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Article

An Approach to Teaching General Chemistry II that Highlights the Interdisciplinary Nature of Science*,†

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The need for a revised curriculum within the life sciences has been well-established. One strategy to improve student preparation in the life sciences is to redesign introductory courses like biology, chemistry, and physics so that they better reflect their disciplinary interdependence. We describe a medically relevant, context-based approach to teaching second semester general chemistry that demonstrates the interdisciplinary nature of biology and chemistry. Our innovative method provides a model in which disciplinary barriers are diminished early in the undergraduate science curriculum. The course is divided into three principle educational modules: 1) Fundamentals of General Chemistry, 2) Medical Approaches to Inflammation, and 3) Neuroscience as a connector of chemistry, biology, and psychology. We accurately anticipated that this modified approach to teaching general chemistry would enhance student interest in chemistry and bridge the perceived gaps between biology and chemistry. The course serves as a template for context-based, interdisciplinary teaching that lays the foundation needed to train 21st century scientists.

Keywords: general chemistry reform, interdisciplinary teaching, medicinal chemistry, Bio2010 models.

INTRODUCTION

Chemistry has evolved from a stand-alone discipline to the language used to communicate the array of events in biological systems [1]. The topics one studies in chemistry can often provide insight into the mechanistic function of most biological phenomena. With rapid technological advances, an essential interest and appreciation of chemistry will be important for all professionals, particularly 21st century scientists. It is, therefore, important that science educators revise introductory chemistry and biology courses to better reflect the interdisciplinary nature of current technology. Several lines of evidence suggest that there is an urgent need to change the way general chemistry is taught. First, pharmaceutical companies employ a large percentage of biologists and chemists. The nature of the industry requires that students are able to survive in a borderless scientific community where the binding equilibrium and cellular mechanisms are equally important. Secondly, undergraduates are constantly bombarded with informal scientific information (i.e., media coverage of disease outbreaks, threat of biological terrorism, and advertisements for medicines) that they must be able to quickly evaluate for integrity. Therefore, curricular content must advance to improve civic engagement as recently suggested by the American society for biochemistry and molecular biology (ASBMB) [2]. Finally, undergraduate research is accepted among scientists as a valuable learning experience [3–5]. Preparation of the most intrepid undergraduates for early research participation will certainly require a first year curriculum that exposes them to the interdisciplinary nature of science while also providing a minimum understanding of chemistry. The need for a revised curriculum within the life sciences has been documented in *Bio2010* [6] and more recently in the Teagle Foundation report [2] and both documents present the risks of fragmented science teaching that does not fully incorporate math and physical sciences into life science programs of study.

While the need to redefine the core of general chemistry is current, the topic has been at the focus of the education community over the past few decades. One of the earliest calls for action was put forth in the late 1920's. This report suggested that general chemistry and other courses should be streamlined to increase the time that students devote to independent research and special interest efforts [7]. The transformation that resulted from this and more recent efforts has resulted in the current version of general chemistry, largely physical in nature, which has predominated since the 1960s [8]. This model, though predominant, fails to be an effective model for engaging students and preparing them for careers in

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emerging subdisciplines of science [6, 9–11]. The primary challenge for the science education community has been commercially available textbooks that emphasize seemingly abstract and discontinuous series of topics to which many students are unable to relate [12, 13]. Despite these observations in literature and minor textbook modifications, there have only been incremental community-wide changes in the way general chemistry is taught. One reform approach to introductory chemistry involves changing the curricular sequence so that both semesters of organic chemistry are taken between the two general chemistry courses [14]. This approach is advantageous because students with aversions to intense mathematic calculations are able to complete several chemistry courses before they approach general chemistry II. This approach, due to the rigorous study demands, is most appropriate for institutions whose student population enter with strong high school backgrounds. Others have suggested linking general chemistry with more biologically oriented courses like general [15] and cellular biology [16]. The major advantage to such an approach is that it reflects the interdependence of biology and chemistry. However, this has required that students enroll in the two courses simultaneously [16]. In some cases, the biology/chemistry fusion has involved two faculty members who are able and willing to teach in departments outside of that of their primary discipline [15]. It is often not feasible for many departments to facilitate these types of interdepartmental teaching arrangements while also accommodating general departmental staffing needs. These interdisciplinary teaching approaches have also selectively targeted highly motivated students with pre-existing interests in physical and life science disciplines. Nonetheless, these innovative models illustrate aggressive efforts to connect chemistry with other disciplines by rethinking course objectives and content.

Although the basic concepts introduced in general chemistry are critical to understanding biological science phenomenon, early undergraduate biology and chemistry majors often have a strong aversion to introductory general chemistry courses. The interdisciplinary nature of science does not become apparent until students are well into their biology or chemistry programs. This suggests that a large population of potential scientists, particularly those from underrepresented groups, forgo this discipline because they are unable to appreciate the relationship that chemistry has to their chosen program of study and to the practical aspects of life. In addition, the importance of chemistry to life science disciplines is often marginalized in textbooks and in general chemistry courses [12, 13]. As a result, biology and chemistry majors taking these courses are left to their own devices to appreciate the importance of chemistry in practical life.

Consistent with the recommendations from Bio2010 [6] and the Teagle report [2] we report the implementation of an approach that emphasizes chemistry as the fundamental discipline on which the molecular life sciences are based. This is accomplished by devoting the entire second semester of the General Chemistry I-II sequence to Medicinal Chemistry. Students learn relevant and interesting molecular mechanism of actions while further strengthening their understanding of fundamental chemical concepts and quantitative relationships developed earlier.

OVERVIEW AND IMPLEMENTATION

Winthrop University is a comprehensive and primarily undergraduate institution that offers a high-caliber liberal arts education. Similar to most institutions, Winthrop's General Chemistry program is structured for science students. Completion of the two-semester sequence is required for majors in human nutrition, biology, chemistry, computer science, environmental science, and pre-engineering.

Despite institutional investments in life science research capacity and successful matriculation of students into health professional and graduate programs, we observed that freshman and sophomore chemistry and biology majors at Winthrop University often failed to appreciate the importance of chemistry in everyday life and the interdisciplinary nature of science. To address these issues, an interdisciplinary General Chemistry I-II sequence was piloted to increase student interest in chemistry and biology. The modified course was designed to 1) better align the course content with the current state of science and 2) present chemistry in a relevant context so that students appreciate how science affects their daily lives.

General Chemistry I lecture credit hours were increased from three to four and a weekly recitation session was added; at the same time, an atoms-first approach was implemented. These modifications allowed coverage of thermodynamics, kinetics, equilibria, and electrochemistry to be shifted to the first semester and provided a cohesive framework of chemistry fundamentals within a single semester.

These changes also made it possible to teach General Chemistry II entirely with a Medicinal Chemistry focus. Students enrolled in the modified course were required to have successfully completed the expanded General Chemistry I with a "C" better. Concurrent registration in the General Chemistry II laboratory was required; nearly all students had also completed at least one semester of introductory biology. A traditional general chemistry text [17] was supplemented with a required introductory Medicinal Chemistry course text [18]. With permission from the author, learning modules from the University of California San Francisco [19] were made available when relevant.

GENERAL CHEMISTRY II COURSE DESIGN

The Medicinal Chemistry focus was designed to build on concepts previously covered, to interest students with relevant applications, to better inform them on the interdisciplinary nature of science, and to develop a fundamental understanding of "how drugs work." Biological models were used to exemplify general chemistry concepts outlined in Table I and the course was divided into three educational units:

- Fundamental topics of general chemistry encompassing core knowledge required to understand the molecular basis of drug action.
- Medical approaches to inflammation with an emphasis on how the fundamental principles of general chemistry govern mechanisms of action.

TABLE I
General chemistry II concepts examined in the study of "How Drugs Work"

General chemistry concept	Illustrative models of basic concepts
Intermolecular forces	Noncovalent interactions, protein structure, enzyme-substrate/ligand-receptor binding
Solubility	Liquid–liquid solubility, octanol-water partition coefficients (P)
Acid-base chemistry	Buffers, amino acids, Henderson-Hasselbalch equilbria
Chemical reactivity	Condensation/hydrolysis reactions for aspirin, phospholipids, amino acids, ADP/ATP, nucleotides
Kinetics	Michaelis-Menton enzyme kinetics model, Lineweaver-Burk plots
Complex ions	Steroid receptor Zn fingers, cisplatin mechanism, Iron complexes
Thermodynamics and electrochemistry	Free energy changes across cell membrane ion concentration and electric potential gradients, inhibitory/excitatory responses for ion channel changes, calculation of cell membrane Nernst potentials
Equilbria	Enzyme-substrate equilbria, drug-receptor equilibria
Molecular structures	Amino acids, phospholipids, neurotransmitters, and many others

- Neuroscience as a connector of chemistry, biology, and psychology encompassing a study of the molecular basis of neurotransmitter function including how various drugs disrupt hormone-receptor interactions.

Due to the interdependent nature of the topics, we employed a simplified spiral approach in which common principles are revisited throughout the semester. We envisioned that this approach would allow students to scaffold their limited grasp of material into detailed understanding [20]. Accordingly, the fundamental topics module presented what students needed to understand the biochemistry of drug action and subsequent educational units reinforced these concepts. The course was also designed to equip students with the critical thinking skills and effective study habits required for success in subsequent courses (i.e., physics, organic chemistry, etc). Problem solving was emphasized through the use of problem sets and quizzes that applied the basics of chemistry (i.e., equilibrium, thermodynamics, etc.) to medically relevant models. Students completed two or three in-class exams and a cumulative final exam that were primarily short answer problems emphasizing problem solving, critical thinking, and integrated applications.

Fundamental Topics of General Chemistry

The first third of the course was devoted to basic topics in general chemistry students needed to know to understand how drugs work. Subjects including chemical bonding, intermolecular forces, equilibrium, and solubility were taught during this phase of the course (Table II). Although the general chemistry text correlated well with the background material for fundamentals, problems that integrated principles and stressed applications were limited. To address this shortcoming, students were required to purchase a supplemental Medicinal Chemistry textbook [18] and faculty teaching the course wrote problem sets that integrated the various concepts in an applied fashion to cement the use of these principles. General condensation reactions followed this sequence of topics as a means of providing students with a useful application of polarity while also exposing them to the reactions (i.e., peptide synthesis, phosphorylation in signaling pathways, esterification reactions) that would ultimately be used throughout the course.

This phase of the course was also used to introduce structural elements of the fundamental macromolecules needed for the remainder of the course. Specific emphasis was placed on phospholipids as the primary barrier through which molecules must penetrate to enter the cell. In this regard, students revisited condensation reactions while also understanding the chemistry of lipids and intermolecular forces in maintaining the structural integrity of the cell. Lectures covering the chemical and physical properties of amino acids were used to demonstrate the most basic and complex aspects of acid-base equilibrium. Our goal was to allow students to develop a general comfort level with the

TABLE II
Concepts studied during fundamentals of general chemistry module

Biological model	Fundamental chemistry concept
Macromolecules and the medium of life	Lewis structures, molecular properties, intermolecular forces, aqueous solutions, structure and polarity of liquids, molecular structure and properties of water, functional groups
Central dogma and nucleic acid structure	Intermolecular forces, resonance, water and aqueous solutions, structure and polarity of liquids, structure and properties of water, hydrophobic effect, hydrocarbons and functional groups
Synthesis and degradation of biopolymers	Polarity, functional groups, condensation and hydrolysis reactions, energetics and equilibria, enthalpy, entropy, and free energy, hydrocarbons
Protecting the cell's interior: lipids and membranes	Polarity, functional groups, condensation and hydrolysis reactions, Membrane permeability, thermodynamics of diffusion
Acid-base properties of amino acids	Acid-base equilibria, buffers, polarity, functional groups
Proteins: molecules with diverse cellular functions	Condensation and hydrolysis reactions, intermolecular forces, protein structure, hydrophobic effect, polarity, functional groups

TABLE III
Concepts studied during the medical approaches to inflammation module

Biological model	Goals for student learning
Proteins as biological catalysts and drug receptors	Forces that stabilize protein structure and the role played by ionization states of amino acids, catalysis and its relation to the Arrhenius equation, rate laws and enzyme-substrate interactions, Michaelis-Menton and Lineweaver-Burk relationships, ligand-receptor interactions, receptor occupancy theory, types of cellular responses to ligand-receptor interactions, receptor response differences to agonists and antagonist
Nonsteroidal anti-inflammatory drugs (NSAIDS): cyclooxygenase (COX) inhibitors	Effects of various types of inhibitors on enzyme kinetics, dose response curves, biological function of COX in inflammation, key structural features of NSAIDs that allow interactions with COX enzymes, aspirin's unique mechanism of action for irreversible COX inhibition, key differences between COX-1 and COX-2 enzymes
Steroidal approaches to inflammation	Receptor occupancy theory, types of receptor responses occurring within the cell, receptor response differences to agonists and antagonists, structure and function of the estrogen receptor, effects of chemical modifications to common estrogen analogues

various amino acid structures and understand how the chemistry of the side chain governs the associated intermolecular forces that hold proteins together. Nucleic acid structure was also introduced in this phase of the course.

Medicinal Approaches to Inflammation

We identified medical approaches to inflammation as an ideal model to exemplify fundamental general chemistry topics such as entropy and free energy, chemical kinetics, and solubility. The specific topics and goals for student learning are outlined in Table III. The fundamental knowledge of protein structure was further supplemented by allowing students to appreciate the significance of proteins in inflammatory responses.

The structure and function of cyclooxygenase (COX) in inflammation provided an interesting illustration of enzyme kinetics allowing students to see the influence of intermolecular forces on entropy, free energy, equilibrium, and enzyme activity. A careful evaluation of the structural differences between the active sites of the COX isozymes, COX-1 and COX-2, and drug design approaches to selectively inhibit COX-2 were discussed with reference to structural differences and the ultimate impact on equilibrium and kinetic constants. Consistent with our spiral teaching method, the distinction between reversible and irreversible enzyme inhibition was made by evaluating the condensation of aspirin at the active site of cyclooxygenases and comparing this mode of inhibition to that seen with celebrex, acetaminophen, and ibuprofen.

To address the importance of proteins as cellular receptors, the approaches to inflammation that target various cellular receptors were discussed. In this aspect of the course, we emphasized drug-receptor interactions qualitatively and quantitatively (see Table III). Students were able to appreciate the similarities that exist between binding constants that describe drug-receptor and substrate-enzyme interactions. Specific emphasis was placed on how pharmacodynamic effects are quantitated and the effects of ligand binding on protein structure. The relative affinities of ligands of the estrogen receptor such as tamoxifen, estradiol, and diethylstilbestrol were examined making reference to the structural properties of both the ligand and substrate that influence the dissociation constants for the receptor. We also evaluated the impacts that antagonists and inverse agonist have on ligand binding to the receptor. In this regard, dose-response curves, dissociation constants, EC_{50} values, and maximum biological effects were important concepts to cover despite their typical absence in a traditional general chemistry course. The chemical reactions that influence activity of the receptor (i.e., phosphorylation and adenylation) were also discussed.

Neuroscience as a Connector of Chemistry, Biology, and Psychology

The neuroscience phase of the course served as an effective capstone by emphasizing chemical concepts previously covered and by introducing modern relevant issues (Table IV). Students often found this to be the most fascinating and appealing part of the General Chemistry experience.

The neuroscience module began with coverage of the cholinergic and adrenergic nervous systems, the main classes of receptors in these systems, and the relevant

TABLE IV
Concepts studied during the neurochemistry module

Biological model	Goals for student learning
Electrochemistry and thermodynamics of neurochemistry	Design and function of voltaic cells, reduction oxidation reactions, the significance of reduction potentials in determining reaction spontaneity, the various types of transport processes involved in moving molecules across membranes, relative cellular concentrations of ions, physical basis for the selectivity of ion channels
Neurotransmitters and neuronal signaling	General anatomy of the neuron, the process by which a nerve impulse passes from one neuron to another, synthetic and degradation pathways of least one cholinergic, adrenergic, and amino acid-derived neurotransmitter and the mechanism of actions for each, how various substances (i.e., angel dust, valium, opoids, cannabinoids, and antidepressants) affect function of the three classes of neurotransmitters discussed

ligands that activate or prevent specific responses. Therapeutic approaches that target these systems to treat respiratory and cardiovascular diseases were introduced. Ion channel thermodynamics and Nernst equilibria were examined to understand and to predict ion movement across both concentration and electric potential gradients. The cooperative actions among the symphony of protein molecules involved in neural signaling provided a rich context for understanding the toxic mechanisms of action for snake venom, botulism toxin, nerve gases, and other neurotoxins.

The remaining two-thirds of the neuroscience module focused primarily upon psychoactive substances. The goal of this educational block was to expose students to the molecular basis for mental illnesses and their associated treatment regimens. Exploring synapse chemistry gave students insights on how neurotransmitter concentrations can be modulated by either therapeutic or other foreign substances. This portion of the course broadened scientific literacy and enhanced historical perspective as coverage spanned stimulants (cocaine, amphetamines), depressants (alcohol, barbituates, benzodiazepines) antipsychotics (typical and atypical), antidepressants, hallucinogens, cannabinoids, opioids, local anesthetics, and general anesthetics. The inclusion of this section seemed particularly fitting for improving scientific literacy based on the historic abuse and general interest in psychoactive molecules.

ASSESSMENT

Student Learning

Assessment of student learning occurred throughout the semester using problem sets, lecture quizzes, midsemester exams, and a cumulative final exam. Students were evaluated on their abilities to apply concepts learned in lecture to address new scientific problems. Exams consisted primarily of short answer problems and were designed to reflect the cumulative nature of the course. Specific learning objectives for each educational unit were outlined and questions that tested their knowledge of these concepts were reflected on each exam. Emphasis was placed on application, rather than memorization, of fundamental concepts and data interpretation (i.e., binding curves, dose-response curves, etc).

Percent scores were aggregated with each educational module and average exam performance was compared to traditional general chemistry sections offered during the same semester. A two tailed *t*-test of the average exam scores for the traditional (67.5%) and modified (65.8%) course revealed no significant difference in student achievement ($p = 0.718$). However, the modified course did require students to learn significantly more new content than the traditional course, which covered many of the same topics examined in high school chemistry. Seven questions that specifically addressed fundamental principles in biology and chemistry were embedded in the final exam and used for knowledge assessment. More than 70% of undergraduates were able to correctly answer questions related to acid-base equilibria, chemical kinetics, and neuron structure.

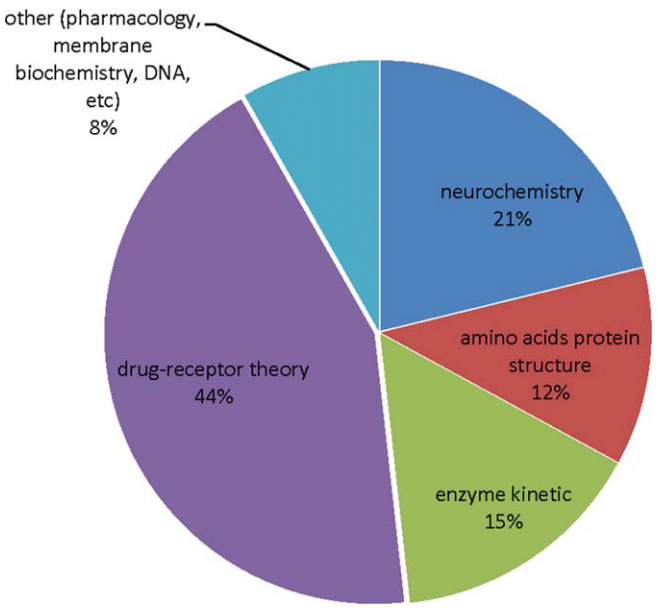

FIG. 1. **Student interest in medicinal topics.** Students were asked to identify the most interesting topic that they studied in General Chemistry II. Data was collected for three course offerings (2008, 2009, 2010). The chart shows the response distribution of all student respondents ($n = 85$).

Evaluation of Student Attitudes

At the conclusion of the course, student attitudes toward the course and its associated topics were assessed through responses to several questions:

What was the Most Interesting Topic that you've Studied in this Semester?—As shown in Figure 1, students identified receptor binding interactions (44%), neurotransmission (21%), enzyme kinetics (15%), and the importance of acid-base chemistry to protein structure-function (12%) as the most interesting topics.

What Principles did you Find Most Effectively Illustrated Using Medicinal Models?—Students found that intermolecular forces and acid-base chemistry were most effectively illustrated through medicinal models. One cited intermolecular forces as "the basis of all chemistry; once you understand that, the rest is simple."

What did you Find to be the Most Challenging Aspects of the Course?—Common challenges included the volume of material and pace of the course as well as the application-based exams. One student noted that the exams required use of their knowledge "in ways that were completely new to us." Interestingly, the drug-receptor interaction section of the course was cited both as the most interesting and most challenging topic. Other challenging topics identified included acid-base chemistry, Nernst equation, and chemical kinetics. The number of chemical structures was also a common concern. The learning objectives included knowledge of amino acid structures, the various phosphate heads, and the structural features of certain drugs. Given the specific challenges that these students cited, the numbers of hours that they committed to the course per week (average 6–9 hours each week for 44% of students), and the comparable performance with traditionally taught courses, it appeared that the rigor of General Chemistry II was maintained.

How did the Course Topics Influence Your Ability to Serve as an Informed Citizen?—In response to this question, many students shared instances in which family members were taking at least one of the drugs whose mechanisms of action were studied. Other students commented that this course further cemented their interests in health professional careers. Representative responses collected in the end-of-semester surveys included:

- "Where steroid receptors are located and that they act as anti-inflammatories (prednisone also makes you hungry all the time. I gained three pounds try to get rid of my rash!)"
- "The effects of beta blockers and the medications associated with them My dad takes them because he has had a heart attack and knowing how the medicine works and relates to my life is interesting."
- "A person taking SSRIs would need more of a hallucinogenic drug to get the same effect as a person who wasn't on SSRIs. SSRIs increase the level of serotonin because they block reuptake. The structure of serotonin and hallucinogenic drugs are very similar and they compete to bind to the receptor."
- "I learned how drugs work overall, which I need to know since I am going to be a veterinarian and will be dispensing medications."
- "There is a lot of biology involved in chemistry, especially in the realm of drug targets. It's as if there is really a fine line between the two."

Comment on the Effects of this Course on Your Interest in Chemistry—Of all students surveyed, 75% responded that this course enhanced their interest in chemistry. On the other hand, 14% reported it decreased interest, while 11% reported no change in chemistry interest resulting from this course.

Qualitatively, there were increased demands for the interdisciplinary medicinal chemistry course in comparison to those sections that employed the traditional approach. Despite the new and unfamiliar content, students realized its closer alignment with professional goals, with their major, and with personal interests.

Since implementing the medicinal chemistry approach, Winthrop has experienced a 40% increase in enrollment in upper level biochemistry courses over the past three years. This growth may in part be due in part to the modified general chemistry offering.

Faculty Impressions of the Course

Content and Approach—It became apparent early in course planning that the medicinal chemistry approach required a more integrated model of learning as opposed to the linear chapter by chapter mode traditionally used. The presentation of central concepts at various points throughout the semester provided students with multiple opportunities to understand those topics. The spiral teaching method also proved to be effective in preparing for final exams because many of the basic concepts were used repeatedly over the course of the semester allowing students to acquire a fundamental working knowledge of these topics. Introducing neurochemistry at the semester's end provided a context in which all previously covered topics could be reinforced. The real-world topics selected preserve the concepts that we felt were central to understanding chemistry.

Implementation Challenges—Course Text. Despite the many benefits, the lack of a text that cohesively covers the material with the appropriate quantitative treatment was a consistent challenge. Comments on end-of-semester evaluations and our own perceptions indicate a need for additional problem solving opportunities. The lack of an appropriate text and well-designed practice problems increased preparation time (typically 8–12 hours per lecture during the first offering) required.

Faculty Development. This represents a key need for implementing this approach. Those teaching the modified course were encouraged to take advantage of professional development opportunities such as the short course in Medicinal Chemistry offered by the American Chemical Society or the NSF Chautauqua short courses on "The Molecular Basis of Disease" or "Psychoactive Drugs and the Molecular Biology of the Neuron." These outstanding offerings were well aligned with course content; faculty found it most beneficial to attend these after teaching the modified course at least once.

Laboratory Program. Alignment of the laboratory program with the modified lecture course also had to be addressed. Since implementation of the medicinal chemistry approach, a new five week laboratory project [21] examining alcohol dehydrogenase (ADH) enzyme kinetics for the oxidation of ethanol to acetaldehyde by NAD^+ has been incorporated as the capstone project for the General Chemistry laboratory program. This laboratory experience builds upon the enzyme kinetics lectures that have already been given by this point in the semester. Students conduct one set of experiments measuring ADH catalyzed reaction rates for various aliphatic alcohol substrates (methanol through butanol). A second set of experiments measures ADH-catalyzed ethanol reaction rates at different pHs. A third set of experiments involves measurement, in triplicate, of reaction rates at different ethanol concentrations followed by student generation of a Lineweaver-Burk plot and calculation of Michaelis-Menton kinetic parameters. These experiments tie together many of the concepts covered in the lecture while also giving students meaningful exposure to one of the ways the human body metabolizes ethanol. These enzyme kinetics experiments have also proven to be tremendous data analysis learning opportunities for students.

CONCLUSIONS

Using medically and biologically relevant models as tools to teach fundamental general chemistry concepts has been successful in enhancing student learning at Winthrop University. Our goals were to modify general chemistry II to enhance chemistry knowledge while also highlighting the discipline as the language of the molecular life sciences. The modified approach that we've employed reflects the current state of science and increases student interest in chemistry while facilitating student learning.

Since we first offered this course, we have worked to overcome the challenges faced while teaching it. For instance, a concise set of resources that addresses these topics with an emphasis on quantitative treatment of the range of topics we present does not exist. We have overcome this obstacle by providing a supplemental text [18] to the standard general chemistry textbook [17] and by using instructor-generated problem sets. The course design is amenable to many interesting topics whose foundation depends on general chemistry. Likely candidates could possibly include a general chemistry that employs models from nanotechnology, intermediary metabolism, or environmental chemistry. Using this course as a proof-of-concept model, we will explore other models and conduct a more in-depth assessment of the model described. The course described employed traditional lectures. However, our future efforts will examine the utility of problem based learning in this course. Above all, we provide additional support for disciplinary overlap while introducing fundamental science principles.

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