



# 2009 AAAS/Subaru Essay Writing Competition for K-12 Educators Finalist Essay



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## **Integrative Laboratory Classes Turn Smart Kids Into High School Scientists**

Since I spend much of my time organizing and supervising independent research opportunities for juniors and seniors at Stuyvesant High School in New York City, I began to ask how they should best be trained at an earlier age. The algorithm for turning smart kids into good scientists is poorly defined, but is widely believed to be dependent on clarifying thought processes and providing adequate interactions between the full range of scientific fields and concepts. One approach to eliminating the divided, serial quality of science instruction, and facilitating these interactions, is the implementation of a European-style course structure in which the students are taught all three major sciences—biology, chemistry, and physics—in each and every year of high school.

Given our limited resources, instead of adopting a European approach, the standard serial curriculum could be modified to include small, integrative laboratory based courses or modules which meet weekly or biweekly during the entire four years. These classes might have different themes, but they would all have equivalent goals: the integration of knowledge across time and disciplinary boundaries

along with the advancement of lab skills. The necessary laboratory skills include: experimental design, data analysis and representation, practical problem solving, observation, making inferences regarding causality, and drawing conclusions. These courses differ from the standard laboratory component, whose primary content goal is the reinforcement of current classroom instruction, but could easily overlap.

Two years ago, I began working on this idea in the context of two intermediate elective courses: laboratory techniques and vertebrate zoology. Here, I am focusing on just one of these classes—laboratory techniques—as a motor for a multi-disciplinary, integrative curriculum because it is a natural fit for the purpose and infinitely adaptable to the skills and interests of the available faculty.

In the past, the laboratory techniques class at the school was designed to communicate basic skills, which future physicians and biological scientists might encounter in the lab and students might read about in their biology textbooks. Although the actual techniques utilized have changed from earlier courses, many of the classic techniques could be utilized for this integrative purpose, just by changing the focus. The main appeal of this class for content integration is that it has an instrumentation component through which physical principles can be explored, biological themes through which the course can be organized, and chemical components in which practical and fundamental concepts can be revisited. Chemistry review is facilitated by having the students prepare their own quantitative solutions and devise purification schemes. Class discussions solidify chemical knowledge by focusing on the basis of the



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methods, such as fluorescence, reflection, and absorbance; size, solvation, and precipitation; catalysis and enzymatic synthesis of organic compounds; and finally, chromatographic interactions and covalent modification. Physical concepts are reviewed, such as forces affecting the flow of air, heat, and electrons, and the engineering concepts involved in designing equipment.

This particular course originally had three lines of development: skill acquisition in molecular biology and biochemistry; analysis of whole organisms and their physiology; and independent project development. All three components progress simultaneously, which is valuable but may be separated to reduce the stress on both teacher and student. One question every teacher in this role should ask is: To what extent does open versus structured activities help achieve the goals of creating budding scientists? Independent project structure can stimulate intense problem-solving discussions within groups. Creativity can be advanced when the teacher emphasizes innovation in testing ideas and then implementation of improvements, rather than the creativity in the initial approach, because this allows students with different backgrounds to participate equally and shortens the latency period before the real work begins. However, with less definition, less advanced or less motivated students find it difficult to obtain results and inevitably become disappointed. At this age, the students are adequately excited by interesting structured labs, and it is not clear that open inquiry projects are necessary or advantageous to the majority of students even in a gifted program. In fact, given the additional supervisory effort required, the interval between meetings in this periodic class, and the

chronic lack of space, I came to the conclusion that such projects do not well serve my particular mission.

In contrast, an interesting context does seem like a critical component to elicit maximum participation and intensity of effort. Since there was already a coral reef growing in the classroom, this provided just such a context for our efforts. In the first semester of the course, the motivation was coral bleaching arising from the release of symbiotic dinoflagellates in response to unfavorable environmental conditions. We characterized a dinoflagellate from a model cnidarian—a fast-growing anemone of the genus *Aptasia*. The students optimized growth, and developed an experimental model system in which to study the bleaching process. They learned how to safely isolate, culture, and identify an unknown microorganism using sterile techniques and experimentation with nutrients and physical conditions. Meanwhile, the students also pursued the goal of learning sufficient molecular biology techniques to transform dinoflagellates with a DNA construct capable of expressing GFP. In this way, they could watch the organisms enter and leave the cnidarians in response to changing environmental conditions. Thus, there was a current throughout the class that linked each of the techniques that they learned even though they were in fact historically and conceptually independent. Although the class groups set up their experiments independently, they put their results on a class wiki, which all students used to help write their lab reports. In one semester, it was not possible to finish the entire project—only optimization of growth was fully completed—but the students remained motivated throughout the



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course and we set up enough background data for another class to complete the transformation using the class results.

This class is continuing again this semester with more emphasis on the physiology of plants and simple animals. Many students really enjoy working with an intact organism, and for this same reason, plant experiments have also long been a favorite for encouraging students to develop experimental design. Of all the skills taught in this class, the construction of rigorous experiments with appropriate controls is the most challenging and probably the most instructionally valuable. Having now eliminated the independent project, this allowed more time for the students to develop well-defined physiology experiments with land plants, nematodes, and invertebrate animals from the reef; with particular emphasis on the use of appropriate controls. Additional time in the development phase also allows for stronger emphasis on lab safety. Having the students draw out their protocols beforehand enables them to actually envision and understand each step that they will take before they do it. This is a valuable skill in general and avoids the rushed haphazard movements that students exhibit when they first try anything. Anticipation or envisioning is also a

valuable approach to teaching students how to use lab equipment safely to avoid potential accidents. It should not be underestimated how many iterations of experimental design are required to effectively train students in these skills. We obtained a grant from Toshiba, which among other things allowed us to expand the collection of sensors available for this purpose, which facilitated complex data analysis.

Lab classes are by nature inclusive because everyone needs to be actively engaged: noise, talking, and moving around are expected. Relatively little homework, other than writing lab reports and tidying up the notebook, is required, thereby making the class additional fun rather than another burden. However, the more one moves away from structure, the less inclusive a class can become. Many students need more supervision to keep them moving than is possible in a flexible, large class. Smart but emotionally or behaviorally challenged students do not always react well to the lack of structure. Courses with flexibility but more defined boundaries seem to provide a better forum for the integration of knowledge for these types of students. The same goals can be met with even more structured classes as long as experimentation and problem solving are emphasized.