A Biotechnology Course Emphasizing Molecular Biology and Practical Experience

Dianne T. Akin
Southern School of Pharmacy, Mercer University 3001 Mercer University Drive, Atlanta GA 30341-4155

This article describes a new course offered to graduate and undergraduate students (in an all PharmD program) at Mercer University School of Pharmacy. The primary objective of this course is to prepare pharmacy professionals for careers in academia, industry or pharmacy practice which will require expertise in molecular biology. The course contains both a didactic component (two semester hours credit) and a practical laboratory component (one semester hour credit). The laboratory component is offered only to graduate students at this time. The course assumes that students have an understanding of basic processes of molecular biology which are taught in prerequisite courses. A wide range of topics in molecular biology and immunology are covered. Lectures, testing methods and laboratory exercises are designed to promote in-depth understanding, confidence and scientific literacy.

INTRODUCTION

Biotechnology is an area of technical science which has become a potent force for change and development in the medical sciences over the last decade. The impact of biotechnology on the pharmacy profession has been gradually increasing over this period, but is poised to explode as many new drugs produced by this technology enter the market and as the technology itself is being refined to become more and more useful in drug development. Banga and Reddy have recently suggested that almost half of the new drugs reaching the market in the next few years will be produced by biotechnology(1).0 It is becoming increasingly clear that professional students require a more thorough understanding of the roles of genetic elements involved in regulation of DNA and RNA metabolism(2). Although pharmacy is an applied medical science, pharmacy professionals must be trained to understand the basic processes of molecular biology. For example, they need to recognize within the complex regulatory elements involved in HIV and other viral infections the many new targets for drug development. They must appreciate the wide variety of strategies which may be employed in gene therapy, understanding the advantages and disadvantages of each. In addition, they will be required to apply and explain pharmaceuticals which intervene in the actions of oncogenes and anti-oncogenes. It is essential that developing pharmacy professionals become aware of the products of new biotechnologies, understanding the strategy behind their design as well as methods of handling and administering them appropriately.

In approaching these needs in our curriculum, the faculty at Mercer University School of Pharmacy have developed a course entitled "biotechnology" with a strong emphasis in molecular biology. It is a rigorous course and its primary focus is to produce students who are literate in the area of molecular biology. These students should be prepared to critically evaluate research in the area, devise strategies for drug design and identify potential targets for future therapies. This course was originally offered as an elective course for graduate and PharmD students spring quarter, 1993. In 1994, it was made a required course for graduate students. It was modified and offered a second time spring semester, 1995.

A total of nineteen students (eight graduate and eleven undergraduate) have taken the course for credit. The intent of this article is to describe the evolution of this course and evaluate its effectiveness in preparing students in pharmaceutical sciences for a future of biotechnological advances. It should be understood that the course is continuing to be improved and modified. A discussion of proposed changes to be incorporated into the course in the future is included.

COURSE DESCRIPTION AND OUTLINE

Lecture Series

The strategy used in developing this course is based on the premise that an understanding of the basic science utilized in molecular biology is necessary for pharmacists to be active in developing and evaluating current and future products for clinical use. For that reason, the course begins (Section 1 of Table I) with detailed coverage of the organization, expression and regulation of the human genome. The course builds on background information provided in the biochemistry sequence required in our PharmD curriculum (a prerequisite). For example, a general knowledge of intervening sequences within genes is assumed so that lectures in this course can focus primarily on the mechanisms of splicing and the roles of alternative splicing mechanisms in gene expression. Similarly, an understanding of general features of the interaction of RNA polymerase with regulatory elements in DNA (*e.g.*, promoters) is assumed. This allows for more in-depth coverage of the protein families that serve as transcription factors, the role of enhancers in gene expression and their placement in the genome, and the techniques that may be used to study interactions between these elements and RNA polymerase. This section is followed by descriptions of DNA manipulations. The many applications of the polymerase chain reaction (PCR) are discussed along with its limitations. Students learn the basic steps of the process as well as strategies that can be used to improve either yield or specificity for various purposes. This section also includes a detailed discussion of various cloning techniques. Restriction enzymes and their many uses are reviewed briefly as are basic cloning techniques. The major

Table I. Lecture outline

Section 1: Organization, Expression and Regulation of the Human Genome
Complexity of the Genome (2 lectures)
Gene Expression and Regulation (4 lectures)
Section 2: DNA Manipulations
Polymerase Chain Reaction (PCR) (1 lecture)
Cloning and Isolation of cloned genes (2 lectures)
Transferring Genes into Mammalian Cells (2 lectures)
Human Gene Therapy (2 lectures)
Section 3: Tissue Culture and Cell Biology
General description of tissue culture and cell transformation (2 lectures)
Cell fusion and production of useful hybridoma products (2 lectures)
Section 4: The Human Genome and Disease
Oncogenes and Anti-oncogenes (1 lecture)
Molecular Analysis of the Cell Cycle (1 lecture)
DNA Based Diagnosis of Disease (2 lectures)
Recombinant DNA and AIDS (2 lectures)
Section 5: Products of Biotechnology
Currently marketed products and future drugs (4 lectures)

focus of the discussion, however, is on selection of appropriate vectors (both prokaryotic and eukaryotic) for various purposes and bioengineering strategies which may be used to provide necessary selection devices or to develop expression vectors.

Techniques used to transfer genes into mammalian cells are reviewed including discussion of the various reporter genes and markers which may be used for screening. This section concludes with a discussion of human gene therapy. Following a general discussion outlining various methods for inserting genes into eukaryotic cells, the focus is primarily on the use of adenoviral and retroviral vectors and the status of current experimentation and clinical trials. A short section follows on tissue culture and cell biology. This four-lecture sequence describes cell transformation techniques and the common pitfalls and limitations of cell culture. It describes cell fusion and how to promote it and expands on the student's knowledge of methods used to produce monoclonal antibodies. The discussion focuses on the usefulness and limitations of monoclonal antibodies as therapeutic and diagnostic agents. Protein engineering techniques used to make monoclonal antibodies more clinically useful are discussed in the final lecture.

In the fourth section, the human genome and disease are addressed. The roles of oncogenes and anti-oncogenes in cancer are discussed in detail. Oncogene production via common chromosomal rearrangements is discussed as well as the role of tumor suppressor genes (anti-oncogenes) in familial cancers. Because of its importance in cancer and regulation of growth, one lecture is dedicated to molecular mechanisms controlling the cell cycle. For example, expression of cyclin genes and the interaction of the cyclin proteins with cellular protein kinases to activate entry into S or M phase are described. DNA-based diagnosis of disease is also discussed. Various diagnostic techniques are described including restriction fragment length polymorphisms (RFLP), genetic linkage analysis, and the use of specific oligonucleotide probes. The challenges of identifying subtle mutations and strategies for overcoming those challenges are also discussed. Finally, this section concludes with a detailed discussion of the AIDS virus and genetic mechanisms which control its pathogenicity. Emphasis is given to points of intervention and current strategies being employed both *in vitro* and *in vivo*. A short description and discussion of model systems for HIV study is included in order to give the student an appreciation for the difficulties encountered in this field.

Table II. Laboratory outline

Exercise 1
Analysis of genomic DNA using restriction endonucleases and electrophoresis (2 lab sessions)
Exercise 2
Isolation of DNA, Use of Southern blotting to identify high-copy DNA (5 lab sessions)
Exercise 3
Cloning of DNA sequence into a plasmid vector and transformation of E. coli (5 lab sessions)
Exercise 4
Effect of mitogens on human peripheral blood lymphocytes in culture (2 lab sessions)
Exercise 5
Cytokine levels quantitated by Enzyme-linked immunosorbant assay (ELISA) (1 lab session)

The lecture portion of the course concludes with a four-lecture sequence on products of biotechnology. These lectures highlight new products derived from either recombinant DNA or hybridoma technology. Products which are approved for use as well as products under clinical investigation are covered. The final lecture focuses on products derived from biotechnology to treat a set of related disease states in the lecturer's area of expertise. Products discussed most recently in this section include various cytokines, receptors, receptor antagonists and antibodies used to treat Rheumatoid Arthritis: interferon gamma (Immuneron), interleukin-1 receptor antagonist (Antril), interleukin-1 receptor, Anti-interleukin-2 receptor (Anti-Leu-2), anti-tumor necrosis factor, chimeric anti-CD 4 (Centura), chimeric anti-tumor necrosis factor (Centurex), muromonab CD-5 RIA (Orthozyme CD 5). and anti-CD-5 Mab-ricin (Xomazyme CD 5 Plus).

Laboratory

Concurrent with the lecture sequence, an accompanying laboratory is designed to provide graduate students with practical experience in molecular biology and cell culture. It is imperative that students entering pharmaceutical industry or academic research have experience in basic laboratory techniques used in molecular biology research. In this course, students have the opportunity to utilize electrophoresis, Southern and Western blotting, restriction analysis, cloning and clone selection in simple exercises to familiarize themselves with these methodologies. In addition, students transformed cells in tissue culture and used ELISA methodology to quantitate cytokine levels.

The laboratory outline in Table II lists the individual laboratory exercises by descriptive titles and indicates the number of three-hour laboratory sessions devoted to each exercise. Students were given readings to prepare for laboratory sessions. Laboratory discussions (30-60 min) preceding each laboratory exercise were used to emphasize critical steps in the methodologies, orient the students and answer questions concerning the exercise. They were also used to engage students in discussions and to orally quiz their understanding of the procedures. This oral interaction is designed

to give students an opportunity to develop the skills and confidence needed to discuss the information comfortably.

Exercises 1-3 were designed to complement the lecture sequence by utilizing DNA manipulations to study DNA organization, transformation, and cloning techniques. In the first exercise, students used restriction enzymes to generate restriction fragments and analyzed them by electrophoresis. In the second, they used a biotinylated nucleotide probe and Southern blotting techniques to detect a specific nucleotide sequence in mammalian DNA. The third exercise was more extensive and utilized the techniques learned in the first two exercises. In this three week exercise, they cloned restriction fragments from the lambda phage into plasmids and used them to transform *Escherichia coli.* Transformed *E. coli* were selected using antibiotic resistance (carried on the plasmid) and loss of ß-galactosidase expression (lost from the plasmid when foreign DNA is inserted) as markers. Following selection, students used restriction enzymes, electrophoresis and Southern blotting to establish the identity of the cloned sequences based on a map of the lambda genome.

Exercises 4 and 5 followed lectures concerning tissue culture and monoclonal antibody production. In these sessions, students conducted a bioassay on isolated peripheral blood lymphocytes in culture (Exercise 4) and performed an enzyme-linked immunosorbant assay (ELISA). Practical experience using ELISA was deemed important since this technique is widely used in screening for monoclonal antibody production.

Following each laboratory, students were required to write a laboratory report describing the laboratory exercise and discussing the significance of their results. In addition, discussion periods provided an ongoing, subjective evaluation of the students' progress and preparation. A laboratory final was also given in which students were asked to interpret data and design an experiment. The emphasis of this final was on practical aspects in the laboratory. For example, students were expected to know which restriction enzymes have similar pH optima and may be used together and how many DNA fragments could be expected following restriction based on the number of times the target site appears in the DNA.

Grade Calculation

In addition to the attendance at lecture, all students were required to complete mid-term and final exams to receive a grade in the course. Both of these exams were given in a discussion format. Exams focused on the understanding of normal processes in molecular biology as well as the ability to describe and identify potential targets for drug action. In addition, both exams required students to examine and critique experimental protocols. Students were asked to suggest alternative approaches and/or to devise experiments to address remaining issues.

Each graduate student was also assigned a current research article. Students were asked to summarize the important points of the paper, answer questions and lead the class in a discussion of the paper's relevance and importance. The specific articles used most recently are listed in the Appendix. Approximately 30 minutes were allotted for these discussions. Presentations included a general introduction followed by the description of methodologies used and a summary of the data and conclusions drawn. Students were asked to evaluate and critique the articles in the following discussion.

The laboratory was not assigned a separate grade. For the participating students (all graduate students) the individual laboratory reports and the laboratory final were used to calculate a laboratory grade which contributed 30 percent to the course grade. The remainder of the grade was calculated based on 10 percent for student discussions and 30 percent each for the mid-term and final exam. PharmD students taking the course as an elective did not receive a grade in either the laboratory or the student discussions. Their grade was calculated based on the mid-term (50 percent) and the final (50 percent).

EVALUATION AND EFFECTIVENESS

Three graduate students and five undergraduates participated in the course for credit when it was first offered. In addition, one graduate student, several PharmD students and several faculty members audited or attended lectures on topics of interest. When the course was taught for the second time, eleven students (five graduate and six PharmD) took the course.

Students participating for credit in either session were asked to evaluate the course using the evaluation form shown in Table III. Questions 1-4 asked students to respond for each of the individual topic headings listed (a-l). In general, both graduate and PharmD students rated individual topics as highly relevant to pharmacy (average scores ranged from 3.8-5.0 for PharmD and 4.4-5.0 for graduate students). Students from both sessions indicated that topics were adequately covered (average scores for individual topics scoring >4.0) but requested increased coverage of several topics. Students from the first session most consistently indicated a need for increased coverage of the "recombinant DNA and AIDS" (average score of 2.1) and the "currently marketed products and future drugs" (average score of 2.4) topics. Students from the second session ranked all topics between 2.2 and 2.9. The lowest score from the second session was also received for the "recombinant DNA and AIDS section,"

When surveyed one year following completion of the course, students from the first session indicated that all lecture topics had proven somewhat beneficial (average scores ranging from 3.1-3.9) to them in their work or study during that time period. Individual students found different lecture areas highly relevant to their own experience over the last 12 months.

Students from the second session were asked to predict the benefit they expect to receive from information contained in the various lectures. All lectures were rated favorably (average scores ranging from 3.7-4.4). In general, graduate students (n=5) expected to benefit more from all lectures (average scores ranging from 4.2-5.0). PharmD students from the second session ranked most topics favorably with an average scores ranging between 3.6-4.2 with the exception of the section concerning 'in vitro manipulation." The average score from PharmD students for this section was 2.8.

Questions 5-12 evaluated the course more generally. Overall students from the first session felt the material was more highly relevant to the industrial environment than clinical practice (4.1 vs. 3.0) although students from the second session did not share that view (3.9 vs. 4.0). Students from both sessions expressed a lack of confidence in their ability to discuss molecular aspects of biotechnology at clinical sites

Table III. Lecture evaluations

Please respond to questions 1-4 concerning each of the lecture topics (a-1) listed below:

a. DNA structures and the complexity of the genome
b. Gene expression and regulation
c. In vitro manipulations (PCR, cloning and selection)
d. Oncogenes and anti-oncogenes/Molecular mechanisms of cell cycle (expanded in second session)
e. Transferring genes into mammalian cells: gene therapy (expanded in second session)
f. Cell culture, cell transformation, cell fusion and hybridoma formation
g. Macrophages as drug delivery systems (included only in first session)
h. Liposomes as drug delivery vehicles (included only in first session)
i. DNA based diagnosis of disease (included only in second session)
j. Protein stability and pharmaceutics of protein drugs (included only in first course)
k. Recombinant DNA and AIDS
l. Currently marketed products of biotechnology and future drugs

1. Please indicate whether you consider the information given in lectures on the topics listed above to be relevant to pharmacy (1= not relevant, 5 = highly relevant).
2. Please indicate whether these topics were addressed on an adequate level (1= very inadequate, 5= very adequate).
3. Please indicate whether these topics need to be discussed more extensively (1) or less extensively (5).
4. (*First session*) Please indicate how the information gained in these areas has benefited you in the profession of pharmacy over the last year (1=not at all. 5= very beneficial).
4. (*Second session*) Please indicate how you expect the information learned in these areas to benefit you in the profession of pharmacy (1=not at all, 5=very beneficial).

Please rate the statements in 5-12 as 1= Strongly Disagree. 5= Strongly Agree

5. Material relevant to the industrial environment was discussed in this course.
6. Material relevant to clinical practice was discussed in this course.
7. Outside assignments were relevant and contributed to my understanding of the material.
8. Class discussions concerning current research articles complimentary to the material covered in lecture would be (first session) or were (second session) beneficial.
9. A term paper would improve my knowledge of the material.
10. In-class presentations would improve my understanding and help me gain confidence in my knowledge of molecular biology.
11. Prior to taking this course. 1 could discuss the molecular aspects of biotechnology with confidence with other health professionals.
12. As a result of taking this course, I am more confident in my understanding of molecular biology as it impacts clinical practice.

prior to taking this course (confidence level of 1.5 out of 5.0). They consistently indicated an increased confidence in this ability following the course (4.8 out of 5.0).

Regarding several options suggested for increasing class participation and research awareness, students from the first session overwhelmingly endorsed the addition of in-class discussions of current research articles (average score of 5.0) over required students presentations or term papers (both options averaging a score of 3.6). Following the added requirement for graduate-student led discussion of current research articles in the second session, graduate students indicated that the experience was highly beneficial (average score of 4.8). PharmD students from the second session again rated discussion periods more highly (average score of 3.8) than a term paper requirement (average score of 2.8).

Only the graduate students were asked to evaluate the laboratory component of the course. A copy of the evaluation form used to evaluate the laboratory component is shown in Table IV. Students from both sessions indicated that laboratories were relevant and complimentary to lectures (average score of 4.0) and that experiences were highly relevant to the industrial environment (average score of 4.6). They indicated that individual laboratory exercises were useful for reinforcing the lecture material to various degrees (average scores ranged from 3.5-5.0). Students also found individual exercises relevant to industrial drug development and design (average scores ranged from 4.0-5.0).

ONGOING EVOLUTION OF THE COURSE

Between the first and second offering of this course, several significant changes were implemented in response to evaluations, suggestions from students who had taken the course, or curricular changes within the graduate program which impacted on this course. The course became a required course for graduate students. This change was effected partly in response to the observation by faculty that there were many courses that would be beneficial to our graduate students (some available through a cross-registration agreement at other local universities) that required a significant understanding of molecular biology. These courses include graduate level courses in immunology, pharmacology and toxicology.

Several changes were made in the lecture material following the first session. Lectures covering protein stability and the influence of pharmaceutics on protein drugs were moved to a graduate level biopharmaceutics course. Students who were not specializing in pharmaceutics had indicated a lower interest in these areas. After moving the lectures, this material is now provided in a course which is available to all graduate students (specializing in either pharmaceutics, toxicology, pharmacology or medicinal chemistry) but required only for students specializing in the pharmaceutics area. Lectures on liposomes and macrophages as drug delivery systems were similarly moved. A separate graduate level course (drug delivery systems) was offered beginning in 1994. This allowed for a more thorough covering of these drug delivery mechanisms in a context that explores many other relevant systems as well.

The time made available by the removal of these lectures from the course was utilized to expand discussions

Table IV. Laboratory evaluation

Please rate the following statements as 1 = Strongly disagree. 5 = Strongly agree

1. The laboratory was complimentary to the lecture sequence and relevant to lecture material.
2. Laboratory exercises provided experiences that are relevant to the industrial environment.

Please respond to questions 3-4 concerning each of the laboratory exercises (a-1) listed below:

a. Identification of nucleosomes via nuclease digestion studies (first session only).
b. Isolation of DNA and identification of highly repetitive sequences via Southern blot.
c. Cloning of a DNA sequence into plasmid. transformation of E. coli and selection based on antibiotic resistance and -galactosidase activity.
d. Bioassay of transforming agents on tissue cultured cells.
e. Quantitation of cytokines via ELISA.
f. SDS-PAGE and Western blotting (first session only).
g. Production of liposomes as drug delivery vehicles (first session only).

3. Please rate the individual laboratory exercises as (1) not useful for reinforcing knowledge and understanding of lecture material to (5) very useful for reinforcing knowledge and understanding gained in lectures.
4. Please rate the individual laboratory exercises as (1) irrelevant to industrial drug development and design to (5) highly relevant to industrial drug development and design.

involving the introduction of foreign genes into mammalian cells (both in tissue culture and in animal models) and human gene therapy. Lectures were also added covering DNA-based diagnosis of human disease and the molecular mechanisms of the cell cycle.

The original laboratory schedule used in the first session proved to be somewhat over-ambitious. In order to relax the pace and allow students more time with each exercise, two exercises were removed. One had involved drug delivery using liposomes. In the other, students used electrophoresis and Western blotting to identify unknown proteins. The latter exercise has been moved to another required graduate course (also available as an elective to PharmD students), instrumentation and analysis, which was expanded during our recent conversion to the semester system. The final schedule of laboratory exercises (shown in Table II) allowed students to complete the procedures at a more reasonable pace in the second session.

A student-led discussion of current research was added as a graduate requirement following the first session. The purpose of this addition was to give students a chance to examine a current research paper in depth and to summarize and communicate the important aspects of that paper to their classmates. Several other approaches were considered including addition of an in-depth term paper or presentations on broader topic areas. After considering the results of student evaluation surveys from the first session, the student-led research discussions were added.

Other changes were implemented regarding approaches used to encourage discussion among students and to develop communication skills and confidence in molecular biology. Originally, two oral laboratory exams (mid-term and final) were given. These may have been effective; however, due to their subjectivity, assigning grades was difficult. In the second session, a written final was administered and pre-laboratory discussion periods were used to engage students in discussion instead. Students appeared to be more relaxed and participated readily in these ungraded exercises.

The changes which are anticipated for this course in the future include further changes to both the lecture and laboratory schedules. A better discussion of some practical aspects of commercial use of biotechnology for production of protein pharmaceuticals, restriction endonucleases and antibiotics will be added as a preface to the final section concerning currently marketed products and future drugs. This discussion will also cover information pertinent to scaling-up operations for production of large quantities of commercial products from genetically engineered microorganisms.

The addition of a PCR laboratory in which students would use an oligonucleotide primer to amplify a single-copy gene and verify its identity by restriction analysis is anticipated within the next several years. In addition, now that several graduate students have completed the course, they will be utilized as teaching assistants for the laboratory in the future. This will not only benefit faculty by decreasing teaching load but will also provide an excellent opportunity for graduate students to continue to develop their skills in communication and molecular biology. Teaching assistants will lead the pre-laboratory discussions, prepare for laboratory, oversee the individual exercises and grade student laboratory reports.

CONCLUSIONS

Many pharmacy schools are discovering that greater emphasis in the field of biotechnology is required to adequately prepare pharmacists for their changing roles which include an increased emphasis on patient care and counseling and greater responsibilities as a part of the health care system. This is evidenced by reports describing various approaches being used to prepare students with an expertise in biotechnology(3-7). Three schools have published descriptions of courses in pharmaceutical biotechnology designed to address these needs(4-6). Many other schools are in the process of developing similar courses and lectures. It is critical at this stage of development, as more faculty undertake the mission of educating our students in this new area, that we share ideas and approaches including our successes, failures, and ideas for improvement.

The purpose of this course is to impart a thorough understanding of molecular biology to our students which can be applied in academic, research or clinical careers. A thorough understanding is required for teaching as well as applying concepts and methodologies in research (industrial, academic or clinical). Reports describing courses in

biotechnology at other pharmacy schools have described courses with a greater emphasis on the chemistry of proteins and mechanisms for maximizing their potential as drugs. These courses have primarily addressed problems of instability, analysis and immunogenicity(6,7). In our curriculum, we are addressing these topics in biochemistry and pharmaceutics courses in both the graduate and PharmD programs. For this reason, the biotechnology course described here is designed with a major emphasis on understanding and applying molecular biology. Instructors at other schools of pharmacy have recognized a need for increased emphasis in this area as well. Schreier, *et al.* at the University of Florida proposed adding four to six lectures to increase coverage of molecular biology and immunology in their pharmaceutical biotechnology course (6). This change was suggested in response to evaluations which requested more in-depth lectures in molecular biology and biotechnological methodology.

The practical laboratory was designed to give students an exposure to some basic techniques used in biotechnology research. Start-up funds were generously provided by Amgen and used to purchase electrophoresis equipment along with other supplies needed for the laboratory in the first session. It is hoped that an increased familiarity with the methodologies used will increase their ability to evaluate current research in the area and engage in this type of research in the future. Although other schools have not reported a practical laboratory component to their course, at least one school indicated that they hoped to add one(6). In our course, every effort was made to discuss both the limitations and applications of the various methodologies.

The practical laboratory component was a definite asset to our course. Student evaluations indicated that the laboratory exercises were generally effective in reinforcing the knowledge gained in lecture (average scores ranged from 3.5 -5.0 in the first session and 4.0-5.0 in the second). Laboratory exercises were also rated as highly relevant to industrial environments, drug development and design (first session scores ranged from 4.0-5.0: second session scores ranged from 4.2-5.0).

A critical component to achieving the goals of the course is to increase the students' ability to communicate concepts in biotechnology. Due to its high level of technical terminology, biotechnology is often a somewhat intimidating field for those not familiar with it. This is not unusual for any science, as indicated by recent experiments in science education(8). Tobias quoted a non-science faculty peer in her study as saying "In science you don't get into the concepts by learning the words, you only really understand the words when you understand the concepts." It is the goal of this course to prepare pharmacy professionals who have sufficient understanding of these concepts to effectively describe and explain these processes to those not familiar with the field. This skill is important not only for future teachers in pharmacy curricula, but also to pharmacists who counsel patients concerning these medications.

However, literacy in the field of biotechnology is not only essential for effective teaching and counseling. It is also necessary to secure the respect of other professionals in the health care system and allow pharmacists the freedom to shape their future roles in health care. Pharmacy professionals must be prepared to interact effectively, discussing drugs and drug actions with experts in biotechnology. The goal is to produce professionals who are highly literate in biotechnology. Speedie recently recognized the importance of scientific literacy. In a 1992 article she listed the first of seven objectives for producing pharmacists prepared for an increased role in patient care as "to provide pharmacists with a high level of scientific and mathematical literacy"(9). In order to be recognized and respected as key members of professional health-care teams, pharmacists must be able to communicate clearly regarding all classes of pharmaceuticals, including those produced via biotechnology.

In a recent survey of student externs at the University of Georgia and their preceptors, the ability to communicate competently with professionals was ranked as the most important area of competence(10). However, the report indicated that students lacked confidence in this area within hospital and clinical practice. In addition, preceptors' evaluation of student competence in communications did not correspond favorably with the importance placed on that area of competency. I suspect that similar results might be obtained from many of our pharmacy schools. The results underscore the need for a thorough understanding and familiarity with technical terminology in order to convey expertise and gain the confidence of peers in this arena.

There is a need to train pharmacists with expertise in molecular biology. This expertise will be needed in academia and industry, as well as pharmacy practice. I have described a course at Mercer University School of Pharmacy which addresses this need. It covers a wide range of topics in molecular biology. It is designed to provide a solid foundation in molecular biology, preparing pharmacy professionals for a future of biotechnological advances. In addition, this is the first report of such a course which includes a practical laboratory component.

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APPENDIX. ARTICLES FOR STUDENT PRESENTATIONS

Bazett-Jones, D.P., *et al.*, "Short-Range DNA Looping by the Xenopus HMG-Box Transcription Factor, xUBF," *Science*, **264**,

1134-1137(1994).

Kalpana, G.V., *et al*., "Binding and Stimulation of HIV-1 Integrase by a Human Homolog of Yeast Transcription Factor SNF5," *Science*. **266**, 2002-2006 (1994).

Kamb, A., *et al*., "A Cell Cycle Regulator Potentially Involved in Genesis of Many Tumor Types," *Science*, **264**, 436-440 (1994).

Rich, D.L., *et al*., "Development and Analysis of Recombinant Adenoviruses for Gene Therapy of Cystic Fibrosis," *Human Gene Therapy*, **4**, 461-476 (1993).

Smith, M.L., *et al*., "Interaction of the p53-Regulated Protein Gadd45 with Proliferating Cell Nuclear Antigen," *Science*, **266**, 1376-1380(1994).