Expanding course goals beyond disciplinary boundaries: physiology education in an undergraduate course on psychoactive drugs

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Near JA, Martin BJ. Expanding course goals beyond disciplinary boundaries: physiology education in an undergraduate course on psychoactive drugs. Adv Physiol Educ 31: 161–166, 2007; doi: 10.1152/advan.00058.2005.—The topic of psychoactive drugs is one of inherent interest to college students. We used this insight to design and implement a multidisciplinary undergraduate course with psychoactive drugs as the central theme. The Medical Science of Psychoactive Drugs examines the biological mechanisms underlying all major effects of psychoactive drugs, including the effects on the brain and other organs and tissues. Physiological principles, molecular mechanisms, and genetic factors involved in drug-induced therapeutic and adverse effects are emphasized. The course is open to undergraduate students at all levels and carries no prerequisites, and enrollment is limited to ~50 students. Major teaching modes include lecture, short homework papers on topics related to the previous class meeting, small-group discussions at several points during each class, and whole class discussions. Because of the diversity of students’ knowledge of basic science, we employ a variety of methods designed to help students grasp the necessary scientific concepts. Our methods are intended to be inquiry based and highly interactive. Our goals are 1) to foster the development of an organized knowledge base about psychoactive drugs that will have practical applicability in the daily lives of the students; 2) to promote the rational application of this knowledge in thinking about current medical, social, legal, and ethical issues involving psychoactive drugs; and 3) to cultivate science literacy, critical thinking, and communication skills among students.

undergraduate physiology; undergraduate pharmacology

Dewey (10) wrote that “All genuine education terminates in discipline, but it proceeds by engaging the mind in activities worthwhile for its own sake.” Education in physiology is clearly an essential part of instruction for the health care and medical professional. However, the role of discipline-specific physiology courses in liberal arts education and in the broad undergraduate training of future biological scientists is less well defined (13, 22, 28). In these settings, it has recently been argued that educational modules that transcend disciplinary boundaries and integrate physiological principles into a broader, multidisciplinary setting provide unique educational advantages (13, 22, 28). Courses designed with this expansive goal allow the physiologist to contribute a unique perspective to the broad medical science of psychoactive drugs. We chose this topic because it provides a central theme of abiding curiosity to undergraduates of various ages and interests. Indeed, we have found in the steadfast interest of our students confirmation of the following statement by Dr. Louis Silverstein (27), a member of the Department of Liberal Education at Columbia College in Chicago, IL: “mention drugs and you have a subject that affects and concerns students in most profound ways, and that they most earnestly desire to know about in an intellectually honest way—the truth in its entirety. For our institutions of higher education to ignore and/or deny the reality and necessity of such inquiry is shameful and destructive of both the scholarly tradition and free speech as well as being harmful to the best interests of our youth.” It is deeply satisfying to the student and the teacher to tap into this wellspring of student curiosity by examining the actions of psychoactive drugs, their underlying mechanisms, and the implications of these that extend far beyond the physiological, pharmacological, or medical. Our multidisciplinary approach allows physiological principles to be interwoven with those from pharmacology, genetics, and chemistry and also those from psychology, sociology, ethics, and law. In this way, students come to understand how physiological principles play out in their full biological and social context.

The personal, social, and economic costs of drug abuse can hardly be overstated. For example, it is estimated that roughly a third of all hospital beds not devoted to maternity or intensive care in the United States are occupied by persons being treated for complications of alcohol problems (7). Furthermore, the economic costs of alcohol, nicotine, and other substance abuse were estimated to be $176, $137, and $114 billion dollars, respectively, in 1995 (24). These totals are comparable with the economic costs of diabetes (7) and coronary heart disease (2). Although the effectiveness of drug education in reducing drug abuse is controversial, attempts to reduce the likelihood of drug abuse through the use of nontraditional educational methods may have a significant positive impact (5, 25). At least one previous study (26) has shown that objectivity and a nonjudgmental attitude on the part of instructors may be important aspects with regard to success of the course and positive outcomes with regard to change in student attitudes toward drug abuse. Furthermore, in one study (30) of a drug education project, strong positive effects were observed only in a “highly interactive” version where communication among students and instructors was an integral part of the design, suggesting that learning modes involving improvement of communication skills, peer learning, and group discussion may have an important impact on the student beyond the learning of scientific facts and principles.

In addition to obvious epidemiological and economic reasons, it is clear that improving education in the medical science of psychoactive drugs is a goal for more than physicians and...
health care workers. For example, the Medical Society of the State of New York officially “supports prevention policies and programs that include . . . adequate professional education about alcohol and drug problems in all programs which prepare students for careers in health, human services, teaching, the clergy, police, public administration and law” (19).

Our educational goals are 1) to foster the development of an organized knowledge base about psychoactive drugs and about the principles of pharmacology and physiology that will have practical applicability in the daily lives of the students; 2) to promote the rational application of this knowledge in thinking about current medical, social, legal, and ethical issues involving psychoactive drugs; and 3) to cultivate general science literacy, critical thinking, and communication skills among the students. In this report, we describe the methods and content employed in the design of a highly interactive multidisciplinary course on the medical science of psychoactive drugs to achieve these goals.

METHODS

Course structure. The Medical Science of Psychoactive Drugs is an examination of the biological mechanisms underlying the pharmacological, physiological, and pathological effects of psychoactive drugs, including the effects on the brain and other organs and tissues. The course is open to undergraduate students at any level and carries no prerequisites, and enrollment is limited to ~50 students. Students exhibit a very wide range of backgrounds, from fourth-year chemistry, biology, and biochemistry majors to first-semester students intending to major in the humanities or business. As a new course, it currently can be used as a science elective by students in nursing or exercise science, but it is not yet a required course for any major or professional program, nor is it yet able to serve as a science elective for biology or psychology majors. The class meets twice a week for 75 min. The two instructors, a pharmacologist and a physiologist, attend and participate in all class meetings. Major teaching modes include lecture, short homework papers on an assigned topic related to the previous class meeting, small-group discussions at several points during lectures, and whole class discussions. Grades are assigned on the basis of class attendance, completion of homework assignments, self-assessment of class participation, and four objective examinations. After the basic science is evaluated, students are encouraged by a variety of means to discover and discuss the various psychological, sociological, economic, and legal ramifications that result from the basic properties of the drug. Students are then asked to reflect upon and articulate their attitudes and values as they relate to these considerations.

Homework is due at the beginning of each class meeting (21, 29). Students are told to explain a specific topic to a friend, roommate, or relative and to write a one-page description of the exercise. Teaching material to another helps consolidate learning, encourages students to keep up with the material, and allows students to work at an individually suitable level of complexity of the material (4). By reading daily homework, instructors are able to monitor the progress of each student as well as of the class as a whole. Although we have not analyzed the homework quantitatively, we are convinced that structuring the assignments as student descriptions of their own explanations minimizes plagiarism (4).

Students take a two-question quiz at the beginning of each class and are awarded points each time they appear in class on time (17). Students also award themselves points on the basis of their own evaluation of their participation in class and team discussions. This is designed to promote engagement with the class, motivate students to keep up with the material on a daily basis, and encourage them to arrive in class on time (8).

At various points during each class, students are directed to discuss specific topics with their assigned partner. Partners are reassigned every two to four classes. Individual students who are having problems with the course material may be paired with more knowledgeable students or with the instructor not lecturing during that section of the course. Partners may also be assigned for particular class blocks on the basis of major and/or year to facilitate peer learning. Discussion topics are phrased as a question or series of questions and are designed to help students use their existing knowledge to reach new insights or to apply information from the lecture in a new way. Often, they are based on a short newspaper account, summary of a research article, proposed legislation or constitutional amendment, or a magazine editorial. We have found that the more advanced science students in the class are a valuable resource to less advanced students during the small-group discussion because they often clarify and emphasize a basic concept presented only moments before by the instructor in lecture. Likewise, the diversity of student’s academic interests and goals often adds a new dimension to the discussion for science majors, who gain insight into the social, medical, legal, and moral implications of drug effects from other students pursuing other career goals (1, 20, 32).

Course content. The course is organized to sequentially cover each of the classes of psychoactive drugs (Table 1). This structure derives in part from our choice of textbook for the course (15). For each class of drugs, initial lectures and discussions focus on factual materials and central scientific concepts. These readily lead to consideration of a broad spectrum of issues and complex medical, genetic, social, ethical, and legal situations.

The course is arranged to initially provide basic information regarding drug absorption, distribution, metabolism, and excretion-
pharmacokinetics. This treatment necessarily involves handling the topic of drug routes of administration and is entirely dependent on grasping a number of physiological concepts (Tables 1 and 2). Pharmacokinetics leads to pharmacodynamics and an exploration of how neurotransmitters and portions of the brain mediate drug effects; this area as well depends in part on physiological principles (Tables 1 and 2). After an explanation as to how neurons and neurotransmitters are involved in the central psychoactive actions of drugs, the course moves to a drug-by-drug format. Although we have chosen a drug-by-drug sequence that corresponds to a standard textbook, drugs could also be treated in a sequence that focuses in separate discussions on therapeutic and nontherapeutic agents.

For each drug class considered, complex cause-effect relationships can best be examined using the perspectives of several disciplines. These relationships are illustrated by a concept map for the nicotine section of the course (Fig. 1). The discussion of nicotine begins with its effects on acetylcholine receptors in the brain. A first topic is the link between these central receptors and dopamine release in the nucleus accumbens and the accompanying reward, receptor down-regulation, and eventual addiction. These same acetylcholine binding characteristics are then also described in skeletal muscle, and the effects of their binding on tonic muscle activity in smokers. Of course, addiction to nicotine results in chronic exposure of the lung to tar and the many carcinogens inevitably found in burning organic matter. From that point, it is an immediate step to consideration of the pathophysiology of emphysema and the basic biology of lung cancer. Group discussion then centers on analysis of the genetic factors that contribute to nicotine addiction potential, susceptibility to toxic effects of cigarette smoke, the history and current legal status of nicotine in the United States and worldwide, the sociological factors that contribute to risk of smoking initiation, and the mechanisms underlying antidepressant and nicotine replacement treatment for nicotine addiction. Some of the more peripheral topics that are discussed in recent offerings of the course were included because of a question or set of questions asked by a student. This continuous evolution of a portion of the course content is likely to keep the contextual topics that confer personal meaning of the material to the student in tune with the general interests of the student population. While we continue to concentrate on the physiological underpinnings of the pharmacology, the stories we tell about how these affect us and our society as well as the debates we have about those effects change with student interests. The theme is nicotine, the approach is integrative, and physiology plays a central role.

RESULTS

Evaluations of the course. Through five semesters, the course has been well received by students (Table 3). Instructor evaluations are consistently among the highest in the department (data not shown). Although it is unknown how these course evaluations are affected by content, characteristics of the instructors, the small class enrollment of 50 students, or teaching style, they may well reflect the fact that the course content is of great inherent interest to the students (27).

DISCUSSION

Interdisciplinary nature of the course. Students learn more and are more engaged when material is presented in a context that is relevant to their daily lives and when they are encouraged to recognize the relationships between the current learning experience and others they have had, both formal and informal (16, 23). The use of specific drug classes as the focus of discussion leads inevitably to consideration of a very broad spectrum of relevant disciplines and how they contribute to physiology plays a central role.

Table 2. Physiological and pathophysiological concepts addressed in the coverage of psychoactive drug actions

<table>
<thead>
<tr>
<th>Drug or Drug Concept</th>
<th>Physiological and Pathophysiological Concepts</th>
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<tbody>
<tr>
<td>Routes of drug administration</td>
<td>Body fluid compartments and drug distribution; pulmonary blood flow; nasal, oral, and rectal mucosal blood flow; intramuscular blood flow; blood-brain barrier; control of gastric emptying and intestinal absorption; venous and arterial pressure; circulatory transit time</td>
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<tr>
<td>Hepatic first-pass metabolism</td>
<td>Liver function; portal circulation</td>
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<tr>
<td>Alcohol metabolism</td>
<td>Mechanism of alcohol flush reaction; vasodilation; blood pressure regulation; skin blood flow</td>
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<tr>
<td>Alcoholic liver disease</td>
<td>Consequences of portal hypertension: ascites, esophageal varices, and gastrointestinal bleeding; consequences of cirrhosis and liver failure</td>
</tr>
<tr>
<td>Alcoholic pancreatitis</td>
<td>Function of exocrine pancreas; mechanism for stagnation of exocrine pancreatic secretion</td>
</tr>
<tr>
<td>Alcoholism-induced vitamin deficiencies</td>
<td>Functions of various vitamins, including thiamine, vitamin A, etc.</td>
</tr>
<tr>
<td>Fetal alcohol syndrome</td>
<td>Uterine blood flow; placental function; placental barrier</td>
</tr>
<tr>
<td>Alcohol as a central nervous system depressant</td>
<td>Medullary respiratory and cardiovascular central function</td>
</tr>
<tr>
<td>Volatile inhalants</td>
<td>Ambient, alveolar, and arterial Po2; hypoxia; ventilation and rebreathing</td>
</tr>
<tr>
<td>Benzodiazepines and selective benzodiazepine receptor agonists</td>
<td>Function of and control of sleep</td>
</tr>
<tr>
<td>Antianxiety drugs</td>
<td>Afferent and efferent limbs of the stress response; sympathetic nervous system control and effects; hypothalamic-pituitary-adrenal axis; effects of cortisol</td>
</tr>
<tr>
<td>Antidepressants</td>
<td>Regulation and dysregulation of appetite and sleep; physiology and pathophysiology of the sexual response</td>
</tr>
<tr>
<td>Antipsychotic drugs</td>
<td>Motor control: higher and low motor nerves and basal ganglia</td>
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<tr>
<td>Opioids</td>
<td>Peripheral and integrated central pain reception; regulation of intestinal secretion and motility and mechanism of antidiarrheal agents; brain stem respiratory control</td>
</tr>
<tr>
<td>Marijuana and synthetic cannabinoids</td>
<td>Function of central and peripheral cannabinoid receptors: modulation of pain, appetite, nausea, and immune function</td>
</tr>
<tr>
<td>Hallucinogens</td>
<td>Central gating of sensory information</td>
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<tr>
<td>MDMA</td>
<td>Control of metabolic rate; temperature regulation and mechanisms of hyperthermia</td>
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<tr>
<td>Amphetamines and related stimulants</td>
<td>Sympathetic nervous system function; control of blood pressure and heart rate</td>
</tr>
<tr>
<td>Nicotine</td>
<td>Central and peripheral nicotinic acetylcholine receptors; pulmonary function and mechanics; consequences of changes in lung compliance: emphysema, hypoxia, hyperventilation, and respiratory failure; hemoglobin and carboxyhemoglobin; elastin and elastase function; mechanisms of carcinogenesis</td>
</tr>
</tbody>
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understanding complex real-world situations. A very large number of topics in physiology and pathophysiology play a pivotal role in understanding the medical aspects of psychoactive drugs, but many other disciplines are also involved (Fig. 1).

**The pivotal role of physiology content in the course.** Understanding the physiological mechanisms of normal function and drug action is central to almost all important aspects of course content. The major physiological concepts considered in our course are presented in Table 2. Physiological principles and concepts appear abundantly and involve all systems, including renal, cardiovascular, endocrine, respiratory, muscle, and neural systems. Simply considering drug side effects, in addition to primary psychoactive effects, allows access to almost every organ system and process. It is our experience that students appreciate the drug-by-drug approach, in which all things relating to the current drug are brought into play when needed, rather than an organ- or systems-driven approach, which is appropriate in a focused physiology course but is, in our view, out of place in this interdisciplinary setting. Considering that the typical student’s initial approach to information about drugs is holistic and self-centered rather than discipline driven, it is logical to start considering very general questions and then turn to disciplinary material for answers. Students learn more, retain it longer, and integrate it better when material is presented in a context in which it has personal meaning (16, 23) and when it is communicated in narrative form rather than as a collection of facts and concepts (11, 12, 31).

One surprising result growing out of our approach is how much students marvel at physiological principles when they appear as surprising explanations for drug effects. The drug effects themselves may be familiar from media or personal accounts of psychoactive drug use. However, the same sources that describe the drug effects rarely, if ever, explain why they happen in a predictable fashion. Hence, undergraduates sometimes view these drug effects as unexplained, almost magical phenomena. When students understand instead, for example, that the “munchies” created by marijuana smoking stem from cannabinoid receptor agonist actions in the hypothalamic appetite control center, it often comes as a revelation. For this reason, this course serves as a physiology course taught from an example-first approach. Each drug serves as case, and the physiology provides part of the explanation. The effectiveness of this approach confirms the theoretical and experimental literature on the use of case-based learning, inquiry-based learning, and peer or group learning (1, 14, 26, 32).

Methods for teaching sophisticated scientific principles to naïve students. The interdisciplinary aspect to our course gives rise to a number of challenges in teaching, in part because there are no prerequisites and students come to the course with a wide range of backgrounds in the sciences. Perhaps 20–25% of our students have no more than the science background required for a general chemistry course.

**Table 3. Student evaluations**

<table>
<thead>
<tr>
<th>Question</th>
<th>Mean Score</th>
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<tbody>
<tr>
<td>1. The objectives of this course were clearly stated and met.</td>
<td>4.74</td>
</tr>
<tr>
<td>2. Supplemental instructional materials (websites, models, laboratory guides, case studies, etc.) helped my learning in this course.</td>
<td>4.29</td>
</tr>
<tr>
<td>3. This course increased my interest in the subject matter.</td>
<td>4.74</td>
</tr>
<tr>
<td>4. This course was worthwhile in terms of my career objectives.</td>
<td>4.57</td>
</tr>
<tr>
<td>5. Overall, I rate this course as follows: 5, outstanding; 4, above average; 3, average; 2, below average; or 1, poor.</td>
<td>4.66</td>
</tr>
</tbody>
</table>

Students (n = 122) in 3 offerings of the course in 2004 and 2005 were asked to evaluate the course on the basis of the 5 questions shown above using Likert scales. For questions 1–4, the options were as follows: 5, strongly agree; 4, agree, but not strongly; 3, undecided; 2, disagree; and 1, strongly disagree.

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Fig. 1. Concept map of the nicotine section of the course. Physiology plays an essential role in the multidisciplinary discussions that begin with nicotine action in the brain and extend to many organ systems.

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How We Teach

AN UNDERGRADUATE COURSE ON PSYCHOACTIVE DRUGS

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required to meet minimum high school graduation and college admissions requirements. Physiology and pharmacology can be difficult for the naïve student because these subjects are built upon prior knowledge from many other scientific disciplines including calculus, physics, chemistry, biology, and biochemistry. In addition, they are becoming increasingly interdisciplinary. Our task is to select those aspects of the basic sciences and other disciplines that are central to the understanding of the physiology and pharmacology of psychoactive drugs and to assemble and present these in a way that is meaningful and useful to students with very diverse scientific backgrounds. To this end, we incorporate visual and physical models whenever possible (3, 9). In addition, we use first-person accounts of drug use and addiction, references to current events, and historical explanations to help students connect real-world effects with the scientific concepts discussed in class (18). The value of narrative as a learning tool has long been recognized. Providing a context of learning of facts and examining the relationship between those facts in the real world stimulates student interest and promotes critical thinking and higher-order learning (11, 12, 31). From the perspective of physiology teaching, these models and narratives potentely enhance the understanding and appreciation of physiological concepts at work in the class, especially for nonscience majors, who might otherwise be reluctant to take a discipline-specific physiology course.

We have some evidence that these methods may be working: students consistently find the course to be worthwhile in terms of their career goals and state that it increases their interest in the subject (Table 3). Nonetheless, the most useful way to determine the effectiveness of the course would be to look for improvement in areas related to our goals of science literacy, critical thinking, and communication skills using objective measures. We are now in the process of designing such metrics with the assistance of education consultants at our institution.

Summary and conclusions. We described a course focused on the medical science of psychoactive drugs that allows physiological principles to be taught in a broad interdisciplinary context. During this course, the majority of students master many important concepts in physiology and pharmacology and develop some understanding of such complex and rapidly evolving areas as the cellular and molecular mechanisms of drug addiction. Their grasp of physiological principles that are likely to influence their daily lives far exceeds that of the general population, as judged by their homework and performance on exams. Their own assessment of their learning is extremely positive as judged by teaching and course evaluations. Our experience demonstrates that, with the appropriate instructional methods built around a suitable theme, it is quite possible to impart the basic principles of physiology and pharmacology to a highly motivated student audience with very limited scientific backgrounds in a fashion that meets the goals of liberal and interdisciplinary education.

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REFERENCES


