# Twenty-first Century Science and the Facilities of the Future

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## Interdisciplinary Undergraduate Science Education

Interdisciplinary lecture and seminar courses can give students a realistic picture of how connections between different areas of science are made in research as well as how those connections can be plumbed to advance knowledge. Because research is becoming increasingly interdisciplinary, such courses will need to be made available to students beginning in their freshman year. The goal of first year interdisciplinary science courses would not be to provide in-depth, hands-on experience, but rather to expose students to the broad range of interesting work that can be done at the interface of disciplines.

Such courses would serve a dual role: biology students, for example, would see that mathematics and computation can play an important role in their future work, while mathematics and computer science students would get a critical perspective of how quantitative methods (statistics, applied mathematics, computer science) can be fruitfully applied in a range of disciplines.

Students could perform hands-on computer simulations that illustrate scientific processes in a more intensive interdisciplinary course, which would meet alternately in a classroom setting and a computer laboratory setting. Class time would be devoted to the exposition of mathematical models in life science, engineering, physical sciences, environmental science, neuroscience, etc. and methods for studying the behavior of such models by computer. The computer lab would involve hands-on experiences in which students work individually or in small groups on computing projects. Each research team would report on its work to the entire class. Suitable topics at this level may be drawn from virtually any existing discipline and easily integrated with tools and approaches employed in other disciplines.

Such a course could easily be made accessible to freshmen. Mathematical models would involve either systems of algebraic equations (accessible with high school mathematics) or ordinary differential equations (made tractable and understandable via Euler's method without the need for a formal background in differential equations). Simulations involving random numbers can also be done with only an intuitive introduction to probability and the use of a random number generator.

Upper-level interdisciplinary courses will provide further opportunities for sophisticated experimentation and analysis of cutting-edge scientific problems. For example, Mechanics of an Organism, an upper-level course at the University of California, Berkeley, effectively brings biology and engineering together. Engineering principles pertinent to particular biological processes are presented first, followed by incorporation of the biological concepts. Different kinds of flow and fluid dynamic forces are discussed before parachuting, gliding, flying, and swimming are analyzed.

Engineering and biology are also nicely interwoven in subsequent explorations of the biomechanics of organisms, tissues, and cells. Upper level courses will also bring teams of students together to solve intricate and complex problems.

Each student would bring to the team a level of expertise within the framework of her or his own discipline, therefore the team would be intimately dependent upon one another's expertise to address the problem at hand. Finally, interdisciplinary research teams will be the framework of future undergraduate research efforts on many campuses. The changing face of scientific study itself will demand this be the case.

## Implications for Space

Science buildings on many campuses have upheld traditions of the past. On some campuses, even small campuses, science departments are found housed in separate buildings while on other campuses the traditional 'layer cake' approach to departmental ecology is maintained (chemistry on top, biology in the middle, geology and physics at or below ground).

Little vertical traffic occurs in layered building and very little interaction between science educators and researchers occurs between departments housed in separate buildings. Such buildings tend to reflect their curriculum: isolated, fragmented, detailed and stale. Too much time working in such an environment creates faculty members that are one-sided in their scholarship and their teaching.

The commitment to integrating research and education must play a fundamental role in the design of any new building. A building must create a research-rich environment that supports a curriculum steeped in investigation, where students and faculty can work as partners in research and education.

It must also take advantage of the logic of interdisciplinary science. For example, in today's era of modern science one finds organic chemists, biophysical chemists, bioinformaticists, computational chemists and biologists, geneticists, molecular biologists, biochemists, microbiologists, and toxicologists all addressing common problems and all using common instrumentation.

By "clustering" these individuals together, instrumentation pods can be shaped and placed effectively for individual and team use, and teaching and laboratory space can be designed so as to provide flexibility and utility for the entire community.

It is also common to find individuals with expertise in areas such as analytical chemistry, physical chemistry, inorganic chemistry, physics, geoscience, environmental science, ecology, population biology, and organismal biology forming teams to address critical issues at the interfaces of these areas.

Coordination of space and location for individuals with interest and talent in these fields is crucial for programmatic effectiveness and economy. These are a few examples of possible clustering effects that one might envision. The list could conceivably be as long as the imagination would allow.

The above will result in a re-distribution of faculty within the building environment such that departmental boundaries become non-existent and lines of communication flourish. The above will demand the planning of laboratories and lecture spaces to provide maximum flexibility, to accommodate unique and evolving pedagogical approaches, and to promote cross-fertilization of ideas and interest areas.

The above will also require enriched spaces for communal approaches to research independent from, yet integrated with, teaching laboratory spaces; spaces for groups to sit and think and interact as a community of learners outside of the traditional laboratories and lecture rooms; community areas for celebration of achievement, of history of the institution and the history of science itself, and welcoming of all individuals (scientists and non-scientists) into the science learning environment. And the space will promote growth in science because the space will provide not only the framework for science itself, but also serve as a catalyst for change.

What, how, and where STEM learning happens must be designed to socialize 21$^{st}$ century learners into 21$^{st}$ century interdisciplinary STEM learning communities. ■