firmer theoretical ground.

My point of departure is the widely known report called How People Learn, (HPL) commissioned by the National Research Council (Bransford et al., 2000). This influential report reviewed the research on cognitive development with an eye toward recommending specific classroom practices. The three most salient conclusions and suggestions that followed them were:

> *"1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom….*
>
> - *Teachers must draw out and work with the preexisting understandings that their students bring with them…."*

The evidence is strong that students are not empty tablets but rather come to class on the first day with conceptions of the how the world works. To take one example, I once asked a class of non-bio majors to explain why it is warmer in the US in summer than in winter. Less than a quarter of the class could correctly describe how the tilt of the earth caused the seasons. More than half the class believed that the earth was closer to the sun in the summer and farther away in the winter. The interesting result for me was not that most students did not know the correct answer, *but that each student already had a concept that made sense to him*. Moreover, research in cognitive psychology shows that when people are presented with new information, they first try to accommodate it in their existing conceptions. Old conceptions die hard, and new ones are hard to accept. One example from BHD is that students seemed to have a very difficult time understanding mutations. The most common misconception was that a mutation is any kind of birth defect, whether it is cause by a heritable change in DNA or not. Thus many could not distinguish between how alcohol causes birth defects and a mutation that causes a similar birth defect. Many also had a difficult time understanding the concept of a gene, the difference between a gene and the protein it encodes, and a gene and the trait it influences. I know they had difficulty with these concepts, but I did not systematically elicit or explore the concepts they *did have* about these ideas.

HPL cites two approaches to make it more likely that students will accept new concepts. The first is to ask them questions that will elicit the conceptions (or misconceptions) they currently possess. Of course this approach is as old as Socrates, but until recently was practical only with small groups of students, not in large lecture classes. Now there are flexible and readily available classroom response systems such as the Classroom Performance System (CPS) sold by eInstruction Corp (www.einstruction.com) that allow the instructor to ask multiple choice questions to students at any time during a class and get instant feedback recorded on a computer and displayed on a projector for the class to discuss.

The second approach is to use contrasting examples, or those that give counter-intuitive results, so that learners will find it impossible to reconcile the results with their mental construct.

> *"A key strategy is to prompt children to explain and develop their knowledge structures by asking them to make predictions about various situations and explain the reasons for their predictions. By selecting critical tasks that embody known misconceptions, teachers can help students test their thinking and see how and why various ideas might need to change…. The model is one of engaging students in cognitive conflict and then having discussions about conflicting viewpoints…. "To promote learning, it is important to focus on controlled changes of structure in a fixed context…or on deliberate transfer of a structure from one context to another" (Bell, 1985:72…)" (Bransford et al., 2000)*

It is more difficult to create these kinds of exercises in biology and it is much easier to just explain "how it works," but the evidence from cognitive psychology is quite clear that simply explaining something is not effective in changing peoples constructs. Since I have taught this course twice already I have a good command of the content I want students to learn. The revision will focus on transforming the classroom experience from primarily lectures to primarily question and assessment.

> *2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application….*
>
> - *Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge….*

I believe most instructors would claim to support and work hard toward this second goal, no matter their pedagogical approach. We strive to find good examples, explain things as clearly as we can, assign readings of relevant literature, meet with students in our offices. But is this enough? Among the devilish details lurking in proposition 2 are these: How deeply can one teach a topic in one semester to students of different backgrounds? What do we mean by competence, and how do we measure it? And what exactly is meant by a firm foundation? How do you know when you have provided one? How do you learn what foundation students bring to class from their previous experiences? How do you help students organize their knowledge, as opposed to merely memorizing vocabulary? And don't we also have an obligation to provide an overview of the field?

I believe one key is here is to be tough-minded and realistic about how much a student can learn in a one-semester science class. Tim Van Gelder has compared learning how to think critically with learning a foreign language, an analogy I find illuminating (van Gelder, 1997). Few would expect fluency after a single course, but a small working vocabulary, a knowledge of simple grammar, and ability to ask directions to the airport is achievable for most. Similarly, I think it unrealistic to expect full scientific fluency in even a small area of biology after one course, but a working knowledge of how scientists ask questions and reason from evidence, and ability to explain a few concepts in topic area being addressed is achievable for most.

> *3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them….*
>
> - *The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas…."* (Bransford et al., 2000)

I find this the most challenging of the three propositions and the one that will require the most rethinking and redesign of in and out of classroom activities. Simply offering lectures and giving periodic exams will not help students learn how they are learning. It will take serious effort to develop both structured exercises and a more nimble approach to classroom discussions that follow.

The final piece of the puzzle is to aligning the type of assessment to the kind of learning we want students to achieve. (Angelo and Cross, 1993; McClymer and Knoles, 1992). In other words, if we want students to be able to think critically, then quizzes, exams, and other graded assignments should assess critical thinking skills.

Detailed project plan

I will teach this course in the fall of 2006 to a class of up to 40 students in lecture three times per week who then divide into two lab sections of 20 each once per week. Tasks to be completed this summer include:

1. Defining objectives. I have a set of objectives from my existing course but it was not prepared with assessment in mind. My working list will be refined to make explicit the outcomes that will be assessed, following the guidelines suggested by the Field Tested Learning Assessment Guide (flaguide.org).

2. Creating on-line resources. All of the course reading materials will be made available on-line. Materials will include several categories:
   a. Reference documents: similar to the chapters of a college level introductory biology book, the reference materials will cover basic cellular chemistry, cell structure, Mendelian genetics, principles of evolution, and principles of early vertebrate development. I will write these, adapting them from my previously prepared Keynote presentations. For example, I think it is important to emphasize the structure of amino acids and proteins, and nucleotides and nucleic acids, because these will be needed to understand differential gene activity and mutations. However, it is not important for BHD to understand details of carbohydrate and lipid structure. Similarly, it is crucial to understand the relationship between transcription and translation, but not ATP synthesis or oxidation-reduction reactions. Background information in genetics will be about the same as for a general

biology class. Information about evolution will stress primate evolution and will be tightly linked to genetics.
b. Experiments: These will be selected, annotated, and edited readings from the primary literature. For each course topic I will choose from one to three papers from classic or recently published studies. At the beginning of the course the papers will be highly edited, perhaps no more than the abstract and one or two essential figures plus my edited version of materials and methods. The idea is to have students focus on experimental logic and interpreting the data, and not become bogged down or scared away by foreign terminology. These experiments will be the basis for class activities.
c. Web links to other learning resources, such as atlases of embryonic anatomy, genome databases, video clips. The Society for Developmental Biology and Cell Biology Society maintain links to several good sources.
d. A laboratory manual, which will also be available in hard copy for use in the laboratory. The protocols for the lab exercises already exist from previous versions of the course.

3. Developing a weekly lesson plan:
Each week will follow a similar but subtly varied plan. Students will have a reading assignment or an exercise to complete before coming to class. The class will begin with a question that students will discuss for a while and then answer using the classroom response system (CPS from eInstruction. The university has several of these systems available for use and academic technology support staff to maintain them. A Macintosh version of the software has recently become available which will make it easier to transfer my previous instructional materials that are all Mac based). For example, if the topic for the week is fertilization I might begin with a factual question such as "where anatomically does fertilization occur in humans?" A factual question determines who has done the reading, (or has that foundational knowledge from another source). Then I might ask a conceptual question such as "what are some possible functions of the zona pellucida (the thick covering around the egg)?" This will be accompanied by 4 or 5 multiple choice answers. Following the question students will either answer immediately, then record their answers using the CPS clickers. Their answers will be recorded by my laptop computer and displayed by a projector. Assuming there is some disagreement in the best answer, students will then discuss among themselves or with me. *Their initial answers and the ensuing discussion will be the core of class time, because this is when I can assess their understanding, and they will be able to immediately test their comprehension.*

Class will continue to proceed in a similar way, although the next class will vary so that the routine doesn't become stale. Questions will be designed to assess understanding at several levels, from simple factual understanding to conceptual, analytical or synthetic. The challenge for me will be to design the more abstract questions to fit a multiple-choice format. For example, I might like to know whether they understand that egg-sperm recognition is highly specific. I could ask, "What prevents sperm from fertilizing cells other than an egg?" but I might get a simple recitation of "special molecules on each cell surface." and it is difficult to think of alternate distractor items. A better question might be to set up a thought experiment. "You have heard that sperm-egg binding is specific. Here is graph of a test where sperm were added to eggs and the number of sperm bound to eggs was counted over time. What would the graph look like if we did the same experiment but added cells from the Fallopian tube?" Their choices could be that sperm binding increases, decreases, or stays the same. Their multiple choice responses would then be the basis for discussion of both the logic of the experiment (a common competition experiment) as well as the biology of sperm-egg binding.

I will use other variations of the question period suggested by CPS users, such as team games. The point is to use the class period to ask probing questions, assess student responses, and give students immediate feedback about their understanding. Another point is to get students used to answering questions to assess their own understanding, rather than for a grade. That is, these are formative assessments, not summative. However, since each student will have his own clicker I will have a record of both attendance and participation. About 10% of a student's grade will depend on his class participation as recorded by his clicker responses.

4. Laboratory activities

The objectives of the laboratory are to provide direct experience with foundational knowledge, a few concepts of development and with scientific reasoning. The labs will focus on just a few topics that extend over several weeks. Briefly, the lab topics will be:

a. Deductive reasoning and hypothesis testing (one or two weeks)

Students are given sealed cardboard boxes containing various objects. Students develop and test hypotheses about the contents of the box. They must describe their thinking as they work through the exercise. This is an excellent exercise for practicing metacognition and a good way to begin the semester.

b. *How to find science information (three weeks)*

These exercises are done in conjunction with the university librarians. The goal is for students to learn the skills and strategies to find and evaluate information about scientific or medical topics. The scheme is first to guide the students on a "treasure hunt" for information located in specific papers we have pre-identified in the literature. This is followed by a project in which a student locates information on a topic of his/her choosing. Mostly done outside of class. Class time is used for reporting back.

c. *Embryonic anatomy using amphibian or chicken embryos (four weeks)*

The goal is for students to learn embryo structure first-hand by comparing live and fixed histological preparations. These are compared with on-line resources for human embryos.

d. *Experiment on teratology using tadpoles (six weeks)*
Retinoic acid (vitamin A) is a potent teratogen that causes embryos to develop without heads, but only when embryos are exposed to it between 9 and 14 hours of development. Earlier or later exposure has no effect. Students will demonstrate this effect on tadpole anatomy and on gene expression, develop a hypothesis to explain it, and devise a test of their hypothesis.

Prior activities or research related to proposal

I have taught the course twice previously, once with one section of 13 students and the second time with 40 students in lecture and two labs of 20. The lecture topics I covered both times were similar and varied only in emphasis:

Scientific reasoning	Gastrulation and Neurulation
Overview of development	Organogenesis
Evolution of fertilization	Mechanisms of differentiation
Spermatogenesis	Cell communication and induction
Oogenesis	Stem cells
Fertilization	Sex determination

The lecture was based on Keynote presentations that were made available after lecture on the course web site. Summative tests included a short answer midterm exam and final, and a short answer lab exam. They were also assigned a term paper analyzing the experimental logic of a scientific paper concerning developmental biology. They could choose the paper with my approval and then identify the hypothesis being tested and analyze the logic of the experimental design.

The lab portion included introductory exercises on deductive reasoning and hypothesis testing, introduction to scientific literature, DNA isolation, basic microscopy, and several sessions on amphibian embryology (in place of human embryology) with a final 4 week experiment on teratology using tadpoles. I think all of the experiments and demonstrations have potential except for the DNA isolation, which turned out to be a mere technical exercise unconnected with the goals of the course.

The main difficulty with the course from my and the student's point of view was the lack of a suitable textbook. Existing books are either for medical students or advanced bio majors and assume a working knowledge of cell and molecular biology and genetics. General biology books have at most two chapters on development, usually one on reproductive physiology and one on general development. The first time I taught the course I used no textbook and assigned readings instead. This approach lacked coherence. The second time I used an undergraduate developmental biology text by Wilt and Hake. But the text did not match well the topics I want to discuss, and it assumed that students had already taken courses in cell biology and genetics.

I considered writing my own textbook, but after further reflection I think that textbooks, even one of my own, simply would not be flexible enough for the way I want to teach. This is the type of background material that students will be expected to read and study before class. Other items in the course pack will include extracts of papers from the scientific literature, stories from the newspaper, chapters from books, etc. (Also DVD or videos, web links).

To prepare to teach about scientific thinking I did extensive background reading in the philosophy of science and in deductive logic. As part of my assessment of student attitudes toward science, I included a pre-test and post-test using the VNOS (Views of the Nature of Science) instrument. Their attitudes may have changed a little but the students resented taking the survey again at the end of the course (the short answer questions are quite time consuming) and most of their answers were cursory. In the future I will convert it to a form that can be answered using the CPS. I have also attended lectures by proponents of active learning such as Eric Mazur, and helped organize a Project Kaleidoscope regional conference at the University of Richmond on How People Learn and science education.

Timetable

June 2006-August 2006

The first half of the summer (May and June) will be spent assembling background resources for the course pack. The second half will be spent organizing classroom questions and activities and getting the questions into eInstruction's CPS database format.

September-December 2006

Teach the class.

January-May 2007

Process assessments and present results. Make CPS database questions available at my departmental web site.

6. Budget with justification

Salary		5000
Equipment		
	Mini centrifuge	1260
	Electrophoresis set	1040
	Micropipettors (4 sets of 3)	2700
		10000

Summer salary is requested to compensate the large amount of pre-class preparation of background materials, exercises, and questions for the classroom response system.

Equipment: Previous versions of the course relied on the equipment that I used for my histology class (slides, microscopes) and was not experimental. To provide for experiments in molecular biology at a minimum requires an investment in equipment for preparing DNA and running gels. The lab will run two sections of 20 students each divided into five groups of four students each. I have budgeted for 2 electrophoresis mini-gel boxes and 1 dual unit power supply to supplement others I can borrow within the department. One Eppendorf MiniSpin centrifuge and four sets of the three common micropipettor sizes; 20 µl, 200 µl, and 1000 µl will be used will be used for DNA preps. The university will supply standard lab equipment and supplies such as pH meter, pan balance, and glassware and plasticware, and reagents.

Context of course in the curriculum

Several years ago our institution changed its science requirement for non-majors from two lab courses to one. At the same time our department changed from offering a single, large, multi-section general biology course taught by a single faculty member to multiple smaller, topics-based courses taught in rotation by *all* department members. These general education science courses are to be designed specifically to teach students how scientists ask and answer questions. With the shift I began offering a course in Biology of Human Development. Other courses in the department include Evolution, Human Genetics, Environmental Biology, and others are in development. Our goal is to increase the options for non-science majors who might want to take more than one science course, make those courses more interesting, get more faculty involved in teaching non-majors, and decrease class sizes, and make the labs more interactive. Also, these courses are designed to stand alone. Rather than being the first course in a series—as is the first in a sequence for majors—they are designed to be (probably) the *last* course in science for most of our students. Thinking about these courses in this way demands that they be approached differently from those intended for majors.

Impact on the institution

The course will directly affect up to 40 students per year. One impact will be to provide a model for incorporating more critical thinking and active learning approaches in our courses both for non-science majors and for science majors. Another will be to be an additional model for using the classroom response system (one other Biology faculty uses the system in a course for majors). A third is that more non-major students will take additional science courses. I hope the biggest major impact will be to provide a model for assessing instruction in science classes.

Evidence of Institutional Support

The university recently rededicated its Gottwald Center for the Sciences following a $38 million renovation and expansion. The laboratory spaces were reorganized specifically to better support student projects within courses with island benches for seating in groups, instrument and prep rooms adjacent to every teaching lab, and teaching labs adjacent to faculty research labs. The Center for Teaching, Learning, and Technology supports the classroom response systems and other instructional media. They also administer the Program for Enhancing Teaching Effectiveness (PETE), which supports innovative teaching methods with in-house grants for projects and travel funds to participate in teaching conferences and workshops.

4. Evaluation, Dissemination, and Continued Support

Because no specific method of assessment was done in previous years it will be difficult to answer the question about how effective the redesign will be compared to previous versions of the course. For example, I expect that exam questions will change significantly from previous versions, so I won't be able to compare student exam responses across years. Also, because the course is taught as a single lecture section it will not be possible to compare different course designs in parallel sections.

On the other hand, beginning in the fall I will have an extensive database of student responses collected by the classroom response system. Those responses will allow me track student progress in understanding scientific concepts during the semester. In future years I will be able to track those areas that students have trouble comprehending and create a catalog of common conceptual errors. Since assessment is iterative, I can use those data to alter the teaching assignments in successive years to track changes in comprehension of particular concepts.

I will also use a modified VNOS pre- and post-course assessment, converted for use with the CPS clicker system to save time, to measure students attitudes toward science.

I will disseminate the results in two ways. One is by presentations at conferences such as ACS and also the Society for Developmental Biology, which has an education session at its annual meeting. The other is by sharing my database of "clicker questions" to other educators by way of my website. By keeping track of others who use the database I'll be able to make contact with others in my area who are interested in this approach.

One extremely important issue that I do not have the resources to address in the present proposal is how best to validate test questions. That is, to "test the test" to make sure it is measuring what I want it to measure. The Bioliteracy project at the University of Colorado at Boulder (bioliteracy.net) is leading an effort in biology similar to that which has been done in physics to create a biology concept inventory, and a set of questions for students that will elicit their misconception about those basic questions in biology. They are working on validating questions about developmental biology and my class would be a good partner for their work. I expect to seek additional support through the NSF-CCLI program to work with the Bioliteracy project to provide a model for validating tests in our curriculum.

5. Literature Cited

Angelo, T. and Cross, P. (1993). Classroom Assessment Techniques. New York: Jossey-Bass.

Bransford, J., Brown, A. and Cocking, R. (2000). How People Learn. Washington, DC: National Academy Press.

McClymer, J. and Knoles, L. (1992). Ersatz learning, inauthentic testing. *Excellence in College Teaching* 3, 33-50.

van Gelder, T. (1997). Teaching critical thinking: some lessons from cognitive science. *College Teaching* 53, 41-46.

6. Curriculum Vita

Gary P. Radice

Education

B.A. Wittenberg University, cum laude with distinction in Biology, 1974
Ph.D. Yale University, 1979

Professional Experience

1996-present	Associate Professor of Biology, University of Richmond
1990-1996	Assistant Professor of Biology, University of Richmond
1981-1990	Research Associate, Indiana University at Bloomington
1980-1981	Research Associate, Stanford University
1979-1980	Research Associate, University of California at Davis

Fellowships and Awards

- Appointed a Faculty for the 21st Century, Project Kaleidoscope (1994)
- NASA Research Fellow (1981-83)
- Research Fellow of the Anna Fuller Fund for Medical Research (1979-81)
- NIH Training Grant award to attend Embryology Course at the Marine Biological Laboratory, Woods Hole, Massachusetts (1975)
- Danforth Graduate Fellowship (1974-78)

Publications since 2000

- Fan, S-Y , R.O. de Sá, and G.P. Radice. (2001). A common pattern of somite cell rotation in three species of pipids. J. Herpetol. 35: 114-116.
- Smetanick, M. T., R. O. de Sá, and G.P. Radice. (2000). Do timing and pattern of myogenesis correlate with life history mode in anurans? J. Herpetol. 34:637-642.

Current Funded Research

- "Origin and Specification of Lymphatic Heart Myoblasts," 6/04-5/05: Thomas and Kate Miller Jeffress Trust. $25,000.
- "Acquisition of a confocal microscope for research and research training," 6/04-5/07. National Science Foundation—Major Research Instrumentation. $340,391.
- "Laboratory Investigations using Quantitative Microscopy," 5/02-4/04; National Science Foundation—Course, Curriculum, and Laboratory Improvement Program. DUE-0127587, $63,320.

7. Disclosure Statement

Concurrent activities: I am currently on sabbatical leave which ends in June 2006, so I am not teaching but I am working on a research grant funded by the Thomas F and Kate Miller Jeffress Memorial Trust. It does not provide summer salary but I will be working on it this summer while I work on the ACS project. In the fall, while I am teaching the redesigned course, I have received three hours of reassigned time to create an interdisciplinary course in biological imaging, which will be taught in the spring. The reassigned time is being paid for by a grant to the University by the Howard Hughes Medical Institute.

I have no other current or pending funding. I expect to apply to the NSF-Course, Curriculum and Laboratory Improvement program in May for a project that will continue and extend the work proposed here.