Innovations in Teaching

Pharmacokinetics Involves Lifelong Learning: The PILL Program

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The goals of this teaching innovation are to promote reflective thinking and active PharmD student involvement in achieving educational outcomes related to pharmacokinetic dosing. The PILL program begins during a didactic Applied Pharmacokinetics course and continues the following year during a required Pharmacokinetics clerkship. During the didactic course, students complete three modules that provide practice in solving pharmacokinetic dosing problems of case study patients, guide them in diagnosing their own errors, and promote reflective thinking. Based on the results from the first didactic class, the following modifications are planned: (i) addition of an orientation session that guides the student in how to think reflectively; (ii) conversion of the case studies to Computer-Assisted Instruction format; (iii) modification of selected case studies to minimize the number of new concepts the learner is expected to use; (iv) expansion of the case studies to provide practice with a greater breadth of drugs; and (v) generalization of the PILL program to a group of pharmacy students with more diverse readiness to conduct self-assessment.

PROLOGUE

In reflection, I believe there were two personal endeavors that promoted my development of expertise in pharmacokinetics. First, I continually monitored my accuracy in predicting the levels my recommended regimens would provide. Over time, this constant self-assessment allowed me to identify strategies for increasing my precision. Also during my evolution as a practitioner, I encountered patients who depicted classic presentation of a pharmacokinetic problem and emphasized the "pearls" of drug regimen design. These patient situations instilled new insights into how I can better manage patients when asked to provide a pharmacokinetic consultation.

D.E. Beck, PharmD

INTRODUCTION

These reflections have led us to postulate that pharmacy students can be taught current pharmacokinetic concepts and the procedures for applying them to actual patients. However, when the student is unaware of his or her cognitive processes and effectiveness in pharmacokinetic dosing, refinement of these skills and development of expertise may not evolve. Since the evolution of expertise requires experience and internalization of this learning over time, this is usually developed after completion of an entry-level degree program(1). Therefore, students must be capable of conducting lifelong learning in order to achieve expertise in pharmacokinetics. The goals of

1Manuscript based on a submission to the 1994 Council of Faculties
Innovations in Teaching Competition
The teaching innovation described in this paper will be referred to as the Pharmacokinetics Involves Lifelong Learning Program (PILL Program). The PILL Program begins during a didactic Applied Pharmacokinetics course and continues the following year during a required Pharmacokinetics clerkship. This paper will primarily describe what has been accomplished in the didactic course.

BACKGROUND AND RATIONALE
Lifelong learning may be defined as learning that occurs throughout one’s lifespan(2,3). These learning experiences may encompass not only acquisition of new knowledge, but also refinement of skills and attitudes. The processes used to accomplish lifelong learning may be either structured or unstructured. Structured processes include post-graduate coursework, continuing education, and certificate programs. An unstructured process that can promote lifelong learning is self-directed learning.

Self-directed learning occurs when an individual identifies learning needs, plans learning activities to attain these goals and then, assesses whether the desired goals have been achieved(4). Individuals will more likely be successful in accomplishing lifelong learning after formal educational experiences if they are able to engage in self-directed learning(5-7).

One mechanism that promotes the achievement of learning autonomy in individuals is cultivation of their reflective thinking skills (8-12). Reflective thinking can crystallize and reinforce previous learning experiences if they are able to engage in self-directed learning(8-12).

Reflective thinking promotes professional growth and development. Examples of outcomes that may result from reflective thinking are identification of a new way of doing something, clarification of an issue, or improvement in skills. Reflective thinking can crystallize and reinforce previous learning, develop a new understanding of concepts, and result in generalizations for future use(8-12).

The literature suggests that students require guidance and practice in developing reflective thinking and other self-assessment skills(8,15-16). Gordon reviewed literature concerning self-assessment and identified 14 studies describing successful outcomes from self-assessment training programs(17-18). He found successful programs involved learners in the collection and interpretation of their own performance data and then reconciliation of this information with an external evaluator/evaluation.

The PILL Program promotes the development of two outcomes described in the Background II paper prepared by the Commission to Implement Change in Pharmaceutical Education (19). First, the program instills in students self-learning abilities and habits. Second, it refines a student’s thinking abilities (e.g., problem solving and critical thinking). The Commission emphasized that in order to facilitate achievement of such educational outcomes, pharmacy educators must make changes in “the way in which students are taught”(19). Teaching strategies proposed by the commission include simulations and asking questions that facilitate critical thinking by the student.

Teaching Process. The PILL program is designed for Doctor of Pharmacy students. Table I outlines the objectives a student is expected to achieve upon completion of this program. These objectives are accomplished during both a didactic and experiential phase.

<table>
<thead>
<tr>
<th>Table I. Objectives of the PILL program</th>
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<tbody>
<tr>
<td>Upon completion of the PILL program, the student is expected to:</td>
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<tr>
<td>1. Demonstrate a structured approach in solving dosing-related problems of patients.</td>
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<tr>
<td>2. Perform critical reflective thinking.</td>
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<tr>
<td>3. Diagnose individual learning needs.</td>
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<tr>
<td>4. Refine autonomous learning skills by performing self-assessments during a didactic course and then use these findings to promote learning autonomy during the required pharmacokinetics clerkship.</td>
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<tr>
<td>5. Identify individualized learning objectives. Then, with instructor guidance, establish learning activities, criteria for self-evaluation, and an assessment of whether goals are achieved.</td>
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DIDACTIC PHASE
Self-Assessment Modules. Students begin the PILL Program by completing self-assessment modules, which emphasize a structured approach to pharmacokinetic dosing. The primary goals of these modules are to provide practice in solving pharmacokinetic dosing problems of patients and to facilitate the development of reflective thinking skills. In Fall 1993, these modules were pilot tested using a written format.

During the pilot testing of this teaching method, nine students completed a total of three modules. The first module emphasized aminoglycoside and vancomycin dosing. Learning experiences in dosing theophylline were provided in the second module and the last one placed emphasis on phenytoin and other anticonvulsants.

A module contains 5-10 case studies developed by the principal author and each case is based on an actual patient encountered in her practice. Case studies are not a new approach to teaching pharmacokinetics. However, these modules are innovative in that they instill in students a structured process for evaluating their pharmacokinetic work up, diagnosing their errors, and using reflective thinking to improve dosing skills.

For each case study, the student is expected to evaluate both population and patient specific data and develop a pharmacokinetic care plan. The student is provided: (i) a brief summary of pertinent patient data; (ii) a page for writing calculations and dosing recommendations; (iii) a Self-Assessment Key that guides the student in verifying whether the work up and dosing recommendation s are correct; (iv) an example of a formal consultation note; and (v) questions to promote self-reflection.

Problem-Solving and Diagnostic Frameworks. During the course, the “Five-Step Pharmacokinetic Work-up” is the prob-
The student is then expected to calculate the patient specific parameters from these levels and compare them to his or her population parameters. Finally, the student is instructed to assess why the population parameters did or did not agree with the patient specific data.

**Reflective Thinking.** After completing each case study, the student is instructed to answer the “Self-Reflection Summary” questions. This page contains four questions designed to allow students to reflect on: (i) whether completing this case was a valuable learning experience and why or why not; (ii) the “pharmacokinetic pearl” of the case; (iii) strategies for enhancing pharmacokinetic dosing skills; and (iv) confidence in performing pharmacokinetic dosing computations. The first two case studies of the Aminoglycoside and Vancomycin Module provide the student with examples of how to use this process for the remainder of cases in the modules.

**EXPERIENTIAL PHASE**

Upon completion of the didactic course, the instructor assists the student in summarizing the self-assessment results and these findings are used to initiate development of a Learning Portfolio. The student also selects 10 cases from the Self-Assessment Modules that were most representative of his or her performance and these are included in the portfolio.

Prior to beginning the Pharmacokinetics clerkship, the student is expected to review the portfolio and then, actively participate in the planning of this practice experience. To achieve this, the student is expected to: (i) identify personal learning objectives for the rotation; (ii) plan learning experiences to achieve these objectives; and (iii) with instructor assistance, develop evaluative criteria and use them to assess whether the personal learning objectives are achieved.

**EVALUATION OF THE DIDACTIC PILL PROGRAM**

Determination of whether a student’s statements exhibit reflective thinking is dependent on the criteria used to define it. Our definition of reflective thinking is in Table IV. Appendix II provides examples of reflective thinking statements noted by the students.

Many of the statements recorded by our students involved only a general awareness of how they could improve. For example, they would indicate they needed to “review” their notes on a topic or concept. We did not categorize these as “reflection” statements. We considered reflective thinking to only occur when the student critiqued his or her individual performance and identified specific strategies for skills improvement.

One of the Self-Reflection Summary questions asks the student to identify the “pearl” of the case. This information

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**Table II. The five-step pharmacokinetic work-up**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.</td>
<td>Calculation of Population Parameters (Parameters based on literature data)</td>
</tr>
<tr>
<td>2.</td>
<td>Calculation of Patient Specific Parameters (Parameters derived from the patient's actual serum drug levels)</td>
</tr>
<tr>
<td>3.</td>
<td>Comparison of Population and Patient Specific Parameters and Selection of The Most Rational Parameters. This step is essential for ruling out spurious level results.</td>
</tr>
<tr>
<td>4.</td>
<td>Calculation of a New Regimen IF Initial Levels are Not Providing the Desired Desired.</td>
</tr>
<tr>
<td>5.</td>
<td>A Plan for Monitoring and Evaluating Efficacy.</td>
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**Table III. Common clinician errors**

1. Errors in application of a pharmacokinetic model or basic pharmacokinetic concepts.
2. Deficiency in applying knowledge about the drug’s pharmacokinetic profile.
3. Negligence in using the “Five-Step Pharmacokinetic Work Up” in a progressive manner. This category includes errors in “Decision Making”.
4. Errors of mathematical computation.
Table IV. Definition of a reflective thinking statement

The student is able to critique his/her performance and realize his/her effectiveness or accomplishments. For example, the student:

- Describes how to correct distortions in beliefs and errors in problem-solving.
- Makes generalizations for use when future patients are encountered.
- Identifies specific points/skills to correct or improve dosing skills.
- Develops a new way of performing a skill.
- Is able to clarify an issue.

The student has more than just an awareness of the learning experience.

has been used by the instructors to ensure the intended learning objective for the case is recognized by the student.

The course evaluation sought student attitudes about the value of the PILL Program as a teaching process. It also evaluated how well the PILL program, compared to concurrent didactic courses, helped students identify their strengths and weaknesses. In addition, this evaluation assessed their comfort level in discussing their strengths and weaknesses with the instructor. The instructors’ reflections on these assessment data are provided below.

INSTRUCTORS’ REFLECTIONS

Reasons for Implementation. This innovation was implemented for two primary reasons. First, students who completed the Applied Pharmacokinetics course in Fall 1992 recommended that more case studies be incorporated into the course. Since 1981, students have noted the use of case studies in this course was an attribute.

Over the last five years we have experimented with various ways to incorporate cases. For example, when the course was first offered, a student was individually assigned a case study to work up. The student then presented this work up to peers in class. Although this technique was effective, each student was an “active learner” only with the assigned case. This approach took up much class time and limited the total number of case studies a student was exposed to. In attempt to provide students with exposure to more case studies, we assigned additional cases as “homework assignments.”

During this time we were also teaching the Pharmacokinetics clerkship and noted several things. Specifically, students sometimes had difficulty finding their own errors without instructor guidance. In providing this instruction, we also came to appreciate the value of the self-monitoring technique used in our own personal practice. Therefore, the second primary reason for implementing this innovation was to promote development of reflective thinking skills.

Student evaluations indicate that everyone in the Fall 1993 class either agreed or strongly agreed that the Self-Assessment Modules were a valuable learning experience. According to the results of an open ended question, 50 percent (4/8) of students indicated the single most valuable thing gained from the modules was practice. From the students’ perspective, it appears as though the modules are meeting their desires for more practice. Other valuable aspects noted by the students were: (i) increased confidence in pharmacokinetic dosing; (ii) exposure to different patient problems (e.g., disease states, pregnancy); and (iii) learning to treat the patient and not the numbers.

From the instructors’ perspective, we also desire for this intervention to enhance self-assessment and other lifelong learning skills. Based on student evaluations, these learners now appear to have a greater comfort level in describing how they can improve their pharmacokinetic dosing skills. This accomplishment is essential in establishing the best atmosphere for self-assessment during the Pharmacokinetics clerkship. For example, in a self-assessment program described by Henbest et al., many medical students initially expressed mistrust about the process (20). However, these authors noted that by the end of the program, students felt they were “on the same side” as the instructor.

At the end of the didactic component of the PILL program, six of the nine students (66.7 percent) agreed or strongly agreed that they were “on the same side” as the instructor. The remaining three students were neutral about this statement. As we enter the clerkship phase of this program, we will need to be aware that three students are not fully comfortable in discussing their self-assessment data with the instructors.

According to the course evaluation, 88.9 percent (8/9) of the students agreed or strongly agreed with the statement, “I now know my strengths and weaknesses in working up patients with a pharmacokinetic problem.” The course evaluation sought this information with respect to their other coursework to assess whether the PILL Program better prepared them for self-evaluation. Based on the course evaluation, these differences were not evident. For example, a similar percentage of students agreed or strongly agreed that they knew their strengths and weaknesses in performing a general work up of a patient.

However, we do not believe this questions the effectiveness of the PILL Program. During the didactic phase, our students have actual patient contact in their concurrent Patient Monitoring course. In this course, they work up actual patients and receive feedback from instructors on their performance. Although they gain information about their strengths and weaknesses, is this knowledge self-identified (8,9)?

In retrospect, a rewording of some statements in the course evaluation form may allow us to determine whether student knowledge of strengths and weaknesses are based on instructor feedback or are self-identified. This is an important difference because a successful self-directed learner must be able to evaluate one’s own performance and not depend on feedback from others.

Although students performed self-assessments when completing the manuals, development of these skills was not the primary factor motivating them to complete the modules. The opportunity for “practice” was clearly expressed by students.

In retrospect, we need to help students realize why reflective thinking and other forms of self-assessment are important and therefore, a component of this course. Based on this finding, we will add a brief “orientation” session at the beginning of the course.

Data from the clerkship phase indicating the frequency of “reflective thinking” are needed before we can assess student growth in this skill. We must keep in mind that the written reflections may not totally indicate the complete thoughts of the learner. This issue can be more fully assessed in a study that involves the use of respondent interviews to capture all reflective thoughts.
On a final note, the most fulfilling part of the pilot didactic course was hearing students critique their own skills during individual sessions with the primary instructor. It was the first time the instructor felt like she was in the role of being a “coach” rather than a “person who graded the student.”

PLANNED MODIFICATIONS

Learning Format. When we embarked upon developing the PILL Program, we knew the most ideal format for presenting the cases would be computer-assisted instruction (CAI). A limitation of the workbook approach used in the pilot study is that students can “look ahead at the answer” and may not evaluate their true problem-solving abilities. According to the program evaluation completed by students, they sometimes looked ahead at the answer key; however, they felt the frequency of errors they recorded accurately reflected their performance.

We elected to begin with the workbook format so that we would have data to “fine-tune” the cases, pilot test the instructional merit of promoting reflective thinking, and assess whether the concept merits the investment of time a CAI format will require. Based on the results to date, we have committed to accomplishing this. A CAI format could possibly allow the student to get immediate feedback about his or her reflective statements rather than waiting for the instructor to provide such information.

Module Revisions. Based on the pilot data and described results, we have identified several strategies to improve the modules. First, we need to provide a better orientation and give greater emphasis about the value and importance of developing one’s reflective thinking skills. Second, we now realize that, in selected case studies, the introduction of some concepts was too new and this caused frustration in some students. The instructors now have a greater appreciation of the “frustration level” of students. Several students showed frustration when their results did not exactly match that of the instructor. We attempted to minimize this by providing students with a correct answer range. Case studies for which this strategy failed are being revised.

In a few cases, the “pearl” identified by the student did not agree with that of the instructor. To achieve a congruency between the student and instructor’s “pearl,” we need to either revise these cases or develop newer cases that provide a better emphasis of the intended instructional point. We are also evaluating whether any self-reflection questions need to be reworded to better prompt students in reflecting.

The breadth of drugs in the modules needs to be expanded beyond that of antibiotics, theophylline, and anticonvulsants. This will require time on the part of the instructors.

Based on the course evaluation, the students who participated in the didactic course were positive, at baseline, about the potential value of this learning experience. These individuals also may have had a higher level of “self-directed learning readiness” because 4 of 9 students had completed a BS degree program in pharmacy and had returned to college for the PharmD degree. Therefore, this teaching method needs to be tested with a larger and more heretogeneous group of pharmacy students.

CONCLUSION

The educational merit of the didactic PILL program rests not only in practice which refines student pharmacokinetic dosing skills, but also in the nurturing of reflective thinking abilities and self-directed learning habits. These later skills are germane to all areas of pharmacy practice and learning throughout a practitioner’s lifespan. Because this pilot project was being tested on only a select number of already self-motivated individuals, its effects on a larger number of students remains unknown. By making adjustments in the original cases, transfer to CAI format, and expansion to include a larger scope of drugs, the PILL program will continue to develop and improve. Regardless of the current limitations, the PILL program appears to be a viable option for the instruction of pharmacokinetics within a pharmacy school’s curriculum.

Am. J. Pharm. Educ., 59, 66-72(1995); received, 1/13/95.

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APPENDIX I. EXAMPLE CASE STUDY, ANSWER KEY, AND FORMAL CONSULTATION NOTE

LM is a 68 year old female who was admitted to ICU following exacerbation of her COPD on 6/18. She is 5ft 2in and 98kg. She had a respiratory arrest on the evening of 6/18. Her lab data are:

<table>
<thead>
<tr>
<th>Labs</th>
<th>6/18</th>
<th>6/19</th>
<th>6/20</th>
<th>6/21</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCr</td>
<td>0.7</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>BUN</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>WBC</td>
<td>6.0</td>
<td>5.9</td>
<td>6.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Segs</td>
<td>88%</td>
<td>85%</td>
<td>86%</td>
<td>90%</td>
</tr>
<tr>
<td>Bands</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
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On 6/21, the patient spiked a fever and was started on tobramycin and mezlocillin for possible sepsis. The pharmacist covering the unit that evening recommended a loading dose of 130mg with a peak level and a random level 7 hours later. The time of dosing and levels are reported as follows:

- LD administered on 6/21 from 17:00 to 18:00
  - Peak at 18:30 - 4.8mg/l
  - Random 00:30 - 2.8mg/l

It is now 6/22 at 9:00AM. Blood culture results and sensitivities indicate Pseudomonas aeruginosa - sensitive to amikacin and resistant to tobramycin.

The patient has not received any aminoglycoside since the loading dose. Outline your recommendations.

Case IV. Self-Assessment

Answers

I. Population Data

- IBW = 50.1kg
- TBW = 98kg
- Vd = 0.35(50.1) + 0.5(47.9) = 25.9 L
- CrCl = \(\frac{[140-68](50.1)}{(1.4)(72)}\) = 30.4mL/min (29-31mL/min)
- Ke = 0.083 hr⁻¹ (0.078 - 0.086 hr⁻¹)

II. Patient Specific Data

- Ke = \(\frac{\ln 4.8 - \ln 2.8}{60}\) = 0.089 hr⁻¹ (0.086 - 0.091 hr⁻¹)
- Vd = \(\frac{(130)(1-e^{-0.089(18)})e^{-0.089(5)}}{(1)(0.089)(4.8)}\) = 24.8 L (0.49 L/kg IBW or 0.25 L/kg TBW)

III. Compare Population and Patient Specific

The patient specific Vd falls within the usual range of 0.1 to 0.5 L/kg IBW. It is consistent with literature describing the volume of distribution in obesity. The Ke agrees with predicted data.

IV. Recommendations

Because of sensitivities, the patient should be changed to Amikacin. The pharmacokinetic parameters from the tobramycin loading dose may be used to design a new regimen. A peak of 20 to 25 would be appropriate for sepsis.

To Calculate Dose:

- \(T_{unheld} = \frac{\ln 22 - \ln 6}{0.089}\) + (1.0 + 0.5) = 16.1 Hrs - Round to q 18 hr
- Dose = \(\frac{(1-e^{-0.089(22)})e^{-0.089(18)}}{(1)(0.089)(24.8)(1-e^{-0.089(18)})}\) = 476mg - Must round to a practical dose

If you round to 475 - predict peak of 21.95

V. Monitor for Efficacy & Toxicity WBC, Temperature, Blood cultures, SCr, BUN

Total
Case IV: Consultation Note

LM is a 68-year-old female who developed respiratory arrest on 6/18 and subsequently developed a decrease in renal function. Tobramycin was initiated on 6/21 for sepsis. Factors contributing to a need for individualized aminoglycoside dosing are:

1. Obesity (Pt. is twice her ideal body weight)
2. Recent decrease in renal function

Patient was loaded with tobramycin 130mg on 6/21 which provided the following levels:

- Peak: 4.8mg/l
- 6.0 hr Post-Peak: 2.8mg/l

These levels indicate the patient has a half-life of 7.7 hours and a volume of distribution of approximately 25 L. The volume of distribution agrees with literature data for morbidly obese patients.

Most recent culture and sensitivity results indicate Pseudomonas aeruginosa which is resistant to tobramycin and sensitive only to amikacin. Based on pharmacokinetic parameters derived from her tobramycin dosing, an amikacin regimen of 475mg q 18 hours will provide peaks of 20 - 25mg/L and troughs <10mg/L. You may begin this regimen at 10:00AM today. Will follow with you and recommend if additional serum levels are needed.

Aminoglycoside (Case III)

Student 10: I need to remember to follow the 5-step process and not cut corners.

Aminoglycoside (Case VI)

Student 2: My troughs were still slightly off when I predicted them using the new dose. But, I figured out what I was doing wrong (Cmin = Cmax[e^(-kt/(1-e^-kt))]*)
*The student was not accounting for the infusion and wait times.

Aminoglycoside (Case XII)

Student 6: Keep trying to work on the specifics of the patient population.* I think this is biggest weakness right now.
*Determining the most accurate population parameters for patients

Aminoglycoside (Flying Solo)

Student 4: I feel I did a good job on this patient...I took my time, looked at whether SCr was steady-state, looked at the times the peak and troughs were drawn, and compared population and patient specific parameters.

Theophylline (Case III)

Student 1: I need to keep resolved disorders* in mind when dosing future patients.
*The patient in the case had compensated CHF; Therefore, it did not alter theophylline elimination significantly.

Theophylline (Case V)

Student 9: I got so caught up in the calculations that I didn’t read the problem close enough the first time. I need to read patient data slower and more carefully; I will pay more attention to details in the future.

*Editorial comments by the instructor.