Accelerated Integrated Science Sequence (AISS) - The Future of Science Education: Successes and Failures

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Abstract

In 2003, the National Research Council of the United States in their BIO2010 report and later in 2009, and the Association of American Medical Colleges & Howard Hughes Medical Institute each called for increased interdisciplinary education in the natural sciences at the undergraduate level. However, there are few B.A. or B.S. granting institutions in the United States offering introductory science education for majors.

In 2007, the faculty of the W.M. Keck Science Department of Claremont McKenna College, Pitzer College and Scripps College, members of The Claremont Colleges in California, began teaching an introductory science program for entering first year students. The goal was to jump-start the process of interdisciplinary thinking for students majoring in the natural sciences. One year of biology, one year of chemistry and one year of physics were combined to form the year-long program known as the Accelerated Integrated Science Sequence or AISS. In its seventh year, AISS has spawned a biology-chemistry introductory course, new interdisciplinary upper division courses and a popular new interdisciplinary/multidisciplinary major. The retention rate in the sciences of students completing AISS is more than 90% vs. less than 40% for the national average of students completing the three introductory sciences separately. Compared with similar science majors who follow the traditional separate introductory sciences path, AISS students are more than twice as likely to major in a combined or interdisciplinary science major and are more than twice as likely to achieve science or collegiate honors. This paper reports on the academic features, participants and outcomes of AISS.

1. Introduction

Increasingly, phenomena studied in science have been crossing the lines between the traditional disciplines of biology, chemistry and physics. Examples of such problems include understanding how birds use the Earth's magnetic field to navigate, how to design and build an artificial eye or optic nerve, and quantum coherence in photosynthesis. These examples require connecting themes and principles attributed to more than one discipline.

For students interested in problems related to the life sciences, such integration is paramount. As stated in the BIO2010 report, "Connections between biology and the other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature." [1] Other U.S. national science and medical professions have made similar arguments.[2][3] To address the growing need for more integration in the introductory science program for undergraduates, the W.M. Keck Science Department developed the educational program - Accelerated Integrated Science Sequence (AISS). [4][5]

Introduced September of 2007, AISS is an honors-level year long, double course with semi-integrated double laboratory which combines the material found in introductory biology, introductory chemistry and introductory physics. Faculty experts from each of the three disciplines, biology, chemistry and physics, teach in the program and are present during all class time. AISS is available only to first-year students through an application process.

Entering first year students from the three colleges are contacted during the summer to apply for AISS. The students are asked about his or her experience and ability in science and mathematics and are required to provide an essay explaining why she or he should be selected for AISS. Students selected for AISS usually possess high marks and scores in mathematics (ACT: 31+, SAT: 700) and multiple years of high school science at either the advanced-placement (AP) level or international baccalaureate (IB) level. While a year of high school physics is no longer required, strong justification for the value of integrated science is essential. The enrollment demand for the course is greater than the number of available slots. Historically, the class size has been 28 students, but will be expanded to 32 students next academic year. The enrollment size is limited by the physical space of the laboratory used for wet-lab experiments.

2. Development and Structure of AISS

Initially, funding for the development and implementation of AISS was provided by a grant from the National Science Foundation of the United States [7]. The development of AISS began with a year of discussion of what topics, themes and structure should be used in the integrated undergraduate program. Three faculty members, one each from the three disciplines, were selected for the first year of the program. These faculty members then received course release time to prepare themselves by teaching each other the major principles covered in his or her introductory course. This process of pre-educating the instructors was dropped for subsequent faculty participants as it proved to be inefficient and unnecessary.[5] Instead faculty are meeting daily to discuss topics, problems and integration.

AISS is held in a multi-purpose classroom. The classroom consists of large tables (1.5 x 2.0 meters). Each table holds four students. This layout provides opportunities for each student to work with fellow students on problems, experiments, computer simulations or other hands-on activities. Laptops are available for simulations and modeling, and when required, students move to a chemistry laboratory.

AISS mets every morning, Monday through Friday. Initially it met Monday, Wednesday and Friday for two hours and Tuesday and Thursday for three hours. After several modifications to the schedule, we now include a one four-hour afternoon period per week which is primarily used for wet-lab experiments and ecology field trips. Simultaneously we reduced the morning time to at most two hours per day. An hour long quiz or a two hour long exam is held once per week.

3. Themes and subthemes

Initially we considered the case study approach of science as used in other integrated science programs such as the one at Louisiana Tech University [8] and the University of British Columbia[9]. However, we felt that any specialty required to cover such topics would discourage other faculty member from participating in the program. Instead, we adopted themes which draw from the fundamental principles that transcend the disciplines. This allowed the individual faculty member to infuse his or her expertise into the program while maintaining a common outcome for the students independent of the set of instructors. [6]

AISS is separated into four major themes: randomness, structure, energy and dynamics. These set of themes were settled on after several previous attempts resulted in generating a series of modules that lacked the integration we desired.

The randomness section includes important concepts related to how random behavior of multi-particle systems play a major role in some physical laws and behaviors of biological systems. The structure section is where we define the state of the system. This is where we cover material properties of matter and types of statics. The energy section consists of science where there is a change in the state of the system, i.e., where the conservation of energy principle is the dominant principle in studying the systems. The outcome for the student is the understanding of the tension between entropic effects and energy differences due to force fields. The dynamics section takes the discrete change in state of energy section

and now treats it as continuous. Table 1 lists the themes and sub-topics commonly found in introductory biology, chemistry and physics.

Table 1: Themes and topics of AISS

Randomness: entropy, Boltzmann distribution, basics of genetics, temperature and specific heat, 2nd law of thermodynamics, diffusion and osmosis.
Structure (the state): static forces and torques, material properties of atoms, electro-chemical bonding, electrostatics and magnetostatics chemical equilibria, biologically important molecules: amino acids lipids, proteins, and membranes, and acid-base equilibria.
Energy (discrete change of state): wave properties, quantum mechanic principles, molecular orbital theory, conservation of energy, thermodynamics, electric potential, electrochemistry, and biological energy transformation.
Dynamics (continuous change of state): Differential equations, population evolution, chemical kinetics, mechanical dynamics, electrodynamics, natural selection, circuits, electro-biology, and ecological systems.

While we list here only the major subheadings, many topics are revisited throughout the course. Sometimes it is necessary to discuss physical fundamentals such as mechanical equilibrium before covering electro-chemical bonding, but on other occasions, systems of interest in biology lend themselves to be discussed before a full treatment of the physical technique used to describe those systems. For example, in discussing voltage-gated channels in membranes in the structure section, the complete understanding and development of electric potential (voltage) does not occur until later in the course in energy section. Regardless of the sequence, there is an emphasis on understanding biochemical processes through fundamental physical laws. Because the biology expert knows the students have been exposed to useful physical principles, the expert is not burdened by covering these topics himself or herself and can address biological questions with greater depth than how the topics are discussed in the traditional introductory biology course.

5. Outcomes and Discussion

The W.M. Keck Science Department is a non-traditional science department in an unusual environment. Keck Science, then the Joint Science Department, was established in 1964 as the science department for Claremont McKenna College (then Claremont Men's College) which focused on economics and public policy, Pitzer College which focused on social sciences and Scripps College, a women's college, which focused on the humanities. Since the three colleges are physically contiguous with each other, a single science department in a single building could be used to serve the few science majors or handful of students planning a career in the health fields.

For the vast majority of colleges in the United States, science is separated into individual traditional departments such as biology, chemistry and physics. For many of these colleges, the departments are housed in separate buildings. We believe the unique structure of Keck Science has provided opportunities and lowered the barrier height for developing multi and interdisciplinary initiatives. AISS is one example. In our department, faculty from different traditional disciplines have offices adjacent to each other and often eat meals together. This has also lead to hires of faculty who specialize in interdisciplinary fields of science.

The original objectives of AISS were: 1) to attract top students interested in the sciences to colleges where traditionally science has not been a field of significant interest and 2) increase student interest in the physical science disciplines: physics and chemistry. By student population, nearly 75% of the science majors of the combined three colleges are women. Women have traditionally been interested in life science majors and are far less likely to major in the physical sciences than men. While the national interest in the sciences at undergraduate institutions has been somewhat flat [10], since the introduction of AISS and the promotion by the colleges, interest in the sciences and completion of majors in the natural sciences has increased dramatically at each of the three colleges. Combined, the total number of science interested applicants have increased nearly 200% and percentage of applicants who have expressed interest in the sciences has increased from an average of under 20% to nearly 40%. Of the accepted applicants, the combined matriculation or yield for science interested students has increased from approximately 20% to more than 35%. For both Scripps and Pitzer, the yield of science interested applicants is now higher than the overall applicant yield at each college. [10]

Of the students who initially enroll in AISS, approximately 80% complete a major in the sciences. This compares to less than 40% for those who enroll in any of the individual introductory courses which is comparable to the national averages.[12] Of those who complete AISS, the rate of retention in the science has been more than 90% every year. Compared with similar science majors who follow the traditional separate introductory sciences path, AISS students are more than twice as likely to major in a combined or interdisciplinary science major and are more than twice as likely to achieve science or collegiate honors.[13] [14]

In terms of predicting the relative success of the students in AISS, the department used an external evaluator from another institution to compare the standardized test scores of the students, ACT and SAT, as well as their entering grades versus the outcome of the students' performance in AISS. Though weak, the verbal section of the SAT test has been found to possess the strongest correlation between scores and the grades students receive in AISS. [14] We believe this is a reflection of the fact that the disciplines use different terminology to represent the same natural phenomena and techniques used to study those phenomena. Students find they must learn to translate the different approaches. It also may be a result of the fact that the majority of the students already possess strong mathematical skills, hence the relative variation in the math scores is small. Early results from a recent ongoing study suggests that overall enthusiasm is a better predictor of success in AISS. Enthusiasm is being measured via the essay a student writes to support his or her application for enrollment into AISS. [15]

AISS has lead to several additions and positive modifications to the department. A new major was created, biophysics, a major which requires course work in the three major disciplines. The design of the major was the outcome of students seeking to continue the interdisciplinary / multidisciplinary experience of AISS. In addition, the department has developed a non-accelerated first-year program, Integrated Biological-Chemistry (IBC), which covers the first semester of introductory biology and introductory chemistry. Like AISS, the demand for IBC is greater than available seats. Finally, self reported data shows that as faculty are teaching in AISS or IB they are constantly being exposed to both new content and pedagogy, the upper division courses are becoming more interdisciplinary and successful pedagogical strategies are being used more frequently.

Overall, AISS has been popular with the students and satisfaction with this demanding program is extremely high. Most cohorts begin with a significant degree of tension since all students have been very successful high school students and the pace and demand of the course exceeds all other courses the students take. However, by the end of the program, most AISS students rate AISS as the best experiences of their first year in college. In addition, surveys of graduating AISS students show that they see AISS as a highlight of their college experience. For a significant percentage of students AISS was the course/program that influenced them the most while in college. [15]

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