Accelerated Integrated Science Sequence (AISS)

An Introductory Biology, Chemistry, and Physics Course

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The overarching purpose in developing the accelerated integrated science sequence (AISS) was to teach introductory science to potential science majors through an integrated approach that brings together the main elements of biology, chemistry, and physics in a comprehensive way. Students learn to think at the intersection of the three disciplines, which will better prepare them for the interdisciplinary nature of scientific research and the scientific workforce. The crucial points of connection during the course are a series of interdisciplinary laboratory assignments, in addition to integrated lectures and discussions. By introducing connections between the disciplines during the students' first year and demonstrating how chemistry and physics relate to biological studies, we hope to attract more of these students into either the physical sciences or interdisciplinary majors in our department.[1]

Interdisciplinary science courses have been offered at many different levels in the college curriculum at various institutions. For example, several colleges and universities have offered nonscience-major courses at the intersection of a variety of disciplines, including astronomy, biology, and geology *(1)*; biology, chemistry, environmental studies, mathematics, and physics *(2)*; and biology, chemistry, geosciences, and physics *(3)*. Instead of focusing on one discipline, students in interdisciplinary nonmajors courses are introduced to a wide breadth of scientific ideas, which enhances their scientific literacy across a range of disciplines.

Other integrated courses have focused on the science major. At the introductory level, students have taken the lecture sections of biology, chemistry, and physics separately, but have come together for a combined laboratory based on research being done at the college *(4)*. Other schools have combined biology and chemistry or biology, chemistry, computer science, and physics to serve as the gateway course for those majors *(5)*. Biology, chemistry, and physics have also been integrated with scientific teaching methods for those planning on teaching high school science *(6)*. Another introductory science course used water as its central theme as students learned the background chemistry, geology, environmental policy, and environmental science necessary for understanding water issues *(7)*. Cell biology and second-semester introductory chemistry have even been combined for the more advanced student *(8)*, while interdisciplinary capstone courses have been developed for third-year science majors *(9)*. These types of courses, whether for nonscience or science majors, help students to think "outside-the-box" and connect disciplines in ways not possible when they take each course separately and focus on each subject as its own entity.

Course Objectives and Structure

AISS is a year-long, honors-level introductory course[2] for first-year students[3] who are considering majoring in one of the natural sciences or in one of our interdisciplinary programs. The class meets five days for a total of twelve hours each week in a dedicated teaching laboratory. Lecture, laboratory, and discussion are integrated such that the group can move quickly and seamlessly from one activity to another. Course material is organized to promote the integration of biology, chemistry, and physics and is co-taught by a biologist, chemist, and physicist.

The basic structure of the course, from a chemical perspective, moves from small-scale atomic structure to larger-scale chemical reactions and interactions (Figure 1). At the beginning of the first semester, we introduce students to the fundamentals of mathematical modeling via Matlab. Although this portion is taught by a physicist, all the examples and case studies focus on biological, physiological, and ecological systems. We then discuss measurement process and error analysis. Unlike the statistical error analysis that is typically emphasized in introductory biology and chemistry courses (e.g., mean, standard deviation, etc.), a greater emphasis is placed on identification and analysis of systematic errors. Then the physicist introduces electric forces, fields, and energy with a particular emphasis on connections with chemistry. This leads into basic quantum mechanics, the hydrogen atom, the periodic table, molecules, and bonding. Once the students can draw Lewis dot structures and understand the basics of bonding, the biologist discusses macromolecules and biological membranes. We then cover thermodynamics from chemical, physical, and biological perspectives. When the students understand energy movement throughout systems, we are able to discuss chemical and physical equilibria.

The second semester starts with a unit on genetics followed by a section on nuclear chemistry and physics, with a discussion about the genetic impacts of radiation exposure. We then cover different types of chemical reactions, including acid–base, oxidation–reduction, buffers, and titrations. An in-depth study of electrical circuits follows that integrates well with electrochemistry and membrane potentials. Discussions of rotational dynamics and magnetic fields from the physical perspective allow us to cover the theory behind NMR with a laboratory focused on biological molecules. Waves and light tie in well with the spectroscopy that we cover throughout the year, and the topic of chemical kinetics leads directly into a discussion of protein and enzyme structure in biology. Finally, when fluid dynamics is covered from the physical perspective, the students study water quality through chemical analysis

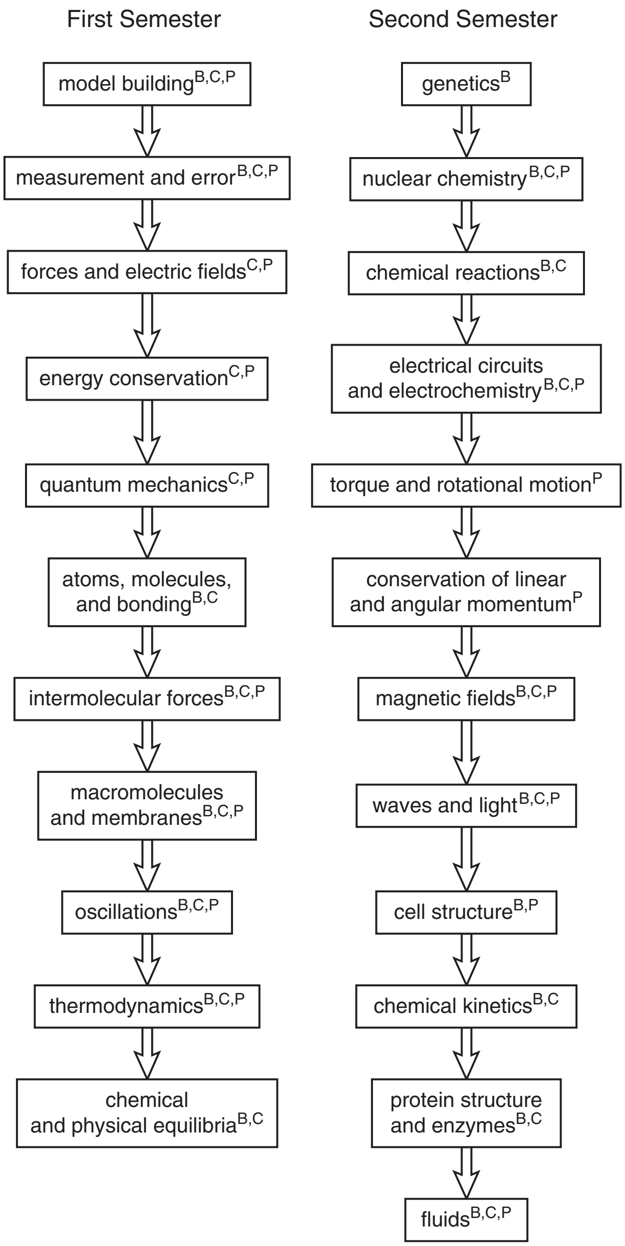

Figure 1. Schedule of main topics covered in the AISS course. The disciplines covered during the section are denoted (B = biology, C = chemistry, and P = physics).

and polymerase chain reaction (PCR) analysis of bacteria in the water. While the lecture and discussion topics are at times interdisciplinary and other times focused on one discipline, the integrated laboratories help the students to grasp the interconnectedness of the disciplines.

Integrated Topics and Laboratory Exercises

The material from many topics covered in introductory biology, chemistry, and physics is similar, such as thermodynamics, atomic structure, and nuclear chemistry. Such overlaps aided in saving time and condensing the course into a double course for two semesters. Other subjects of integration were not so obvious, but worked well in practice, such as connecting simple harmonic oscillations and resonance in physics to the discussion of climate change and Fourier transform infrared (FTIR) spectroscopy from chemical and biological perspectives. A sample of topics of integration is provided in Table 1. For example, to study water, students go to a local mountain stream and take water flow, nutrient, and chemical measurements. In the laboratory they analyze the samples for water hardness with potentiometric titrations and do a PCR analysis of the water samples to learn about the bacteria in the water. Another topic involves the study of action potential across crayfish muscle cell membranes. The students have already learned about building and using circuits, so they analyze a circuit model of the neuronal membrane. In the midst of this, we talk about electrochemical reactions and the Nernst equation.

One thread that helps tie the various elements of the course together is computer modeling. The course starts with a computer modeling section in which students learn how to develop models and program in Matlab. Initially, the students focus on biological systems, such as disease models and population dynamics. Matlab is used throughout the course, however, and is particularly useful from a chemical perspective for modeling chemical kinetics for different orders of reaction. The students also use the molecular modeling program Spartan to learn about atomic structure, bonding, and rotational dynamics of a more complex molecule. Finally, the students look at biological computer modeling by applying Matlab to population genetics, relating allele and genotype frequencies in a population, which leads them to examine the assumptions underlying the Hardy–Weinberg equation. Thinking about scientific principles from a theoretical standpoint is a useful tool when working on interdisciplinary projects.

Table 1. Sample of Integrated Topics in the AISS Course

Central Topic	Biology	Chemistry	Physics
Oscillations	Global warming	Greenhouse gases and climate change; Infrared spectroscopy	Simple harmonic oscillations; Resonance; Fourier transforms
Water	Water quality; PCR analysis of bacteria in water; Microbial growth from water	Environmental sample collection; Water hardness analysis; Potentiometric titration	Hydrodynamics
Membranes	Biological membranes; Action potential	Electrochemistry; Nernst equation	Circuits (e.g., capacitors, resistors, etc.); Circuit model of neuronal membrane
Computer Modeling	Population dynamics	Chemical kinetics	Model building; Computer programming

The integrated laboratories are a key component of the AISS course. Through these laboratories we connect theoretical physical principles to applications in biology and chemistry and vice versa (Table 2). Another goal throughout the course is to introduce students to a variety of chemical techniques for analyzing molecules. For example, FTIR is used to investigate structural differences in DNA double helices that can lead to significant differences in biological activity. Gas chromatography–mass spectrometry (GC–MS) analysis is used to demonstrate magnetic fields and physical forces *(10).* Another laboratory exercise focuses on biological membrane potentials in which students address the biology of biological membranes, the chemistry of the Nernst equation, and the physics of the circuit model of the neuronal membrane. The ability to see practical applications of theoretical principles is useful for the students.

The students were surveyed several times throughout the year and will be followed through graduation to ascertain whether the AISS course is providing a good foundation for their upper-division courses and whether we are attaining our goal of attracting more students to the physical sciences. When asked during a survey at the end of the year, "What have you enjoyed most about the course so far? Please be as specific as possible", the following responses with regards to the interdisciplinary nature of the course were given:

> I really enjoy when all three professors teach about one subject that spans over all the disciplines.
>
> The professors often have very interesting interdisciplinary examples that combine basic single discipline knowledge we've previously learned. For example, radioactivity combined genetics, biology, and physics and we learned about radioactivity from each discipline's perspective.
>
> I enjoy seeing how the different disciplines relate to each other and how similar they are.
>
> I really enjoyed the integrated aspect of the course. I am learning concepts with insights I would not have achieved had I taken the subjects separately (i.e., quantum–nuclear physics and chemistry).
>
> I love the interdisciplinary nature of the course. Switching between subjects helps me to see concepts from all angles and get a deep understanding of how the science and the math works.

Overall, almost 35% of the AISS students related what they have enjoyed most in the course to the interdisciplinary nature of the teaching.

Course Assessment

Preliminary results[4] suggest a slight percent increase in physical science majors (chemistry and physics) is achieved when compared to actual science graduates from the 2007–2008 academic year (Figure 2). There are a slightly lower percentage of AISS students planning to study interdisciplinary majors (biology–chemistry and neuroscience) and biology.[5] These data relate to AISS student opinions at the end of their first year, so more conclusive data will be collected once the students declare a major at the end of their second year and actually complete their major upon graduation.

Table 2. Sample of Integrated Chemistry Labs

Laboratory	Connection with Biology or Physics
Using Dynamic NMR and Spartan Modeling To Investigate the Rotational Barrier in *N,N*-DMA	Angular momentum; Magnetic fields; Computer modeling
FTIR Investigation of DNA Structure and Flexibility	DNA structure; FT calculations; Oscillations
Using GC–MS To Analyze Organic Compounds	Magnetic fields; Physical forces; Identifying isotopes

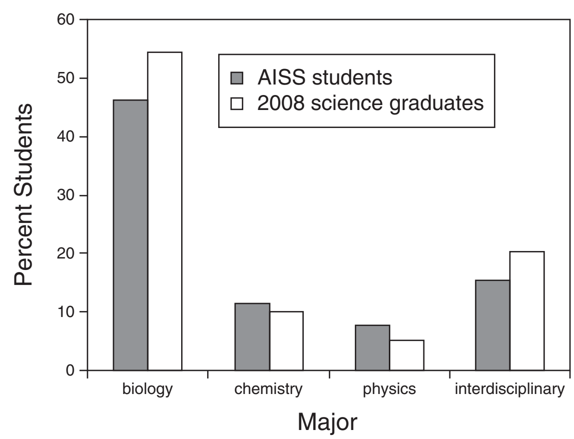

Figure 2. Comparison of potential AISS students' majors at the end of their first year compared with 2008 science graduates from the Joint Science Department.

Because of the accelerated nature of the course and inability to cover every topic covered in our typical introductory sequence, we were concerned that students would not feel as prepared as others to take upper-division courses. When asked about their confidence in understanding introductory science material the majority of the students either agreed or strongly agreed that they were ready for upper-division courses in biology (69.2%), chemistry (61.5%), and physics (84.6%). In addition, the majority of the students either agreed or agreed strongly that their laboratory experience (53.8%) and laboratory skills (53.8%) prepared them well for additional science courses they might take.

Towards the beginning of the second semester of their second year, the first cohort of students were surveyed about which science courses they were taking and their grades from the first semester in their second year, in addition to how well AISS prepared them for these courses. The students were enrolled in a broad range of upper-division courses, including organic chemistry, physical chemistry (thermodynamics), modern physics, and evolution. The mean course grade was in the A/B range, suggesting that AISS prepared them for success in these upper-division courses. Of the AISS students surveyed during the first semester of their second year, 73% of them were currently enrolled in organic chemistry and 13% in physical chemistry (thermodynamics). When asked how well AISS had prepared them for these courses, 13% said they were somewhat prepared for both organic and physical chemistry, while 60% said they were well prepared for organic chemistry. The remaining students were not enrolled in chemistry at the time. With regard to organic laboratory, 40% felt somewhat prepared while 33% felt well prepared. None of the students felt poorly prepared for their upper-division science courses. The results for the second-year second-semester survey were similar to the results obtained from the students at the end of their first-year second semester. Students will be followed throughout their college career to determine how well prepared they feel for additional upper-division courses.

One final indicator of the ability to attract AISS students into science majors is student demand for summer research opportunities. The number of AISS students participating in interdisciplinary scientific summer research after their first year also indicates that the students are serious about becoming science majors. Nearly 40% of the AISS students in the first cohort and 30% in the second applied for and received funding to do interdisciplinary summer research projects in our department. Only 1 or 2 first-year students in the past have done this, which is less than 1% of students in our introductory science courses. This dramatic increase in first-year student participation in extracurricular research constitutes one of the notable impacts of the AISS program.

Expansion of AISS

We would like to open the class to a broader range of students, especially to those students who are interested in majoring in science, but who might have a weaker math background than our original cohorts. Because the accelerated nature of the class might be difficult for these students, alternative course designs such as a combined introductory biology–chemistry or chemistry–physics could potentially prove more suitable. Students would still benefit from the interdisciplinary nature of the subject material, but have more time to cover the mathematical concepts necessary to prepare them for upper-division courses.

Other significant barriers to expanding the course are the faculty-intensive nature of the course and space and equipment constraints. The course is currently time intensive for the faculty involved as all three faculty are present in the classroom at all times to encourage cross-disciplinary interactions. As course organization progresses, however, it may be possible to develop modules for AISS so that all faculty do not have to be present at all times. If one faculty member could teach the same module multiple times during the semester, then a larger cohort of students could be taught in the course. The key is to continue to introduce the topics in an interdisciplinary way so as to not lose that aspect of the course. In our department, space and equipment also restrict course growth. For example, for the chemistry laboratory portion of the course, we share laboratory space and equipment with our traditional general chemistry program. General chemistry labs run every afternoon and some evenings, so AISS is restricted to meeting in the mornings. We only have equipment and space for 30 students, so by doubling the laboratory supplies and with another chemistry laboratory, we could offer two sections of the course.

The AISS course design, with appropriate modifications in place, could potentially be implemented into other colleges and universities. For many liberal arts college science programs, one central (albeit nonstructural) challenge would be overcoming traditional disciplinary boundaries that often separate biology, chemistry, and physics departments. Large, public universities face a similar activation barrier, compounded by the issue of having to educating a large number of students in the introductory science courses. However, many universities have honors programs, and an AISS-type course could first be introduced into this setting. In a large university, laboratory and equipment availability may be less of an issue than it is in smaller institutions, and enrollment in the course may not be limited by those factors. Graduate teaching assistants or post-doctoral fellows could also help facilitate the course. Lastly, the issue of addressing the needs of mathematically less well-prepared students is not trivial. However, an AISS-type course with its frequent use of and emphasis on applications of mathematics to science could potentially serve as a vehicle for teaching mathematical concepts in a hands-on manner via scientific inquiry as a supplement to traditional mathematics courses. As an alternative, interdisciplinary biology–chemistry or chemistry–physics courses could be offered, as we plan to do with our students who have not previously had calculus.

Conclusions

The AISS course was run successfully as a pilot program during the 2007–2008 school year and is currently being repeated again during the 2008–2009 school year. During the first semester of the first year we had 29 students and 26 students continued with the second semester (90% retention rate) while in the second cohort, 27 students started the course and 25 continued in the second semester (93% retention rate). Overall, the initial offering of the AISS course was successful. The students learned to think at the intersections of the disciplines and novel interdisciplinary labs were developed that are actually being implemented into the traditional chemistry curriculum this year. There was a small percentage increase in the number of physical science majors, although we will have to address the downturn in interdisciplinary majors. In addition, the students felt prepared for both the lecture and laboratory material in upper-division courses and almost 40% of the AISS students from the first cohort completed an interdisciplinary summer research project in our department.

Acknowledgments

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Notes

1. The Joint Science Department encompasses the biology, chemistry, and physics programs for three of the Claremont Colleges (Claremont McKenna, Pitzer, and Scripps Colleges) and shares one building. Though a majority of the majors in Joint Science are related to biology (biology, environmental science, molecular biology, or organismal biology and ecology), we have had significant success with interdisciplinary majors, such as biology–chemistry and neuroscience.

2. AISS is designed as a two-semester sequence with each semester serving as a double course to replace in the student's standard science courses: two semesters each of introductory biology, general chemistry, and introductory physics. AISS compresses six semesters of class into the equivalent of four semesters.

3. The students chosen for our first cohort had broad, interdisciplinary scientific interests and strong math backgrounds. We were only able to offer admission to about half of the applicants who applied to take the course. In the future we plan to open the course up to a larger student pool.

4. Evaluation of the AISS course was done by two experts in educational assessment: the two co-authors from the Claremont Graduate University.

5. Biology includes the molecular biology, environmental science, human biology, and organismal biology majors.

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