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Honors Analytics: Science, An Interdisciplinary Lab-Based Course on Visual Perception

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INTRODUCTION

Interdisciplinarity has consistently been a hallmark of honors courses, particularly in the arts, humanities, and social sciences. Such an approach has been less universal in honors courses in the natural sciences, particularly in laboratory-based courses (Ramaley). We believe that a mark of success of any such course is the degree to which it moves from multidisciplinary to interdisciplinary. Moreover, if the course fulfills a general education requirement in science, it needs to include exposure to the scope of scientific investigation, the techniques of science, and the nature of the scientific process. At Belmont University, we created and for ten years offered Honors Analytics: Science as part of an interdisciplinary, alternative general education curriculum for students in the honors program. This four-credit-hour science course, which had no math or science prerequisites, included a two-hour lab component and serves as the only science course in the curriculum. Students in all majors took the course, even science majors, typically in their junior year. While practical impediments arose after ten years that precluded our continuing to teach the course, it had been a highly successful solution to the challenge of offering interdisciplinary science courses in honors. We provide an account of the course here as a potential model for other honors programs.

Honors courses at Belmont for a long time used a "professor pool" model, in which a faculty member coordinated a course and was allotted a budget to bring in faculty with expertise in other areas. In the Analytics courses, the coordinator was initially a mathematician who also had a background in physics. At a later date the coordination was assigned to a biologist who had an undergraduate major in chemistry. Later yet, a psychologist became the coordinator. As a result, we can provide disciplinary perspectives on the content and pedagogy of the course, including laboratory exercises, along with our collective views on the practical details of the model, the strengths of the approaches we employed, shortcomings we perceived, and suggestions for how the course could be improved by other institutions.

PEDAGOGICAL AND ADMINISTRATIVE CONSIDERATIONS

The faculty member who was the course coordinator received full teaching credit for the course, and the other faculty members received stipends for each lecture or lab period they led. The coordinator was present for all lectures and coordinated all payroll requests, examinations, grade submissions, and attendance records. Each instructor contributed questions to the midterm and final exams about the material they had discussed to that point in the course. The same four science faculty taught the course for the ten years it was offered.

We used several techniques to maximize the interdisciplinarity of the course: (1) the coordinator position was rotated among faculty, ensuring that each faculty member experienced as much of the course as possible; (2) all faculty were present during several class discussions, for example on the importance of models in science; (3) all faculty read and approved exam questions before they were given, and in some years all faculty graded all questions. In addition, since Belmont strongly emphasizes undergraduate research in science, we typically required that all students complete a research project, and the best ones were presented in the Belmont Undergraduate Research Symposium.

SETTING THE STAGE FOR INTERDISCIPLINARITY

Some of the most challenging problems and most profound advances in science today are interdisciplinary in nature. In promoting an interdisciplinary frame of mind, our course objective was to move beyond either an overview or a simple series of brief introductions to several disciplines in order to show underlying connections as well as distinctions among the sciences. During the first class period, we immediately began to challenge the students to think about the natures of the different scientific disciplines: What are the differences in the tools these scientists use and why? What kinds of questions do they ask? What are some of the great problems and concepts they have considered? What is gained by approaching scientific questions in a discipline-specific way? What can be gained by collaboration among the disciplines? Our semester together would be devoted to exploring these and related issues by focusing our attention on the study of visual perception.

One of the great, scientifically influential problems is the mind-body problem. Descartes and subsequent philosophers profoundly influenced the scientific approach to understanding the concept of perception. The philosophical framework for our study of visual perception was laid during four class periods of readings about the mind-body problem and lively discussions of the problem led by a guest teacher with a background in the philosophy of science. With this historical background, we turned our attention to the current scientific understanding of visual perception.

PHYSICS

The physics portion of the course explored the physical properties of light, including how light is produced, how light interacts with light, how it interacts with matter, how it can carry energy and information, and how these properties affect visual perception. The first laboratory experiment used the ripple tank as a medium for the study of the easily observable properties of waves: reflection, refraction, diffraction, resonance, and absorption. Students observed how these properties were affected by changes in frequency or wavelength. Using various shapes of wave fronts, reflectors, and lenses, we demonstrated how waves can be focused or dispersed. Students drew wave superposition diagrams to help them appreciate the phenomena they had observed.

Lectures and demonstrations showed how these wave properties are evident in sound and light and how waves exhibit these properties in other types of media. We demonstrated resonance, the production of standing wave patterns by reflection, with sound wave generators and speakers, and also the students produced it with springs and ropes. We discussed electromagnetic radiation, which includes visible light, its generation, and propagation. We presented special interrelationships among light, energy, and the structural properties of atoms. We examined the electromagnetic spectrum to help students see the relationship between visible light and other electromagnetic phenomena such as x-rays and radio waves, each related to the structural/energy properties of the atom from which they are produced.

We explored a simple particle-spring model of matter to help students hypothesize how waves of various wavelengths might interact with such matter. The questions we posed included: Under what conditions of wavelength and particle spacing is the wave energy most likely to be absorbed by the matter? What circumstances will cause the waves to reflect off the matter? What conditions will cause the waves to pass through the matter but be refracted or bent? A key consideration was helping students understand the nature of color and how the perception of color is related to the wave properties of light and the reflective/absorptive properties of matter. We explored the question of whether a wave model or a particle (photon) model of light best contributes to our understanding of visible light and how each model provides important insights.

A lab experiment on light and lenses, which required students to produce images of a light source with different lenses and to draw the corresponding image diagrams, helped them discover the key principles of image production by lenses. This experiment provided information about the law of refraction and how it is the basis for understanding the lens mechanism the eye uses to focus light and, thereby, to form images on the retina.

Laboratory experiments were assigned in written form with specific instructions on how to perform the experiment, what data to collect, and what observations to make. The instructions included questions to challenge deeper thought. Students typically worked in pairs to complete the laboratory experiments. Each lab team prepared a written report on their lab experiment. We assigned occasional problem sets or readings as well.

BIOLOGY

Following the portion on physics, the biology emphasis started with lectures on the nature of chemical bonds and the structure of water, which served as an introduction to the structure and function of proteins with an emphasis on enzymes. The logical move to the structure of phospholipids and the cell membrane as an aggregate of phospholipids and proteins served as a transition to cellular organelles. As a background to neuronal cell function, the next topic was how ions and molecules get into and out of cells, including the importance of the phospholipid bilayer and membrane proteins being explained, as demonstrated in a laboratory investigation of diffusion of molecules and ions and the diffusion of water (osmosis).

We then employed the transport abilities of the cell membrane to explain the structure of the neuron and its ability to generate action potentials, followed by examination of the transmission of neuronal signals across synapses and how these can modify the actions of the next neuron for either excitation or inhibition. Using only the concepts learned to date, the following lecture described the memory network that modifies the gill-withdrawal reflex in sea slugs as an example of how neurons connect to form biologically meaningful function.

Moving from the cellular to the organismic level, the class reviewed the anatomy and overall physiology of the human nervous system and studied the action of reflex arcs. Laboratory investigation of the properties of sensory physiology (touch receptor fields, retinal receptor density, topography of the retina) allowed the students hands-on experience with calculations that revealed the properties of sensory receptors. We then transitioned to look specifically at the anatomy of the human eye, including refraction by the cornea and the lens, and investigated how it transduced the wavelengths of light, which had been introduced in the physics portion, into receptor potentials within the retina. Their laboratory dissection of a cow's eye energized the classroom discussion of eye anatomy for the students. A lecture on the retina followed, explaining the networks within the retina that result in action potentials that travel to the brain. The remaining class discussions focused on the various functional lobes of the brain, the pathways taken by visual impulses as they pass through some of those lobes, and then a final discussion of how networks could be envisioned to accomplish certain kinds of movement. Two quizzes and a problem set on neural circuits provided an assessment of student understanding throughout the biology portion of the course.

PSYCHOLOGY

The psychology portion of the class built on the coverage of light in the physics section and the physiological explanation of the stimulation of the visual nervous system. Since most of the students had never taken a psychology course, the first lectures covered an overview of the history of psychology with an emphasis on the scientific nature of early psychology. The next classes covered the classical psychophysical methods for studying vision and a brief conceptual overview of modern stimulus detection theory. Other classes devoted time to: divided and selective attention, theories of attention, and views of automatic and controlled information processing; the binding problem, how it relates to the mind/body issue, and the re-emergence of the study of consciousness; pattern perception, contrasting the historical Gestalt approach to pattern perception with the newer Multiple Spatial Channels Theory approach; the use of Fourier analysis and contrast sensitivity to illustrate how complex images can be converted to simpler images, including how this can be a model for human visual pattern perception; and a number of classic and more contemporary illusions. The last major topic presented was depth perception. After presenting the classic monocular or pictorial depth cues, we explored oculomotor and binocular cues for depth. Students spent time viewing stereoscopes, analygraphs, and stereograms as well as depth illusions.

The three labs for this portion of the course consisted of computer simulations from Colin Ryan's *Exploring Perception: A CD-ROM for Macintosh and Microsoft Windows*, consisting of a CD ROM with 240 separate explorations of sensation and perception topics. The first lab explored psychophysics, with activities and questions about classical methods such as the method of limits and the just-noticeable difference as well as more modern stimulus detection procedures. The second lab included simulations of various Gestalt concepts such as laws of proximity and similarity. This lab also covered gratings and spatial frequency as well as classical illusions such as the Ponzo illusion. The third lab presented illustration of various monocular depth cues, such as interposition and shading, as well as binocular disparity and motion parallax.

COMPUTER SCIENCE

The computer science portion of the course examined the connectionist model of visual recognition and memory (e.g., Müller and Reinhardt). The first lecture introduced a simple computational model of a neuron and explained how two layers of such neurons, i.e., a *simple perceptron*, could perform recognition tasks. A lab exercise used an ordinary computer spreadsheet to implement a perceptron, and students trained their perceptrons to recognize shapes in a grid. Homework exercises, which could be done without computer assistance, reinforced and expanded on the lessons of the first lab.

The next two lectures built on this foundation by posing the exclusive-or (XOR) Problem, a discrimination task that is easy for human beings but impossible to solve with a simple perceptron. We showed that a network of perceptron layers, each feeding forward into the next, could solve the XOR problem; we went on to describe the construction and operation of multi-layer perceptrons and the supervised learning process used to train them; and we advanced the argument that, given enough neurons, layers, and training, a multi-layer neural network is capable of any instantaneous recognition task that human beings can perform. Homework exercises reinforced the lessons in construction and training, and the second lab exercise (with a somewhat larger spreadsheet) demonstrated the enhanced recognition capabilities of multi-layer perceptrons; it also demonstrated the large numbers of connections and training repetitions needed to perform such simple tasks as counting and letter recognition. Training a multi-layer network is like teaching with flashcards or other rote techniques, a similarity not lost on students during the tedious last stages of their lab exercises.

The next lectures presented the problem of unsupervised learning and memory. Having shown that feed-forward networks could only perform tasks they were repetitively trained to do, we then introduced the principles of the Hopfield network, a simple model of memory that allows unsupervised learning. Again, homework exercises reinforced the basic capabilities of Hopfield networks, and a spreadsheet-based exercise explored the potential and pitfalls of a moderately complex Hopfield network.

The lectures, homework, and labs illustrated how the anatomical features of the brain, already described in the biology section of the course, could produce visual recognition and memory. The final computer science lecture compared parts of the eye, the optic nerve, and the visual cortex to the models we had developed and argued that the randomness inherent in biological networks, combined with the massive connectivity of the neural networks in living brains, would allow brains to perform these tasks better than electronic computers. Grades for the computer science portion were based on homework problems completed individually and lab reports completed in groups of two or three.

COURSE WRAP-UP

The last four or five classes in the course were devoted to retrospection. The guest philosopher led the first two sessions with the other faculty members present to participate in the discussion, thus providing students an opportunity to reconsider the mind-body problem, how it affected their study of visual perception, and how their views and attitudes about the mind-body might have changed as a result of the semester's study. The last two or three classes were open forums with all faculty members present, giving students an opportunity to raise any questions about the course and giving faculty members an opportunity to offer suggestions about important conceptual threads that ran through the course or their disciplinary perspectives on scientific inquiry. Students were required to write evaluations of the course, which were used as a part of the planning process for the next semester. Individual instructors drafted the final exam questions and distributed them to all the instructors for consensus on the pooled final exam. The six to eight questions were open-ended, and the final was a take-home examination to be completed individually.

RETROSPECTIVE

We feel that the course as we offered it had several strengths, especially its interdisciplinarity: the principles of the wave nature of light presented in physics were employed in the concept of pigment absorption by rods and cones in biology; the concepts of excitatory and inhibitory synapses from biology were used to explain lateral inhibition in psychology; and the networks in sea slug memory explained by the biologist laid the foundation for the concept of neural networks explained by the computer scientist. Students indicated in their end-of-semester evaluations that they grasped the nature of these concepts as explained and employed in different disciplines.

The "professor pool" model also seemed to work well. Students came to understand how individual faculty members, as representatives of their disciplines, would respond to their queries. They also began to understand us as professionals, how we viewed scientific questions, how we individually viewed our common enterprise, and what they each expected of us. At the same time, the presence of a coordinator served as a unifying element in the various panel discussions, exams, projects, and student evaluations. Another design principle that helped this course was that it was junior-level; the students who were in the class really wanted to be in honors and were willing to do the work.

What was difficult in the implementation of this class was the heavy teaching load for the non-coordinator faculty members during their presentation portions, when they were in essence teaching a four-credit-hour overload. As hard as it was to teach our portions as overloads, however, we would have been pleased to continue the course. What resulted in discontinuing the course was a largely insurmountable obstacle: the rapid growth of the university led the honors program and university administration to triple the number of students in the program, resulting in three Honors Analytics sections per year. This increase made the overload demands unmanageable for our small pool of Analytics faculty members. In addition, one of the faculty members involved in the course was moved partially into administration. We thus reluctantly decided to move from the interdisciplinary format of the Visual Perception course to a new format in which different Analytics sections were taught by individual faculty members from different disciplines.

The format of this course could nevertheless be implemented at other institutions under any of the following conditions: (1) the number of students is similar to ours, i.e., a single section of ten to fifteen students, and a budget is provided for a professor pool; (2) a particular faculty member is, by interdisciplinary expertise, able to serve as coordinator as well as cover two or three course sections; or (3) the same group of faculty (four in our case) is responsible for two or more class sections—e.g., HON 332.01, HON 332.02, etc.—and the guest faculty are given teaching load credit for their contributions such that, for instance, teaching a quarter of three different sections counted as three credit hours of a teaching load.

Teaching this course was a wonderful experience for all of us and for the honors students. The small class size combined with five contact hours per week made for excellent relationships with talented students. The ability to plan coverage, discuss new ideas, and review the implementation with faculty dedicated to the students and to science provided a stimulating experience that combined the best of pedagogical creativity with the opportunity to become students ourselves.

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