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TEACHERS' TOPICS

A Process-Oriented Guided Inquiry Approach to Teaching Medicinal Chemistry

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Objective. To integrate process-oriented guided-inquiry learning (POGIL) team-based activities into a 1-semester medicinal chemistry course for doctor of pharmacy (PharmD) students and determine the outcomes.

Design. Students in the fall 2007 section of the Medicinal Chemistry course were taught in a traditional teacher-centered manner, with the majority of class time spent on lectures and a few practice question sets. Students in the fall 2008 and fall 2009 sections of Medicinal Chemistry spent approximately 40% of class time in structured self-selected teams where they worked through guided-inquiry exercises to supplement the lecture material.

Assessment. The mean examination score of students in the guided-inquiry sections (fall 2008 and fall 2009) was almost 3 percentage points higher than that of students in the fall 2007 class ($P < 0.05$). Furthermore, the grade distribution shifted from a B-C centered distribution (fall 2007 class) to an A-B centered distribution (fall 2008 and fall 2009 classes).

Conclusions. The inclusion of the POGIL style team-based learning exercises improved grade outcomes for the students, encouraged active engagement with the material during class time, provided immediate feedback to the instructor regarding student-knowledge deficiencies, and created a classroom environment that was well received by students.

Keywords: medicinal chemistry, guided inquiry, active learning, process-oriented guided-inquiry learning (POGIL), team-based learning

INTRODUCTION

Faculty members who teach medicinal chemistry have worked to bring clinical relevance to their subject matter and maintain the field as a key component in the basic science curriculum of colleges of pharmacy.[1] Integration of strategies such as case studies,[2-5] computerized tutorials,[6-9] and the concept of structurally based therapeutic evaluation[10-12] have helped to keep the field vibrant, not only with regard to clinical relevance but also compliance with current Accreditation Council on Pharmacy Education (APCE) standards regarding integration of active learning and critical thinking in the curriculum.[13] This manuscript describes the integration of POGIL into the PharmD curriculum via a 1-semester medicinal chemistry course. Concepts of POGIL were first published in the late 1990s and developed as part of general chemistry courses, but the impact of this philosophy is far reaching due to federal funding for the POGIL project through the National Science Foundation.[14-17] One initiative of the POGIL project involves conducting workshops for faculty members across disciplines to learn the POGIL philosophy and receive guidance on how to integrate POGIL into their classrooms. The POGIL project also provides opportunities for faculty mentoring and review as faculty members new to the technique work to integrate its strategies into their own courses.[17]

POGIL is a student-centered technique which in some cases replaces all course lecture content.[18,19] POGIL exercises are carefully designed to facilitate the student's exploration of a model, whether it be a figure, diagram, set of chemical structures, table, or something specific to the discipline. The questions contained in the exercise are intended to follow the 3-phase "learning cycle," logically progressing the students though exploration, concept invention, and application. In addition to helping students master content, they also gain competence in important process skills such as critical thinking, problem solving, and communication, all of which are an essential part of pharmacy education.[13,19] POGIL has been integrated successfully into many courses, including biochemistry, physical chemistry, math, and marketing[18-22]; however, nothing

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has been published to date using this strategy in a pharmacy curriculum. Within the realm of pharmacy education, there have been calls for curricular innovation that include a reduction in instructor-centered teaching (passive lecturing) for a number of reasons.[23] In general, students express a high degree of satisfaction with active-learning strategies such as POGIL.[19] One multi-institutional study of student satisfaction with POGIL strategies in an organic chemistry classroom found significantly fewer negative attitudes when this strategy was used (<8% of the 1000 students studied versus 30% negative attitudes from the control/lecture group).[24]

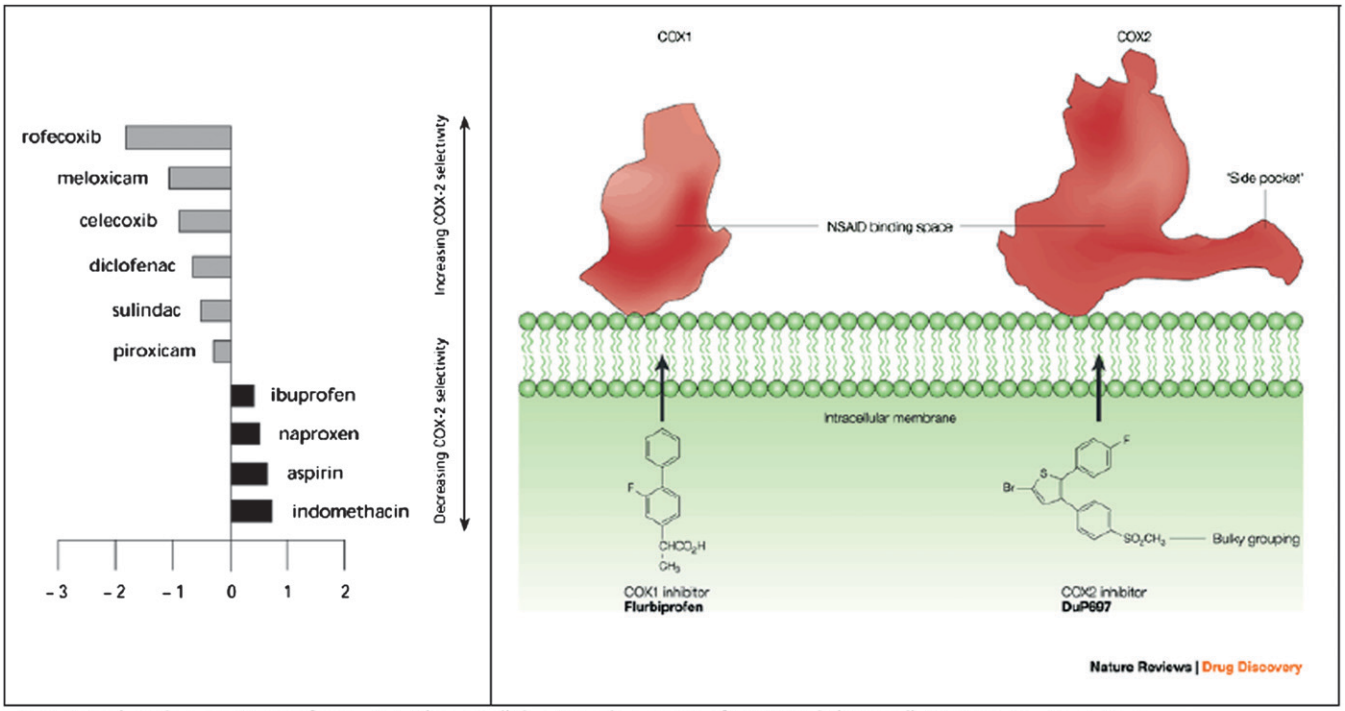
The Gatton College of Pharmacy at East Tennessee State University (ETSU) has defined 29 learning outcome expectations that must be addressed in various points throughout the curriculum. A key learning outcome expectation applicable to the medicinal chemistry course is: "Apply basic knowledge and principles of pharmaceutical sciences, clinical sciences, and socio-behavioral sciences to engage in critical thinking and solve problems." The integration of POGIL-style exercises into the course was meant to address this outcome, specifically for the process skills of critical thinking and problem solving. This modification in content delivery operated under a dual-hypothesis model. The primary hypothesis was that the integration of POGIL-style exercises would result in equivalent outcomes on the standard multiple-choice examinations. The secondary hypothesis was that students would prefer the student-centered classroom over an instructor-centered classroom due to the better and more extensive development of process skills as mandated by the College's learning outcome expectations. The ultimate goal of incorporating these POGIL-style exercises into the course was to improve the quality of the content delivery, including the quality of students' experience with the content, without sacrificing the depth of the content.

DESIGN

The Medicinal Chemistry course is part of the third semester of didactic material within the PharmD curriculum. This 4-hour course serves as the sole source of medicinal chemistry instruction within the curriculum. During the first day of class, the students were briefly introduced to the use of team-based guided inquiry learning. The team-based learning is achieved through the use of POGIL-style exercises, referred to as "in-class exercises" in the syllabus. This introductory session included an explanation of the different roles the students would be playing in their self-selected groups. Each group was comprised of 3-4 students and each student had a specific job to facilitate the functioning of that group. The manager of the group ensured that all tasks were completed, that members participated fully and with understanding, and that the group effectively communicated with the facilitator/instructor. The reporter of the group communicated the group findings to the entire class via whatever media the instructor chose (clickers, oral report, white board, etc). The recorder of the group prepared the completed exercise that would be turned in for instructor feedback and thus represented the collective written voice of the group. Finally, the technician performed duties to assist the group, including looking up references, locating content in the textbook, and performing calculations. If the group only had 3 members, then the same individual served as both the reporter and technician. Immediately prior to the start of an in-class exercise, the instructor assigned the managers for that day with an innocuous but fun criteria such as "whoever was born farthest away from Johnson City, TN" or "whoever has the most siblings." Manager assignment triggered the groups to focus and begin working, ensured that one person did not monopolize a group, and provided a nice icebreaker for the students, especially early in the semester. Once the manager of each group was established, he/she assigned the other roles within the group.

Each in-class exercise was designed to be completed in 50 minutes or less, and could be used with or without a complementary lecture. If lecture material was meant to complement an in-class exercise, it could be provided before or after an in-class exercise was completed. Complementary lectures usually were provided before an in-class exercise due to the marked increase in student anxiety noted by the instructor when the alternative was practiced. Occasionally, a reading assignment was given prior to the related in-class exercise. During each exercise, the instructor/facilitator quietly patrolled the room, listening to student discussion and intervening if necessary. Every attempt was made to avoid answering students' questions directly; instead, a more Socratic approach was utilized to guide the students to answer the questions themselves. Students in the fall 2008 section completed 21 in-class exercises during the course of the semester and students in the fall 2009 section completed 24 such exercises.

An example of a model used in 1 exercise in fall 2008 and fall 2009 is provided in Figure 1.[25] An additional aspect of this model was a set of selected structures of nonsteroidal anti-inflammatory drugs (NSAIDs) created using Symyx Draw 3.2 (Symyx Technologies, Santa Clara, CA). The exercise guided students through exploration of structural differences between cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2) inhibitors. The students were asked to examine aspects of structural flexibility and rigidity, as well as the hydrophobic and hydrophilic characteristics of each structure shown. Finally,



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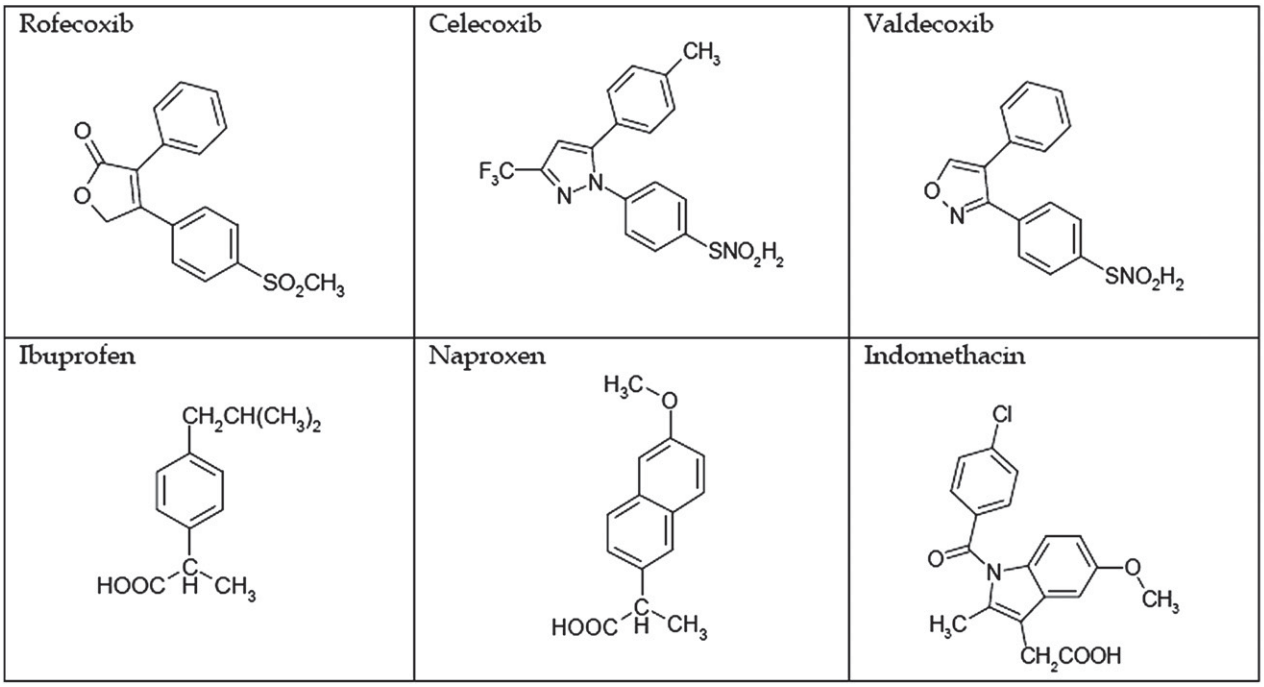

Figure 1. Model from POGIL- style in-class exercise on COX-1 and COX-2 selectivity by NSAIDs[25]

they were asked to make inferences about COX-1 and/or COX-2 selectivity for drugs that were not presented in the original model. Ultimately, if given a novel NSAID structure, the students could then rank its COX-1 or COX-2 selectivity based on the nature of its structure.

ASSESSMENT

The students compared in this study were not significantly different in terms of overall entering undergraduate grade point averages (GPAs), undergraduate science GPAs, or composite scores on the Pharmacy College

Table 1. Demographics of Students Enrolled in a Medicinal Chemistry Course

	Fall 2007, n = 66 Mean (SD)	Fall 2008 n = 73, Mean (SD)	Fall 2009 n = 78, Mean (SD)
Cumulative GPA	3.3 (0.4)	3.4 (0.4)	3.4 (0.4)
Math/Science GPA	3.3 (0.5)	3.3 (0.5)	3.3 (0.5)
Composite PCAT Percentile Score	69.3 (13.9)	73.5 (12.3)	70.8 (15.4)

Abbreviations: GPA = grade point average; PCAT = Pharmacy College Admission Test

Admission Test (PCAT).[26,27] The PCAT scores and GPAs (Table 1) were compared by conducting a one-way ANOVA with GraphPad Prism (GraphPad Software, Inc., La Jolla, CA).

Four semester examinations counted 75% of the final grade and a final examination counted 25%. All examinations were comprised of 50 multiple-choice questions, with each question having 4 or 5 answer choices, and the "all of the above" or "none of the above" choices were never used. Examination content was proportional to time spent during class, including lecture and team-based exercises. Successful completion of the team-based POGIL in-class exercises had the potential to influence students' final course grade in that the points earned from these were included with the regular examination scores. However, the inclusion of these points was not considered in the statistical test comparing the examination averages because the actual number of points acquired in this manner differed among semesters. The comparison of test scores was performed using an unpaired two-tailed student's *t* test with GraphPad Prism software. The fall 2007 examination score average was significantly different ($p < 0.05$) from both the fall 2008 and fall 2009 examination score averages. The 2 active-learning groups (2008 and 2009) were also compared using the unpaired two-tailed student's *t* test and no significant difference was found ($p < 0.05$). These data are summarized in Table 2.

Student satisfaction was not quantitatively measured, but rather qualitatively evaluated using the College's Student Assessment of Instruction (SAI) tool. Thirty-two percent (23/72) of students completed the SAI for Medicinal Chemistry in fall 2008 and 62% (48/78) completed it in fall 2009. Of the students who responded to the question "What aspects of this course were most helpful to your learning?" 70% of the fall 2008 students and 88% of the fall 2009 students referred specifically to the use of in-class exercises. Some of the student comments in the free-form section included: "The ICEs were the key to my understanding." "I think that I learned a great deal of information in this course, and was challenged to use higher-level thinking skills by the ICEs." "The in-class exercises require us to apply the material and think about it rather than just rote memorization." "Working hands-on with the ICEs is much more effective than listening to hours of lectures."

DISCUSSION

Students who participated in the student-centered learning environment via the team-based guided-inquiry exercises outperformed those who did not on conventional multiple-choice examinations. While the differences between the groups (fall 2007 versus fall 2008, and fall 2007 versus fall 2009) was not overwhelming, it was significant and ultimately resulted in a shift of the grade distribution from one that was B-C centered (fall 2007) to ones that were A-B centered (fall 2008 and fall 2009). To truly appreciate the significance of this grade distribution shift, one must consider the high competency level of these students. As professional school students, they underwent a rigorous admissions process that resulted in 3 groups with no significant differences in PCAT composite scores or GPAs. Nevertheless, they showed differences in their mastery of medicinal chemistry course content dependent on how the material was delivered. Because they were allowed to practice skills such as communication, teamwork, critical thinking, and problem solving while working in the group setting, one could argue that the fall 2008 and fall 2009 students better achieved one of the Gatton College of Pharmacy's key learning outcomes expectations. Furthermore, students were extremely satisfied with the incorporation of the team-based guided-inquiry learning, stating in their summative evaluations that they felt comfortable and confident with what historically had been difficult and abstract

Table 2. Comparison of Examination Scores of Pharmacy Students Enrolled in a Medicinal Chemistry Course

	Fall 2007, n = 66	Fall 2008, n = 73	Fall 2009, n = 78
Examination Score, Mean (SEM)	82.3 (0.7)	85.1 (0.9)	85.0 (0.7)
Comparisons	**2007 vs. 2008**	**2007 vs. 2009**	**2008 vs. 2009**
P	0.017	0.010	0.957
95% confidence interval	-4.9 to -0.5	-4.7 to -0.7	-2.1 to 2.2
R square	0.04165	0.04623	0.00002039

subject matter. Frequent small group interactions with materials that were turned in for evaluation by the faculty member also allowed for more regular assessment of content mastery, providing the opportunity for necessary clarifications before a high-stakes examination was administered. This type of intervention based on frequent student feedback, as well as the process of facilitation of the small-group exercises, provided multiple opportunities for quality student-instructor interactions that would not have been possible using a traditional lecture-style format.

Examination score average was chosen as a comparator between the groups for 2 reasons. The examination content among the classes was similar as it originated from the same textbook and similar lecture slides. However, as demonstrated by the data is Figure 2, the total percentage breakdown of question types according to Bloom's Taxonomy differed among the 3 iterations of the Medicinal Chemistry course. The examinations given to the POGIL groups could arguably be considered of higher difficulty as a larger percentage of the test was level 2 (Application) questions and a smaller percentage was level 1 (Knowledge) questions. This subclassification of examination question types was adapted from that used by the University of North Carolina School of Pharmacy.[28] Also, examination score average did not include any influence of the points earned through successful completion of the in-class exercises, which was the case with the final course grades. Nevertheless, the examination score averages shifted from a B-C centered distribution in the fall 2007 group (86% of students) to an A-B centered distribution in the fall 2008 (82% of students) and fall 2009 (78% of students) groups (Figure 3).

While examination scores and student satisfaction data point to the positive impact of the incorporation of team-based guided-inquiry exercises into this medicinal chemistry course, certain factors regarding the groups being compared must be considered. The fall 2007 group

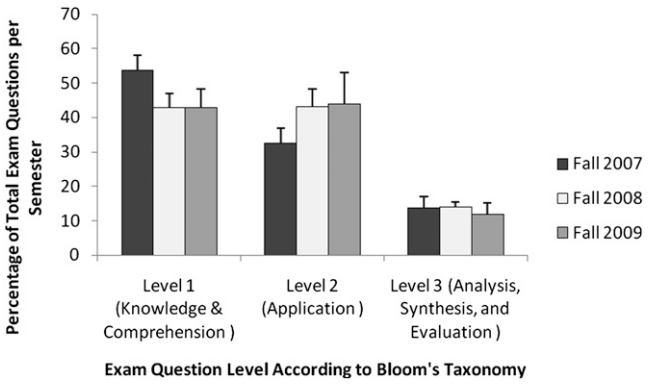

Figure 2. Percent composition by semester of PMSC 4124 examinations based on Bloom's Taxonomy[26]

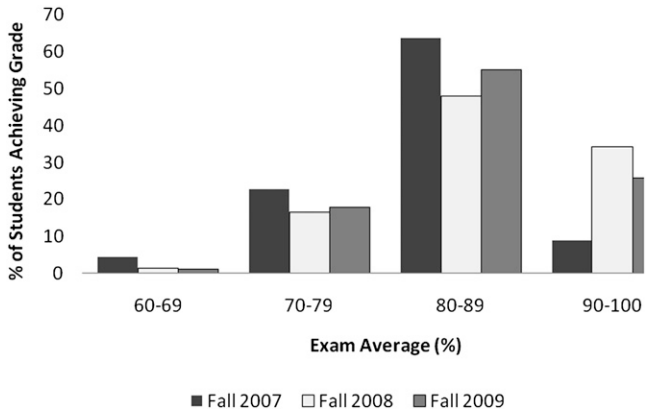

Figure 3. Distribution of examination averages for medicinal chemistry from fall 2007 to fall 2009.

was the first class of students entering the Gatton College of Pharmacy. Because the college opened early, they started their first year in January 2007 and finished in August 2007, and started their second year and the Medicinal Chemistry course in September 2007. The stress of this compressed schedule and the reduction in actual hours spent in the Medicinal Chemistry course could have contributed to their decreased examination performance. In addition, fall 2007 was the first time the medicinal chemistry course was taught at the college; thus, each subsequent iteration of the course presumably was improved in terms of content delivery. Also, based on feedback from the previous year's students, the later groups of students knew what to expect from the course, which could have given them an advantage. However, every effort was made to reduce the impact of old examinations being passed from one student group to the next. Furthermore, the A-B centered grade distribution could have been a contributing factor to the high student satisfaction in the fall 2008 and 2009 groups.

CONCLUSIONS

The integration of team-based guided-inquiry learning materials designed after the POGIL model had an overall positive impact on a medicinal chemistry course. The depth and integrity of the content was not sacrificed by the reduction in time spent lecturing, and students expressed a high level of satisfaction with the design and execution of the course. In addition, the use of self-selected teams for completion of the guided-inquiry exercises helped develop key process skills such as critical thinking and communication essential for the successful practice of pharmacy.

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