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INSTRUCTIONAL DESIGN AND ASSESSMENT

Integrating a New Medicinal Chemistry and Pharmacology Course Sequence into the PharmD Curriculum

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Objective. To evaluate the implementation of an integrated medicinal chemistry/pharmacology course sequence and its alignment with a therapeutics series.

Design. Each topic was divided into modules consisting of 2-hour blocks, and the content was integrated and aligned with the therapeutics series. Recitation sessions emphasizing application skills in an interactive environment followed each of three 2-hour blocks. To ensure that students achieved competency in each unit, students failing any unit examination were encouraged to undergo remediation.

Assessment. Student feedback was collected by an independent researcher through social media and focus groups and relayed anonymously to course directors for midcourse improvements. Responses from surveys, interviews, and student ratings of faculty members and of courses were used to implement changes for future editions of the courses.

Conclusion. The majority of students and faculty members felt the integration and alignment processes were beneficial changes to the curriculum. Elements of the new sequence, including remediation, were viewed positively by students and faculty members as well.

Keywords: medicinal chemistry, pharmacology, integration, alignment, curriculum

INTRODUCTION

The importance of biomedical and pharmaceutical sciences in pharmacy education is highlighted in Accreditation Council for Pharmacy Education (ACPE) Standards, where Guideline 13 requires schools of pharmacy establish a curriculum that provides students with the scientific knowledge that would assist them in achieving competencies in the different disciplines of pharmacy, which include the biomedical and pharmaceutical sciences[1] and in the CAPE Educational Outcome that includes developing, integrating, and applying knowledge from the foundational sciences.[2] As part of the curricular revision initiated in the fall 2010 term at the University of Michigan College of Pharmacy, 2 of these sciences, pharmacology and medicinal chemistry, were combined into 1 course sequence called Principles of Drug Action. This integration, coupled with a higher commitment to active learning and alignment with clinical coursework, attempted to address numerous redundancies, the occasional disconnect between the 2 courses, and a perception by students of a lack of relevance of these disciplines to pharmacy and pharmaceutical care.

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An interest in integrating curricular topics is growing in higher education generally, particularly in the biomedical field, in the United States and beyond.[3,4] Many factors likely contribute to this increased interest in integration including continued growth of knowledge, a need for relevance in the curriculum, improved retention, and increased student-faculty member interactions.[5] Advantages of integrated, interdisciplinary coursework include increased application skills among students and a better understanding among faculty members of what is taught elsewhere in the curriculum.[6-9]

PharmD students are embracing the integration of the biomedical and pharmaceutical sciences with the clinical sciences as necessary to their pharmacy careers.[10] Textbooks now allow for the integration of these disciplines, too. For example, the preface to *Foye's Principles of Medicinal Chemistry* explains that their "organizational philosophy" addresses the increasing integration of medicinal chemistry with pharmacology in pharmacy schools across the United States.[11]

Studies show advantages of integrating these disciplines. Alsharif and colleagues found that pharmacology and medicinal chemistry complement each other and that students at 4 different institutions were most satisfied when the pharmacology and medicinal chemistry lessons

coincided with each other.[12] Ives and colleagues found the integration of these disciplines helped eliminate redundancies and increase both student satisfaction and amount of content covered. They also found that faculty favored integration and noted increased student participation and performance.[13] Advantages of this integration observed by Stull and Carter included students approaching issues from a multidisciplinary standpoint and interdisciplinary faculty members working together to improve outcomes and goals for students.[14] Ried et al evaluated students' perceptions of their ability to provide pharmaceutical care and concluded that students valued integrating "basic" sciences in order to formulate a proper decision.[15] Moreover, extending such integration to include clinical sciences enhanced students' interest, improved students' ability to apply basic sciences to clinical practice, and improved student attitude towards these disciplines.[16,17]

A number of challenges are inherent in integrating disciplines across the curriculum. From a student point of view, integrated courses may have a significant amount of material overlap, and faculty members may disagree over content, coordinate poorly on examinations, and integrate material ineffectively. Among faculty members, the major concern is the intensive effort needed for proper integration of the course material.[18]

The objective of this study was to assess the implementation of integrated medicinal chemistry and pharmacology courses and aligning the presentation of topics in the integrated course sequence with that of the therapeutics sequence. While many colleges and schools of pharmacy moved to integrate the biomedical and pharmaceutical sciences with the clinical sciences into 1 integrated course and a number of studies have been published highlighting this integration, this study looked at integrating medicinal chemistry and pharmacology, while aligning the presentation of topics with the clinical sciences courses, without a formal integration of all 3 disciplines. This integration model was designed to fit within a multidisciplinary integration model, or a step 9 out of 11 on Harden's integration ladder.[19] This model aims to include basic science concepts in the curriculum, and delivery of the designated content by experts from each discipline. It also allows for discussion of each topic at more than 1 point in the curriculum, rather than covering each topic singularly in 1 course. Our study also examined innovative components of the course sequence such as an inclass remediation plan, recitation sessions that aimed to bring a clinical flavor to the basic science courses, and inclusion of the Top 200 Drugs modules, which were aligned with the drug groups discussed in the course sequence to provide students with the science background to help learn these modules.

DESIGN

In the fall 2010 term, the College of Pharmacy at the University of Michigan, implemented a new curriculum for their PharmD program. In the old curriculum, medicinal chemistry and pharmacology were taught as 2 separate course sequences. The medicinal chemistry sequence was taught as three 3-credit courses in the winter of the first year and fall and winter of the second year. The pharmacology sequence was taught as 2 courses in the second year, a 3-credit course in the fall and a 4-credit course in the winter. There was little alignment between the topics discussed in the 2 course sequences or with the therapeutics sequence. For example, centrally-acting drugs were taught in the winter of the first year in the medicinal chemistry course, at the end of the fall semester of the second year in pharmacology, and in the fall semester of the third year in therapeutics (Table 1). Attempts to better align the topics resulted in limited success due to conflicts with other aspects of the different course sequences.

In the new curriculum, the pharmacology and medicinal chemistry courses were integrated into three 5-credit courses called Principles of Drug Action, taught during the winter of the first year and fall and winter of the second year. The 3 courses were designed to align with the therapeutics course sequences so each topic was discussed in the Principles of Drug Action sequence first, then discussed again in the therapeutics sequence the same or following semester. For example, cardiovascular agents

Table 1. Alignment of Selected Topics in the Nonintegrated Courses vs the Integrated Principles of Drug Action Sequenc

Topic	Centrally-acting Agents	Cardiovascular Agents	Diabetes
Prior to Integration			
Medicinal Chemistry	Winter (S) – P1 year	Fall (S) – P2 year	Fall (F) – P2 year
Pharmacology	Fall (S) – P2 year	Winter (F) – P2 year	Winter (S) – P2 year
Therapeutics	Fall (S) – P3 year	Winter (F) – P3 year	Winter (S) – P2 year
Integrated Course			
Principles of Drug Action	Fall (S) – P2 year	Winter (S) – P1 year	Fall (F) – P2 year
Therapeutics	Winter (F) – P2 year	Fall (F) – P2 year	Fall (S) – P2 year

F=first half of the semester; S=second half of the semester

were discussed in the Principles of Drug Action sequence in the second half of the winter semester of the first year, and then discussed in therapeutics at the start of the fall semester of the second year (Table 1).

The second phase of the process involved the integration of the medicinal chemistry and pharmacology content into the new course sequence. Five to 6 faculty members from each discipline held a series of meetings during which they examined course content, eliminated redundancies, and identified and filled content gaps. The number of required faculty meetings varied by section/course. Some topics required considerable more work than others to integrate, but typically 3-5 hourly meetings took place. Each topic was assigned a number of 2-hour blocks, with the faculty members designing a content module for the topic based on the general course outcomes. Table 2 describes the content of a typical module, which covers one topic. In this case pharmacological and physiological backgrounds were discussed at the beginning of the block, followed by medicinal chemistry topics such as molecular mechanism of action, structure activity relationships, and metabolism. Faculty members also discussed other topics including the clinical pharmacology of the drugs during the blocks.

Generally, at the end of each set of three 2-hour blocks, an interactive recitation session was held. Each recitation session covered 1 or 2 drug classes and was run by 3 graduate student instructors, supervised by the course sequence director. All graduate student instructors were required to attend a 1-day training session conducted by the university and 1 session with the course sequence director at the college prior to the semester. The recitation sessions typically started with a quiz, then short presentations illustrating the integration of pharmacological and chemical concepts of the topic, followed by interactive exercises to demonstrate these concepts. The final portion of the session was spent discussing case studies illustrating clinical applications of the drug classes. Clinical faculty members were involved in the design of some of the cases to provide a link to the clinical courses. They were also invited to participate in the discussions alongside a basic science faculty member to demonstrate how clinical decisions are often influenced by basic sciences. When first implementing these sessions, clinical faculty members were involved in the discussion of these cases. Later, they continued to review cases, and worked on adding capstone sessions that would involve integrated cases with faculty members from basic and clinical sciences present to lead discussions. Two examples of these cross-over cases are shown in Table 3.

An inclass remediation plan was introduced as part of the Principles of Drug Action course sequence. The primary purpose of this plan was to ensure that students became competent in each unit (which covered several topics) of each course, since it was conceivable that a student could fail 1 or more unit examinations (eg, not achieve a minimum level of mastery of that subject area), but could still pass a given course due to higher performance in other sections. It also gave students a chance to overcome difficulties they may have encountered during 1 or more unit examinations of the sequence. The instituted plan was optional, but strongly encouraged.

The remediation plan required students failing (achieving less than 70% on) any of the 4-unit examinations in each course to meet with the course director and discuss possible reasons for their performance and whether they should participate in the remediation exercise. The student was then given 2 weeks to restudy the material tested on the unit examination, with a graduate student instructor assigned to serve as a tutor, if necessary. A remediation examination was administered at the end of the 2 weeks. The students were able to increase their unit examination score by receiving up to 10% of the total unit examination points, depending on their performance on the

Table 2. Setup of the Adrenergic Agents Module in the Principles of Drug Action Course

No. of 2-hour blocks	Three plus recitation sessions
2-hour block 1 – first hour	Pharmacology of sympathetic nervous system
	Different adrenergic receptors including signal transduction
	Adrenergic neurons including biosynthesis, storage, and metabolism of neurotransmitters
	Physiological effects of stimulating adrenergic receptors
2-hour block 1 – second hour	Chemistry of norepinephrine and epinephrine biosynthesis and metabolism
	Receptor binding of norepinephrine, epinephrine and related agents
	Agents that act at adrenergic neurons and their SAR*
2-hour block 2 – first hour	Pharmacology of adrenergic agonists and their clinical application
2-hour block 2 – second hour	Chemistry of adrenergic agonists including their SAR, receptor binding and metabolism
2-hour block 3 – first hour	Pharmacology of adrenergic antagonists and their clinical application
2-hour block 3 – second hour	Chemistry of adrenergic antagonists including their SAR, receptor binding and metabolism

* Structure-activity relationship

Table 3. Examples of Cases Studies Used in Recitation Sessions

A 68 year old female presents with "a swollen left calf" that has been red and tender for 2 days. An ultrasound shows a deep vein thrombosis in the left leg only. She is 5'4" tall and weighs 50 kg. Her BUN/Cr is 15/2.5. The physician wants to use Enoxaparin and asks you to dose it.
A. What dose do you use, and what factors do you take into consideration?
B. How will you monitor the patient?
C. Seven days after starting the Enoxaparin, the patient's platelets drop from 280,000 to 40,000. She complains that her right calf is now hurting, it is also now red and tender and an ultrasound shows a new DVT[a] in her right leg as well as some progression in her original clot in her left. What could be happening, and what do you do?
NA is a 58-year-old, white male who has been diagnosed with Stage I hypertension (152/92 mmHg). NA is a smoker and continues to smoke in spite of experiencing the initial stages of COPD[b] (emphysema with airflow obstruction). NA is a postal employee who delivers the mail on foot, walking 3 miles a day in all kinds of weather.
Upon his doctor's recommendation, NA has been watching what he eats and has restricted his sodium intake but with no effect on his hypertension. His blood lipid profile is normal. The doctor wants to initiate monotherapy with a β-adrenergic blocker. Evaluate each drawn structure in relation to this case and make a recommendation.

[a] Deep venous thrombosis

[b] Chronic obstructive pulmonary disease

remediation examination. However, their new score could not exceed 70% on the failed unit examination. Students were also required to pass (achieve greater than 70% on) the remediation examination to receive any points. Basically, the students could increase a failing score to the minimum passing score of 70% by successfully going through the remediation. Because the course had a comprehensive final examination, there was added incentive to go through the remediation process as this would likely help the students perform better on the final.

A requirement to successfully complete the PharmD curriculum at the college is to pass a high-stakes examination covering the Top 200 Drugs, based on sales in the United States. Students are required to complete self-learning modules and quizzes throughout each of their first 4 semesters, each covering 50 drugs, prior to taking the high stakes examination.

The first group of modules (first 50 drugs) was part of the first-year Community Pharmacy course given in the fall, which focused on drugs that a pharmacist would likely see in that setting. The next 3 groups of modules were integrated into the Principles of Drug Action sequence and were aligned with the topics discussed in class. For example, during the discussion of adrenergic agents, students were required to complete the seventh module of the Top 200 drugs that contain all adrenergic agents in that list. During the recitation session that covered adrenergic agents, these drugs were specifically discussed.

Each of the 3 Principles of Drug Action courses were assessed in a similar manner. Eight quizzes, each covering three 2-hour blocks, were given at the start of each recitation session, which also served as motivation for students to be ready for the sessions and enabled them to participate actively in the discussions and activities. Every six to seven 2-hour blocks were tested via a unit examination, 4 in total per course. Each course had a capstone final examination, which was cumulative and represented 25% of the grade. Most quiz questions were knowledge-based, typically multiple-choice or fill-in-the-blank. Unit examinations focused largely on problem-solving essay questions, with an emphasis on higher-order thought skills based on Bloom's Taxonomy.[20] The questions on the final capstone examination were either multiple-choice or short-answer questions, with a mix of knowledge-based and higher-order thought questions.

During the first installment of the course sequence, it was decided that student input would be sought and modifications to course structure and instruction would be implemented during the semester based on their comments, where appropriate. To allow feedback from students, a course Facebook group was created and discussion questions were posted weekly. Only students enrolled in the class and 1 student researcher had access to the group, and none of the faculty members were able to see the discussions. Students were asked to respond to the discussion posts about specific issues regarding the integration of the courses, including any suggestions they had for improvement. Students had the opportunity to post their own questions and comments to the Facebook group as well. Students who did not have a Facebook account or chose not to participate in the group had the opportunity to e-mail their opinions and answers to the student researcher.

At the end of each week, the student researcher prepared an anonymous summary of the topics discussed for the course sequence director. Based on this feedback, the course sequence director and the faculty members implemented changes to the course in areas such as the structure of the recitation sessions, teaching approaches, and the

integration process. One example change was the use of recitation sessions that included all students rather than the small group discussions originally planned. Another example was streamlining lectures so pharmacological concepts were always discussed first, followed by chemical concepts.

To gauge student perception of the new courses, a survey was administered at the end of the semester to students enrolled in the first and was the basis for changes in subsequent years. The survey was composed of 11 questions using a 5-point Likert scale and 1 free-text comment. In addition, 2 groups of 6 student volunteers each met with a student researcher, once mid-semester and once at the end of the semester. The student researcher conducted one-on-one interviews with 2 key faculty members and the 3 graduate student instructors involved in the course during the summer of 2011. The study received institutional review board approval from the University of Michigan.

To investigate the effect of integration of the 2-course sequence on student learning, we looked at final letter grades from 1 course from each discipline in the 2 years prior to integration (2009 and 2010) and compared them to letter grades in the equivalent course in the new sequence in the most recent 2 years after integration (2013 and 2014).

The study looked at the letter grade range (A-D) and converted each letter grade to the point average as defined by the University of Michigan (A=4.0, A-=3.7, B+=3.3, B=3.0. . .etc.). For the 2 courses prior to integration, the average grade point average from the 2 courses for each student was calculated. Table 4 shows the letter grade distribution from the 2 sets of courses. The overall grade distributions were similar, although a higher percentage of students received grades in the A range (21% of students versus 16% of students) in the integrated course. Notably, the same number of students (2) received a failing grade (D+ or below) in each set of courses. This is consistent with results in all the other courses in the sequence before and after integration, where approximately 1% of students received a failing grade each year.

When comparing the grade point average for each set of courses as described above, the integrated course showed a higher, but insignificant *($p=0.25$)*, grade point average (2.99 vs 2.91). Statistical analysis was conducted using an unpaired 2-sample test, with a $p<0.05$ considered to be significant.

Table 4. Comparison of Letter Grades Prior and After the Integration Process

Letter Grade	Prior to Integration (n=152) No. of Students (%)	After Integration (n=161) No. of Students (%)
A	24 (15.8)	34 (21.1)
B	78 (51.3)	88 (54.6)
C	48 (31.6)	37 (23.0)
D	2 (1.3)	2 (1.3)

EVALUATION AND ASSESSMENT

The responses to the relevant questions from the end-of-semester survey are shown in Table 5, with the results reported as percentages of responses and the mean and standard deviation based on the 5-point Likert scale. The response rate for the survey was 67%. The majority (78%) of responding students felt that the integration was an improvement in the curriculum, while only 3% strongly disagreed. An overwhelming majority of students (92%) agreed that the course's instruction and structure improved as the semester progressed, without any students disagreeing with that statement. Students in the focus group sessions pointed out that students enrolled in the course sequence felt their views posted on the Facebook group were instrumental in implementing the changes that targeted improvement in course instruction and structure. The majority of students (81%) responded that the course would be more efficient with fewer professors, and none of the students strongly disagreed. This was the general consensus from the focus groups as well, with 58% of students agreeing that recitation sessions contributed to their learning and 25% disagreeing. Based on written comments, most of those who did not view the sessions positively either felt that the cases discussed were at a more advanced level than the instructions given in class or felt that much of the information seemed repetitive. Recitation sessions were identified by 35% of the students as what they liked the most about the course, making it the most common answer.

Although 94% of students were in favor of a remediation plan, approximately 50% of students in the focus groups felt that every student should be given the opportunity to improve their grade and remediate even if they passed the examination. All students participating in the remediation program agreed or strongly agreed that it improved their competency with the material. Analysis of student performance indicated that students who participated in remediation showed a higher rate of improvement than other students enrolled in the class on the final examination.

The focus group echoed the results from the end-of-semester survey. Most students responded that 5-credit courses placed an excessive workload and increased pressure on students that may have affected their learning. Students praised the course structure and felt it was run efficiently and that most of the problems were related to instructional shortcomings of individual instructors. Both

Table 5. Results from Postcourse Student Survey (n=65)

Question	Strongly agree/agree	Strongly disagree/disagree	Mean (SD)
I believe the integration of medicinal chemistry and pharmacology into 1 course was a beneficial change in the pharmacy curriculum.	78%	3%	4.0 (0.84)
As the semester progressed, the instruction and structure of the course improved.	92%	0%	4.5 (0.65)
The course would have been more efficient with fewer professors.	81%	11%	4.1 (0.95)
The recitation sessions were effective and beneficial to my learning.	58%	25%	3.5 (1.07)
I agree that this course should offer a remediation plan to students who fail examinations.	94%	3%	4.5 (0.80)

Means and percentages were calculated based on a 5-point Likert scale, with 1=strongly disagree, 2=agree, 3=neutral, 4=agree and 5=strongly agree

faculty members interviewed emphasized that the integration eliminated redundancies as expected and helped faculty members better understand what was taught in both disciplines. The surprising element according to 1 faculty member was that integration uncovered gaps in the curriculum not addressed by either discipline in the old format. These gaps were addressed in subsequent editions of the courses.

Mean scores on 3 common questions used at the University of Michigan (Table 6) showed significant improvement on course evaluations of the pharmacology and medicinal chemistry courses for the new integrated course (2010-2013) compared to evaluations prior to integration (2008-2010). These evaluations were conducted at the conclusion of each course and asked students to indicate their agreement or disagreement with the statements below, based on a 5-point Likert scale, with 5=strongly agree and 1=strongly disagree. Table 6 compares the scores for each question, expressed as the mean scores of evaluations of the courses 2 years prior to integration and mean scores of evaluations of the first 2 years postintegration. The mean score for each question improved significantly after the implementation of the integrated courses, with the statement "I learned a great deal from this course" showing the highest improvement. There may have been factors contributing to this improvement beyond actual improvement in course delivery, such as the inclusion of a remediation option, although this factor may be balanced by the perceived difficulty of an integrated course sequence. Statistical analyses were conducted using an unpaired 2-sample test, with a $p<0.05$ considered significant.

DISCUSSION

The effect of integration on student learning showed promising but limited improvement. Notably, the number of students receiving a failing grade remained constant, but a larger number of students received grades in the A range. The lack of significant improvement in grades in the integrated courses may have been the result of many factors, such as the courses being worth 5 credits, which resulted in a heavy workload for students, many of whom still viewed it as 1 course. Another factor may have been that the assessments in the integrated courses focused on problem solving and questions requiring higher-thought processes, which may have led to more challenging tests. The majority of survey participants, focus groups, and Facebook discussion groups agreed that integration of the 2 courses was a beneficial change to the curriculum and supported the different elements of the course sequence, such as course and assessment structures, active-learning components, recitation sessions, and the remediation plan. Course evaluations showed that students were more satisfied and felt they learned better in the integrated course than in the individual courses.

A number of factors helped make this transition successful. Seeking immediate feedback from students and implementing their suggestions when possible was a valuable tool, fostering student engagement and positive changes to the courses. Faculty buy-in and involvement

Table 6. Comparison of Scores on Course Evaluation Prior to and After Integration

Question	Prior to Integration, mean (SD); n=322	Post Integration, mean (SD); n=193
Overall, this was an excellent course.	3.25 (1.183)	3.80 (0.847)*
I learned a great deal from this course.	3.67 (1.003)	4.38 (0.62)*
I had a strong desire to take this course.	3.60 (1.124)	3.87 (0.982)*

* $p<0.05$

is the key to a successful integration process and many of the initial problems were the result of the lack of communication among faculty members. As they began to see the advantages of the integration, faculty members became more involved and contributed more to the success of the course sequence. The process required a substantial time commitment from faculty members during the initial phase of integration and commitment from the administration to encourage and support faculty efforts.

This model could be utilized in colleges and schools of pharmacy considering integration of basic science courses without going to a fully integrated model of teaching, which would integrate pharmaceutical, administrative, and clinical sciences. Components of the model could be included in various curricula; for example, inclass remediation may be useful for schools looking to address a lack of basic student knowledge as students progress through the curriculum. The integration of the Top 200 Drugs modules could be used to better include clinical information in basic science courses or vice versa.

In the coming years, a number of changes are planned. The course sequence will be distributed across 4 semesters instead of 3, reducing the amount of material covered in a single course, workload having been a concern raised by students and faculty members. We are studying the best alignment model for clinical and basic sciences and are experimenting with capstone case studies that cover both sciences. More time will be dedicated to case studies during recitation sessions in the future, including capstone cases that address basic and clinical science aspects after the concepts are covered in both course sequences. The course sequence director will ensure that a number of threads are covered in each topic discussed—including molecular and cellular mechanisms of action, structure activity relationships, metabolism, clinical use, drug-drug interactions and toxicity—and will include the use of curricular mapping of course content and outcomes. Students will be given a chance to earn a predetermined number of points, which will be added to their course grade based on their performance on the Top 200 Drugs examination. This change is in response to the observation that a number of students aimed for simply passing that examination rather than performing to the best of their abilities. We also plan to explore ways to use the Top 200 Drug modules to give the courses more clinical applicability.

SUMMARY

Implementation of the new integrated medicinal chemistry/pharmacology course sequence in the College of Pharmacy at the University of Michigan resulted in a successful transition from the 2-course model, where there was little communication between faculty members and little alignment with therapeutics, to an integrated course sequence that addressed shortcomings of the old model, provided opportunity for active learning and applications to the clinical setting, and highlighted the relevance of these basic science disciplines to pharmaceutical care. The remediation process ensured that all students completing the course achieved an acceptable level of mastery in all individual sections of the course.

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