In our curriculum, students learn basic medical physiology and pathophysiology during a 74-week integrated multidisciplinary program. This problem-based program consists of two phases aimed at student acclimation to the educational approach and to coverage of fundamental information, followed by 10 phases devoted to in-depth coverage of the organ systems. Physiological principles are given major emphasis during these latter 10 phases. In this approach, students meet in small groups, identify basic science learning issues (including physiology) from written biomedical cases, research the issues, and discuss these issues in relation to each case. These groups (6–7 students plus a tutor) meet for 3-hour sessions three times each week during each phase. Students receive cases, along with study guides designed to assist in selecting appropriate information sources for each phase. Each student is evaluated on group process skills, oral presentation and defense of a case analysis, and a multiple-choice exam. Internal and external [National Board of Medical Examiners (NBME) Part I] evaluations for the Classes of 1987–1993 indicate that our problem-based approach results in student learning of medical physiology.

Key words: physiology education; student-centered learning; integrative approach to physiology

Mercer University School of Medicine opened in 1982 with the primary mission of educating physicians to meet the health care needs of rural and other underserved areas of Georgia. The founders of the medical school chose, as a part of the four-year medical educational program, an innovative approach patterned after the M.D. program at McMaster University in Hamilton, Ontario, Canada (reviewed in Ref. 5). Thus the small group tutorial, problem-based educational model was adopted and continues as the single tract available for educating students in the basic biomedical sciences at Mercer. This model is also thought to enhance those attitudes and skills necessary for lifelong self-directed learning. At Mercer the cornerstone of this curricular approach is the Biomedical Problems Program, during which students learn all of the medically relevant basic sciences in the context of clinical case narratives. Students are responsible for in-depth critical analysis of each case in a multidisciplinary and fully integrative manner. The Biomedical Problems Program spans the first two years of the curriculum, during which the students also participate in the Clinical Skills Program and the Community Science Program (3). The latter programs emphasize more clinically oriented processes, skills, and information.

In view of the diverse interpretations of the phrase “problem-based learning,” it should be noted that the program as implemented at Mercer closely resembles that referred to by Rangachari (7) as a student-centered approach that utilizes a problem-based methodology. The primary task is not to arrive at definitive clinical diagnoses (problem solve) but rather to utilize the clinical cases as stimuli for
I N N O V A T I O N S  A N D  I D E A S

YEAR 1

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YEAR 2

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<td>(6)</td>
<td>*</td>
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</table>

FIG. 1

Major areas considered during Biomedical Problems Program and sequence in which they are considered. No. of weeks dedicated to each area, referred to as phases, is shown in parentheses. *Phases during which physiology faculty group provides learning objectives and significant formal evaluation of physiology knowledge occurs. NBME, National Board of Medical Examiners.

learning the basic science concepts, principles, and details.

This paper details those aspects of our program that facilitate the learning of physiology. An overview of the major features of the Biomedical Problems Program is provided to indicate the framework in which this learning occurs. A brief description of this program has already appeared as part of a broader description of the first two years of our curriculum (3).

OVERVIEW OF THE BIOMEDICAL PROBLEMS PROGRAM

The Biomedical Problems Program is divided into 12 time blocks (referred to as phases) covering 74 weeks. As shown in Fig. 1, there are two introductory phases (identified as phases A and B) that are devoted to acclimation of students to the problem-based approach and to coverage of fundamental elements of molecular and cellular biology. During these phases, students study the basic properties of cells, including structural features, metabolic processes, response-communication mechanisms, and specialization, as a foundation for later study of integrative function and complex interactions in tissues and organ systems. The introductory phases are followed by 10 phases devoted to in-depth multidisciplinary coverage of the organ systems. A block of time immediately before the administration of Part I of the examination prepared by the National Board of Medical Examiners (NBME) is also included to allow students to review for this examination.

Small groups of six or seven students, along with a tutor (Ph.D. or M.D.), meet for 4-hour sessions three times each week during each phase. The students are responsible for formulating and carrying out a study plan appropriate to each case. Unlike the traditional educational approach in which students are scheduled for discipline-specific lectures on a regular basis, students in the Biomedical Problems Program are required to identify and discuss the pertinent basic science information from each and every discipline during the consideration of each case. Students are therefore almost continuously responsible for specific information from each discipline over the entire two-year span of the Biomedical Problems Program. Thus physiology is studied in relation to the other basic and clinical sciences over the two-year period. In addition to accrual of knowledge in the biomedical science disciplines, this educational approach places strong emphasis on the development and application of the process skills required for independent analysis of biomedical cases. Process skills in this context refer to 1) Group and Interpersonal Skills: how effectively the student interacts and communicates; 2) Problem-Solving Skills: the student’s critical approach to identifying and applying the basic science involved in the case; 3) Information-Gathering Skills; 4) Evaluation Skills:
the student’s assessment of his or her own understanding and that of the other group members. Tutors are responsible for promoting the use of these process skills in the critical analysis of cases. Another critical role of the tutor is to facilitate maximal coverage of case-related information from all pertinent disciplines during the small group sessions without being directive or serving as an expert resource in her or his discipline. Emphasis of the latter point is important because of the studies indicating that tutors’ subject expertise has important effects on the process of discussion in a problem-based tutorial (8). Students are provided with phase-specific cases, along with certain resource materials designed to assist in selecting appropriate information sources. One such resource is the Study Guide, which contains discipline-specific learning objectives and recommended reference sources. Because there is not time for discussion of all basic science information during group sessions, and it is not possible to include enough cases to cover all of basic science, the study guides serve as the comprehensive indicator of the information that students are expected to learn. The study guides for the organ systems phases, which may contain as many as 300 learning objectives per phase, are organized in a discipline-based or topical manner. Only in the two introductory phases are the learning objectives keyed directly to any case in the phase. Thus the total content appropriate for each phase is specified by the faculty; however, the selection of content and the extent of consideration during group sessions are determined by the case-oriented approach taken by the students. Although faculty-initiated lectures in the traditional sense are not considered to be consistent with the overall concept of the problem-based program, faculty response to student requests for organized discussion of specific questions or particularly difficult topics is considered to be appropriate and is actively encouraged. The major stipulation is that students first make reasonable attempts to analyze and understand the particular topic before requesting faculty presentations. Monitoring of the numbers and duration of these sessions has not been attempted, because student attendance is not mandatory and the sessions vary considerably according to student needs. Our general experience has been that clarification of most topics is accomplished in informal discussions between a few students and individual faculty members. Occasionally the number of students requesting discussion of the same topic is sufficient to schedule a large group session. Sessions attended by a majority of the students are relatively rare.

Evaluation of the performance of each student during each phase is based on 1) tutor assessment of group process skills during the small group sessions, 2) performance on an oral examination that involves presentation and defense of an analysis of an unfamiliar case, and 3) scores on a multiple-choice examination, the Multidisciplinary Exam (MDE), consisting of ~200 questions. Students are evaluated on a Pass-Fail basis only in the first two areas, whereas the more objective nature of the multiple-choice exam format permits a quantitative estimate of specific content and knowledge base. Only objective evaluation results are considered in this report. Faculty of each of the basic science disciplines contribute multiple-choice questions to the examination, the number of questions submitted being consistent with the relative emphasis on each discipline during the particular phase. The MDE is a compilation of discipline-specific questions given as a single exam at the end of each phase during the first and second years. The basic science disciplines involved include Anatomy, Biochemistry/Nutrition, Embryology, Genetics, Histology/Cell Biology, Microbiology/Immunology, Neuroscience, Pharmacology, and Physiology, all of which are administratively organized as the Division of Biomedical Sciences; Pathology, which exists as a separate department; and Behavioral Science, which is currently a joint effort by the Division of Biomedical Sciences and the Department of Psychiatry and Behavioral Science. Each MDE question is keyed to a discipline-specific learning objective provided for the students in the study guide for the phase. To achieve satisfactory performance on this evaluation component for the phase, students must answer >65% of the total number of questions correctly. Thus the MDE has characteristics of the criterion-referenced testing that Turnbull (11) has recommended as the primary method of evaluation in medical schools. Progress in individual disciplines at any given point during the two-year program is indicated by cumulative average multiple-choice exam scores in each of the individual disciplines at the end of each phase.
These allow both individual student self-assessment and discipline faculty assessment of progress in the individual disciplines for diagnostic purposes. It should be noted that students are not required to pass individual disciplines during each phase; promotion to the third year, however, requires a cumulative average of 65% in each discipline.

Performance on Part I of the NBME is used as an external evaluation of knowledge base in the biomedical sciences after completion of the Biomedical Problems Program. Students must pass Part I before entering the third year of the curriculum.

PHYSIOLOGY IN THE BIOMEDICAL PROBLEMS PROGRAM

Students learn the concepts and principles of basic medical physiology, along with other disciplines, as an integral part of the Biomedical Problems Program. Ample opportunity to consider physiological and pathophysiological principles occurs throughout; however, major emphasis on detailed physiological mechanisms at the molecular, cellular, and systemic levels occurs most naturally during the consideration of the organ systems. The problem-based approach places primary responsibility on the students for identifying learning issues related to physiology from the cases. They are then responsible for researching and studying the physiology pertinent to each case. At the subsequent small group session, they are responsible for application of appropriate physiological information during an integrated explanation of the case, i.e., the physiological mechanisms underlying and/or actively involved in the case. The physiological information need not be specifically identified as such during the integrative multidisciplinary discussions occurring in small group sessions; however, students are expected to demonstrate adequate knowledge of the relevant physiology on subsequent student evaluations. Although students cover certain aspects of molecular and cellular physiology as they study other disciplines during the early phases of the Biomedical Problems Program, the physiology faculty do not formally evaluate this knowledge until the organ system blocks. Similarly, evaluation of knowledge in the area of neurophysiology is not done by the physiology faculty group per se, because assessment in this area is conducted primarily by the Neuroscience discipline faculty. The placement of the responsibility for coverage of neurophysiology with the Neuroscience discipline faculty reflects a decision made early in the history of the school because of available faculty resources. Inclusion of neurophysiology evaluation data in this report was not possible because these results are not kept as a separate section by the neuroscience faculty. Evaluation in all other areas of human medical physiology is the primary responsibility of the physiology faculty group. Approximately 20% of the multiple-choice exam for most organ system phases is specifically directed at evaluation of student knowledge in physiology. Thus physiology subscores on the multiple-choice exam provide internal evaluation of student performance in this discipline. Subscores on the physiology section of the NBME Part I provide an external estimation of relative student performance at a national level.

It should perhaps not be surprising that Mercer students have little difficulty in recognizing the relevance of normal physiology and pathophysiology to the cases discussed during the small group sessions. As pointed out by Tosteson (10) and reiterated recently by Carlin (1), physiology logically serves as an infrastructure on which other disciplines build. Furthermore, many faculty and students in both the basic and clinical sciences consider physiology to be one of the most, if not the most, clinically relevant basic science (9). Thus offering students the opportunity to learn physiological concepts and principles in a setting that utilizes clinical narratives should dramatically increase the probability that students will learn and retain medically relevant physiological information (6). The Mercer problem-based program also incorporates the organ-system approach, which has been advocated for some time as an effective method to facilitate integrative learning in a medical curriculum (1). The Biomedical Problems Program may also be considered to offer an opportunity for medical students to obtain a relevant education in the specific discipline of physiology and at the same time a greater appreciation for its relative importance among the basic and the clinical sciences. This contention is supported by the observations that students 1) consistently incorporate consideration of physiology and pathophysiology into their case
innovations and ideas

discussions during small group sessions and 2) routinely include significant discussion of physiological and pathophysiological mechanisms during the oral examinations. Furthermore, it has been our experience that students gain a good foundation in the concepts and principles of physiology during the Biomedical Problems Program, with minimal requirement for assistance from the physiology faculty. The areas for which students do request assistance in physiology are those areas that traditionally have been identified as conceptually difficult. The results of student performance evaluations appear to support the hypothesis that the problem-based approach is an effective method to educate students in medical physiology.

STUDENT PERFORMANCE IN THE BIOMEDICAL PROBLEMS PROGRAM

The accumulated data on student performance for the Classes of 1987–1993 are summarized in this section. The Charter Class (Class of 1986) is not included in this group because the MDE was implemented after this class completed their first year (3). Student performance data derived from one internal student evaluation method (multiple-choice exam) and an external student evaluation method (NBME I) are provided. To facilitate comparisons, the data from NBME I are presented as class averages that have been normalized to national averages. Thus the data points depicted in Figs. 4 and 5, showing NBME I performance, were derived by expressing the Mercer average for each class as a percentage of the respective national average for that year.

Student performance data from the internally generated and administered MDE are summarized in Fig. 2: data points for the class averages for all multiple-choice exam questions given during the Biomedical Problems Program (~ 2,000 questions) and for the physiology multiple-choice exam questions only (~ 200 questions). As shown, student performance in physiology has consistently been equal to or a few points above performance on the total multiple-choice exam. The greatest improvement in scores on both the total multiple-choice exam and the physiology section of the exam occurred between the classes of 1987 and 1988. Possible explanations for this observation include improved ability of the

faculty to prepare questions appropriate for the Biomedical Problems Program, faculty provision of the students with discipline-specific learning objectives for the phases, and greater student acceptance of objective evaluation methods. Since that time, performances on both the physiology section of the exam and the total exam have remained relatively constant among the classes.

A more detailed indication of student performance in the physiology discipline of the Biomedical Problems Program is provided by the data summarized in Fig. 3, in which the scores on the physiology section of the multiple-choice exam are compared with those on the total exam for the six phases of the Biomedical Problems Program in which physiology receives major emphasis. Each bar represents the mean score for five classes (1989–1993) in each of the six phases. The numbers of physiology questions on each phase of the multiple-choice exam expressed as a percentage of the total number of exam questions (usually 200/exam) for the respective phase were 7% for the musculoskeletal phase, 21% for endocrinology, 21% for cardiovascular, 19% for respirology, 22% for renal, and 15% for gastroenterology. It has been suggested by some faculty that the exam scores for a given discipline are generally low when the number of questions for that discipline is low. The data shown in Fig. 3 do not support this contention for physiology; no obvious relationship between the number of physiology questions on the exam and the average physiology score on the multiple-choice exam is apparent in these results. It is evident from inspection of the results depicted in Fig. 3 that student performance on the physiology
section of the multiple-choice exam is comparable to performance on the total exam in these phases of the Biomedical Problems Program.

Figure 4 compares the average student performance on the physiology section of NBME I with that on the total NBME I for the Mercer Classes of 1987–1993. For all but one class, the average performance on the physiology section has been equal to or better than the average performance on the total NBME I exam. It is of obvious concern that student performance on both the physiology section and the total NBME I appeared to show a gradual decline over the first six of the seven classes, with the possible exception of the class of 1990. Although a complete explanation for the apparent steady decline in NBME scores over this time period is not available, one contributing factor appears to have been the expansion of the class size. The greatest absolute decrease in physiology scores on NBME I (Class of 1990 compared with the Class of 1991) occurred when the Mercer class size was increased from 24 students per class to 42 students per class. This decrease in performance on NBME may be related to student entrance qualifications because it coincided with the greatest single decrease in average Medical College Admissions Test scores for any class during this interval. Thus expansion of class size in the face of an already decreasing pool of qualified applicants is the most probable explanation for this particular drop in student performance. The slow but steady decline in national student performance on the total NBME I scores from 1986 to 1989 (comparable to Mercer classes of 1988–1992) was also noted by Iwamoto and Volle (4). Their data also appear to indicate that mean NBME I performance for a subset of 22 “newer” schools (established since 1963), which includes Mercer, has declined to an even greater degree over this time period. Data contained in the report of Goodman et al. (2) also suggest that performance of the traditional curriculum students at Rush Medical College on NBME I has shown a similar decline over this time period. A corresponding decline in the NBME I performance of the Rush Alternative Curriculum students (another problem-based program) is not evident over this time period.
however, it must be noted that those students are a very select group. Comparison of NBME I scores (means ± SDs) of 72 Alternative Curriculum students matriculated from 1984 through 1988 at Rush Medical College with that for 160 Mercer problem-based curriculum students that matriculated from 1983 through 1988 for either the total exam (485 ± 90 vs. 466 ± 90, respectively) or the physiology subject area of the exam (491 ± 92 vs. 476 ± 96) does not reveal significant differences. It is significant to note that the performance on both the physiology section and the total NBME I for the Class of 1993 appears to be improved over that of the Class of 1992. The improvement does not appear to be related to entrance qualifications, because the average MCAT score of the Class of 1993 was not significantly higher than that of the Class of 1992. Assessment of whether this apparent improvement in Boards scores for the Class of 1993 can be related to the revisions of the aims and the format of NBME I will require performance data on additional classes.

Although the NBME I performance data discussed above are informative as to relative performance scores compared with national averages, they do not provide any indication of success rate on passing the exam. Table 1 summarizes student performance on the total NBME I and the physiology section of it in terms of the pass rates on the first attempt and on one of the total number of allotted attempts. Mercer minimal standards stipulate that students must pass NBME I before promotion to the third year and that only three opportunities to pass the exam are allotted. In contrast to the requirement that an average passing score on the total exam be achieved, there is no such requirement for any of the discipline areas. Thus students are not required to pass the physiology section of NBME I; however, it was of interest to compare the pass rates on the physiology subsection with the overall pass rates.

Of the 208 students that have taken NBME I over this seven-year period, 82% passed the total exam on the first attempt and 98% passed at one of the three allotted attempts (Table 1). One hundred thirty-five (97%) of the 139 students from the Classes of 1987–1992 that passed the total exam on the first attempt also passed the physiology section.

Furthermore, comparison of pass rates based on the first five classes (1987–1991) indicates that 84% (107 of 128) passed the physiology section on the first attempt, whereas this rate improved to 92% (118 of 128) when all attempts were considered. An overall pass rate on the total NBME I for Mercer students during this seven-year period of 98%, along with an acceptable success rate at passing the physiology section of NBME I, indicates that Mercer students learn the basic biomedical sciences, including medical physiology, during the problembased program.

Particularly perplexing is the apparent lack of correlation between average class performance on the physiology sections of the multiple-choice exam and NBME I (Fig. 5). As noted earlier, a steady decline of NBME I scores appears to have occurred, whereas no significant change in student performance on the physiology section or the total (data not shown) multiple-choice exam was observed. Thus student performance on the multiple-choice exam appears not to be predictive of performance on NBME I, at least when average class performance is considered. A definitive explanation for this lack of correlation is not immediately apparent. The exams constructed by the Mercer faculty may be more directly related.

### Table 1

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<th>Class Year</th>
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Success is shown in percentages of those students passing the National Board of Medical Examiners (NBME) Part I total exam or physiology portion. *Does not include 6 students who repeated and passed exam after June 1991, because physiology discipline subscores were not available for these students as a result of changes in score-reporting procedures by NBME. **Data on physiology discipline subscores for class of 1993 were unavailable because of changes in score-reporting procedures by NBME.
to the learning that occurs in the problem-based approach than is the NBME I. Furthermore, students may be better able to anticipate questions prepared by Mercer faculty than questions developed by those who prepare the NBME exams, because Mercer exam questions are linked to the study guide learning objectives. It will be of considerable interest to determine whether the correlation between student performance on the multiple-choice exam and NBME I improves now that NBME has revised the exam format.

These results indicate that Mercer students gain an adequate knowledge of basic science factual information. Mercer students perform well on the types of evaluation methods that were originally designed for the more traditional approach. In the traditional faculty-centered model, the lecturer determines both the factual information to be emphasized during the learning process and the emphasis during the evaluation. In the Mercer problem-based model, faculty-centered evaluation methods are used, even though the students are given significant responsibility for identification of the factual information to be learned. Our students are encouraged to take a self-directed approach to initial identification of the information to be learned, followed by consultation of the study guide to ensure that their coverage is comparable to that expected by the faculty. Although we currently have no reliable mechanism to assure primary dependence on self-directed learning skills with secondary use of the study guides, our experience suggests that many students that are initially very dependent on the study guides improve their independent study skills over the two years. Placement of major emphasis on the application of basic science information in the analysis and integrated explanation of biomedical problems appears to provide a context in which students can both learn and retain the factual information. Furthermore, students are required to assess critically and revise appropriately their knowledge base as new issues, or issues previously considered from a different perspective, arise during the process of case analysis.

CONCLUSIONS

Student performance scores on the physiology sections of the phase examinations (multiple-choice exam) and the NBME I examination indicate that Mercer students achieve a satisfactory knowledge base in medical physiology during the problem-based program. Scores on the physiology section of the multiple-choice exam are usually equal to or better than scores on the total exam (all disciplines together). Mercer student performance on the physiology section of NBME I is generally comparable to the national average on the physiology section (91–105% of national average). Furthermore, for our students, performance scores on the physiology section are usually higher than the scores on the total NBME I. The available data also suggest that the pass rates on the physiology section of NBME I are comparable to those of the total exam.

We conclude that the Mercer problem-based approach is successful at providing students with the opportunity to learn medical physiology in the proper relationship to the other basic biomedical sciences and to master the process skills necessary for critical analysis of biomedical cases.

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