INSTRUCTIONAL DESIGN AND ASSESSMENT

Process-Oriented Guided Inquiry Learning Strategy Enhances Students' Higher Level Thinking Skills in a Pharmaceutical Sciences Course

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Objective. To determine if the process-oriented guided inquiry learning (POGIL) teaching strategy improves student performance and engages higher-level thinking skills of first-year pharmacy students in an Introduction to Pharmaceutical Sciences course.

Design. Overall examination scores and scores on questions categorized as requiring either higher-level or lower-level thinking skills were compared in the same course taught over 3 years using traditional lecture methods vs the POGIL strategy. Student perceptions of the latter teaching strategy were also evaluated.

Assessment. Overall mean examination scores increased significantly when POGIL was implemented. Performance on questions requiring higher-level thinking skills was significantly higher, whereas performance on questions requiring lower-level thinking skills was unchanged when the POGIL strategy was used. Student feedback on use of this teaching strategy was positive.

Conclusion. The use of the POGIL strategy increased student overall performance on examinations, improved higher-level thinking skills, and provided an interactive class setting.

Keywords: POGIL, active learning, process skills, instructional assessment

INTRODUCTION

Developing students' critical-thinking and problem-solving skills is an educational goal common to perhaps every academic program or discipline. Critical to achieving this goal is the use of teaching and learning strategies that engage students and promote development of the process skills of application, analysis, and evaluation. Yet, despite a growing body of evidence demonstrating the efficacy and superiority of active-learning strategies and national reports calling for the adoption of these methods,¹⁻⁴ instructional strategies in science and math disciplines tend to be passive, leading to student disengagement and contributing to the "leaky pipeline" of science.⁵⁻⁹ The reasons science faculty members give for being reluctant to adopt active-learning strategies include the significant amount of time needed to prepare materials, the reluctance to reduce the amount of material covered, and the perception that students are unwilling to engage in or prepare for these types of classroom activities.¹⁰⁻¹² In the pharmacy academy, active-learning strategies are recognized as important to achieving educational

outcomes and, therefore, widely adopted in professional programs.¹³⁻¹⁵ However, the use of active-learning strategies is not uniformly distributed. Faculty members in the biomedical and pharmaceutical sciences are 3 times less likely than faculty members in the clinical and social and administrative sciences to use these techniques.¹⁵

Process-oriented guided inquiry learning (POGIL) is a teaching strategy that was initially developed in college chemistry and biology courses and is used successfully to engage students in the classroom and to promote learning.¹⁶⁻²⁰ The POGIL strategy begins with introducing students to a model, diagram, problem, or set of data and then requires them to work as a team to answer a series of questions leading to development of a concept or principle (guided inquiry). Thus, it uses elements found in team-based and problem-based learning. The POGIL strategy is based on the idea that learning has 2 components: content and process. While content is important for operating in any discipline, the ability to develop a deep understanding of a concept and the ability to apply that knowledge to solve novel problems—the process component of learning—is the critical skill.^{21,22} The process skills and team-based activities associated with the POGIL strategy provide a means to achieve the CAPE 2013 Outcomes of producing learners, problem solvers, collaborators, and communicators.²³

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This study was designed to assess the effectiveness of the POGIL strategy on enhancing students' problem-solving and critical-thinking skills in a required course in the professional pharmacy program. Introduction to Pharmaceutical Sciences is a first professional (P1) year course designed to integrate foundational material from the biological and chemical sciences into an understanding of the basis for drug behavior in the body. It is a concepts-based course that prepares students for later course work in pharmacology, medicinal chemistry, pharmacokinetics, and pharmaceuticals. Given that deep understanding, long-term retention, and development of problem-solving and critical-thinking skills are necessary for success in a professional pharmacy program, we felt implementing the POGIL strategy at an early stage of the curriculum would provide students a better foundation of learning skills for later course work in the pharmaceutical sciences. Our hypothesis was that using the POGIL strategy would enhance students' problem-solving and critical-thinking skills as ultimately evidenced by students' improved performance on examination questions requiring higher-level thinking skills. We sought to determine: (1) if instruction using the POGIL strategy increased student performance on examinations, specifically their performance on questions requiring higher-level thinking skills; (2) what students' perceptions of the POGIL strategy were; and (3) how the POGIL strategy impacted students' perceptions of their ability to attain learning objectives.

DESIGN

Introduction to the Pharmaceutical Sciences is a 3-credit hour course taught in the first semester of the P1 year of the doctor of pharmacy (PharmD) program. The course is divided into 2 major topic areas: principles of pharmacokinetics (absorption, distribution, metabolism, and excretion) and principles of pharmacology (receptor mechanisms, dose response curves, and factors altering drug action). Concepts covering medicinal chemistry (acid base functional groups, structure activity relationships, pharmacophores) are integrated into both parts of the course. The course meets for 75-minute sessions twice a week. Table 1 provides an overview of how the course progressed from lecture-based to POGIL-based over the 3 years of the study.

For those classes using the POGIL strategy, students were assigned randomly to groups of 4 with adjustments made to evenly distribute transfer students among the groups and to separate close friends. Students were asked to sit with members of their group for all class meetings. Each class period consisted of brief lectures on background material and 1-4 POGIL activities. Each POGIL session lasted 10-30 minutes and concluded with the answers provided by a group spokesperson randomly called upon to report. The materials for the POGIL activities were incorporated into the class materials and posted on the learning management system Blackboard 9 (Blackboard, Inc. Washington, DC). The instructor and a student assistant (a third-year pharmacy student) acted as facilitators during POGIL exercises. Facilitation focused on listening to student discussions and offering guidance without revealing answers to the exercises. After each class, the facilitators met to discuss the POGIL activities, identify any misconceptions the students may have had, and make necessary revisions to the exercises. An example POGIL activity is provided in Appendix 1.

Classroom assessments included 4 examinations weighted equally and 8 homework assignments (equal number for each section). Final letter grades for the course (A, B, C, D, F) were assigned using a 90, 80, 70, 60% scale. The examinations consisted of 50 multiple-choice questions of which 95% were identical in 2011, 2012, and 2013. Students were not allowed to keep examinations nor were previous examinations made available to them. No significant changes in course content were introduced between 2011 and 2013.

Bloom's Taxonomy²⁴ was used as a guide to place questions into lower-level and higher-level categories. Lower-level questions were identified as those requiring only knowledge and/or comprehension with higher-level questions identified as requiring application and/or analysis. The instructor and 2 faculty members in the pharmaceutical sciences independently rated the questions into 1 of the 2 categories. Table 2 lists the number of questions in each category for each examination. The questions listed as uncategorized were not included in the statistical analysis for 3 reasons: (1) the questions were not worded identically on each examination, (2) there was not a consensus on which level of Bloom's Taxonomy the questions belonged, or (3) the validity or reliability of the question was in doubt based on the point biserial score.

Table 1. Content, Teaching Strategies, and Instructor Assignments for Introduction to Pharmaceutical Sciences Course from 2011-2013

Year	Instructor	Pharmacokinetics Section	Pharmacology Section
2011	Team-taught	Lecture format	Lecture format
2012	Team-taught	Lecture format	POGIL strategy
2013	Single instructor	POGIL strategy	POGIL strategy

Table 2. Distribution of Examination Questions Based on Thinking Level Classifications

Category	Examination 1	Examination 2	Examination 3	Examination 4
Lower Level	22	21	20	20
Higher Level	20	20	18	20
Uncategorized	8	9	12	10

Each examination consisted of 50 multiple choice questions

Course evaluations were carried out using the “Student Ratings of Instruction” form provided by the IDEA Center (Manhattan, KS). Additional questions were included on the form to assess students’ perceptions of the POGIL teaching strategy. Students completed the form outside of class 2-3 weeks before completion of the semester. Participation in the evaluation was voluntary, and all responses were anonymous. The study was submitted to the Drake University Institutional Review Board and approved under exempt status.

Student performance on examination questions was analyzed using 1-way analysis of variance. Comparisons were made between years for each examination. For example, Examination 1, 2011 was compared to examination 1, 2012 and examination 1, 2013. Similar comparisons were made for examinations 2, 3, and 4. Differences within comparisons were determined using Tukey’s HSD post hoc test. Student ratings of the course, their self-assessed progress on objectives, and final grade distributions were treated as non-parametric ordinal data and analyzed using the Kruskal-Wallis test with pairwise comparisons for post hoc analysis. An a priori alpha of 0.05 was used for all analyses. All data were analyzed using IBM SPSS Statistics, version 22 (IBM Corp., Armonk, NY). The Kuder-Richardson formula 20 (KR-20), a measure of internal consistency reliability,²⁵ was calculated for each examination using DataLink Connect software, version 4.2 (Apperson Education Products, Renton, WA).

EVALUATION AND ASSESSMENT

The academic profile of the students making up the 3 classes in this study was not significantly different in terms of cumulative grade point averages (GPA) and math-science GPA. Table 3 provides a summary of the demographics and academic profile of the student population.

In 2011 and 2012, the lecture format was used in the first half of the course covering pharmacokinetic principles and assessed with examinations 1 and 2. When the POGIL strategy was implemented in 2013, student performance on examinations 1 and 2 did not change significantly, with differences ranging from 0.7-1.2 percentage points (Figure 1). In 2011, the lecture format was used for content focusing on pharmacological principles and assessed with examinations 3 and 4. When the POGIL strategy was used in 2012 and 2013 for this section of the course, examination scores improved significantly, ranging from 3.3 to 4.5 percentage points higher for each examination (Figure 1). Questions from examinations 3 and 4 were reviewed and classified into lower-level (knowledge and/or comprehension) and higher-level (application and/or analysis) to determine if the increase in scores on those examinations resulted from enhanced performance on questions requiring higher-level skills. Student performance on lower-level questions did not change from 2011 (92.0%) to 2012 and 2013 (91.4%) when the POGIL strategy was used (Figure 2). On questions requiring higher-order thinking skills, student performance significantly improved postPOGIL use by an average of 7.0 percentage points (75.8% to 82.8%) (Figure 3). The KR-20 value, a measure of relative reliability of questions within an examination, was greater than or equal to 0.7 for each of the examinations.

In addition to improved examination performance, the final grade distribution for the course shifted significantly away from lower grades postPOGIL use (Figure 4). When POGIL was implemented throughout the course in 2013, there were no grades of D or below and half as many grades of C (27% of the class vs 13%). The distribution of grades of A and B increased from 20% to 25% and 52% to 61%, respectively.

A course evaluation using the IDEA Center format was provided to students at the end of each semester. The

Table 3. Demographics of Students Enrolled in Introduction to Pharmaceutical Sciences Course from 2011-2013

Class	Number Enrolled	Percent Male/Female	Percent Transfer	Cumulative GPA Mean $\pm$ SD; Range	Math/Science GPA Mean $\pm$ SD; Range
2011	112	29/71	8	3.61 $\pm$ 0.24; 3.01-4.00	3.51 $\pm$ 0.30; 3.00-4.00
2012	111	37/63	10	3.59 $\pm$ 0.26; 3.03-4.00	3.49 $\pm$ 0.31; 3.00-4.00
2013	111	31/69	15	3.62 $\pm$ 0.24; 3.00-4.00	3.52 $\pm$ 0.29; 3.00-4.00

Abbreviations: GPA=grade point average; SD=standard deviation

One-way ANOVA; Cumulative GPA: $F=0.302$, $p=0.74$; Math-science GPA: $F=0.252$, $p=0.78$

Figure 1. Average examination scores in Introduction to Pharmaceutical Sciences course from 2011 to 2013. Asterisk denote significant differences from 2011 score for that specific examination using one-way ANOVA. Examination 1: $F=0.5$, $p=0.5$; Examination 2: $F=0.3$, $p=0.7$; Examination 3: $F=8.6$, $p<0.0001$; Examination 4: $F=5.3$, $p<0.005$

standard form includes questions asking students to rate their progress on the main objectives of the course and to identify elements of the instructor's teaching style and methods. In terms of attaining relevant objectives, a majority of students (87-94%) rated their progress as either substantial or exceptional (Table 4). During the 2 years the POGIL strategy was used, students were asked to rate their level of agreement to 3 statements regarding development of critical-thinking and problem-solving skills. A majority (84-91%) of the students agreed or strongly agreed that the course provided opportunities to develop these skills and that their skills were enhanced by taking the course (Table 4). Additionally, students identified that the team-oriented approach used in the class was apparent when the POGIL strategy was used (Table 5). The students' rating of the difficulty of the course and amount of work for the course decreased significantly when the POGIL strategy was implemented for the entire course in 2013 (Table 5).

Students were also provided an opportunity to submit comments to open-ended questions included in the

Figure 2. Average scores on examination questions rated as lower level in Introduction to Pharmaceutical Sciences course from 2011 to 2013. One-way ANOVA; Examination 3: $F=0.1$, $p=0.9$; Examination 4: $F=1.0$, $p=0.4$

Figure 3. Average scores on examination questions rated as higher level in Introduction to Pharmaceutical Sciences course from 2011 to 2013. Asterisks denote significant differences from 2011 score for that specific examination using one-way ANOVA. Examination 3: $F=12.5$, $p<0.001$; Examination 4: $F=11.5$, $p<0.001$

IDEA Center evaluations. When asked, "What is your impression of the use of inclass group work?" in 2012 and 2013, 71 and 75 written responses were submitted, respectively. The instructor and the student assistants independently rated each response as either positive, neutral, or negative. In both years, the distribution was nearly identical, with approximately 72% of the students providing positive or supportive statements of the in-class group work, 16% responding they were neutral toward the group work, and 12% indicating they did not like the inclass exercises.

DISCUSSION

In this study, we investigated whether the advances in student learning seen in previous studies using the POGIL strategy could be realized in an introductory pharmaceutical sciences course and thereby provide a rationale for extending the use of the POGIL strategy to advanced course work. The design of this study allowed for comparisons of student performance prePOGIL and

Figure 4. Distribution of final letter grades in Introduction to Pharmaceutical Sciences course from 2011-2013. The distribution of grades in 2011 was significantly different compared to 2012 and 2013. Kruskal-Wallis test: $H=6.08$, $p<0.05$.

Table 4. Student Ratings of Progress on Relevant Objectives

	Average Score – 5 point scale		
	2011	2012	2013
Gaining factual knowledge (terminology, methods, trends) ^a	4.5 ± 0.6	4.5 ± 0.7	4.5 ± 0.7
Learning fundamental principles, generalizations, or theories ^a	4.4 ± 0.7	4.5 ± 0.7	4.5 ± 0.7
Learning to apply course material (to improve thinking, problem solving, or decisions) ^a	4.3 ± 0.8	4.5 ± 0.7	4.5 ± 0.6
Inclass problems providing opportunities to develop problem-solving skills ^b	NA	4.5 ± 0.7	4.4 ± 0.8
Inclass problems providing opportunities to develop critical-thinking skills ^b	NA	4.6 ± 0.7	4.4 ± 0.7
Problem-solving and critical-thinking skills being enhanced after taking the course ^b	NA	4.4 ± 0.7	4.3 ± 0.8

Students were asked to use the following scale to rate the degree of progress made on the stated objective:

^a 1=no progress, 2=slight progress, 3=moderate progress, 4=substantial progress, 5=exceptional progress

^b 1=definitely false, 2=more false than true, 3=in between, 4=more true than false, 5=definitely true. Kruskal-Wallis test. No significant differences ($n=107$ for 2011 representing 96% response rate; $n=97$ for 2012 representing 87% response rate; $n=108$ for 2013 representing 97% response rate) NA: Questions not asked in 2011

postPOGIL in the same course over 3 years. We were able to minimize or control for certain variables such as student demographics and lack of content changes, and use identical assessment measures with internal consistency reliability scores ($KR-20>0.7$) deemed sufficient for classroom examinations.²⁵ Therefore, making the switch to the POGIL strategy was the only major difference between the comparison groups.

The course was divided into 2 major topic areas: pharmacokinetic principles and pharmacologic principles. In the section of the course focusing on pharmacologic principles, student examination scores improved both years that the POGIL strategy was used. Improvement on the examinations resulted from students scoring higher on questions requiring higher-level thinking skills. In the section of the course focusing on pharmacokinetic principles, student performance on the examinations did not change significantly when the POGIL strategy was used. The lack of effect in the pharmacokinetics section of the course may have been a result of its concepts already being, in effect, covered in a POGIL-like manner.

Moreover, the pharmacokinetics section was based heavily on mathematical models. Students spent significant time using equations and practicing problems to understand major concepts (eg, ionization, distribution, partitioning, elimination rates, half-lives). Thus, some elements of the POGIL strategy were already present in this section before formally implementing the strategy. In contrast, the pharmacology section was more reliant on biological models (receptor theory, cell signaling, factors affecting therapeutic variability, pharmacogenomics) that were more conceptual and less mathematically based. As a result, the use of the POGIL strategy for the pharmacologic concepts represented a more significant shift in class activities and approach to solving problems. Consequently, before the POGIL strategy was introduced, students, on average, performed better on the pharmacokinetics-based examinations than on the pharmacology-based examinations (83.0% vs 80.0%, respectively), despite both examinations having a similar proportion of higher-level and lower-level questions (Table 2). Once POGIL was introduced, performance in the 2 sections of

Table 5. Student Ratings of Fostering Collaboration and Course Difficulty

	Average Score – 5 point scale, Mean ± SD		
	2011	2012	2013
Forming teams or discussion groups to facilitate learning ^a	2.9 ± 1.2	4.8 ± 0.4*	4.8 ± 0.4*
Asking students to help each other understand ideas or concepts ^a	3.6 ± 1.0	4.4 ± 0.8*	4.4 ± 0.8*
Acquiring skills in working with others as member of a team ^b	2.6 ± 1.3	3.9 ± 1.0*	4.0 ± 1.0*
Difficulty of subject matter ^c	4.2 ± 0.7	4.1 ± 0.7	3.9 ± 0.6*
Working harder in this course than other courses taken ^d	4.2 ± 0.7	4.2 ± 0.7	3.8 ± 0.7**

Students were asked to use the following scales to rate their responses to the statements in the table:

^a 1=hardly ever, 2=occasionally, 3=sometimes, 4=frequently, 5=almost always. $H=177$, $p<0.001$. $H=43.9$, $p<0.001$

^b 1=no progress, 2=slight progress, 3=moderate progress, 4=substantial progress, 5=exceptional progress. $H=71.2$, $p<0.001$

^c 1=much less than most, 2=less than most, 3=about average, 4=more than most, 5=much more than most. $H=18.3$, $p<0.001$

^d 1=definitely false, 2=more false than true, 3=in between, 4=more true than false, 5=definitely true. $H=20.4$, $p<0.001$ Kruskal-Wallis test

* denotes significant difference from 2011

** denote significant difference from 2011 and 2012 ($n=107$ for 2011 representing 96% response rate; $n=97$ for 2012 representing 87% response rate; $n=108$ for 2013 representing 97% response rate)

the course was similar (83.5% vs 83.7%) because more closely aligned strategies (ie, POGIL) were being used for both sections.

Final grade distribution (Figure 4) for the course also changed favorably postPOGIL. In 2011, prior to implementing the POGIL strategy, 2-4% of the class received a grade of D or F, and approximately 27% of the class received a grade of C. After implementation of the POGIL strategy, the grade distribution shifted significantly, with no grades of D or below, half as many Cs, and more Bs. This shift in grade distribution is consistent with other studies comparing the POGIL strategy to lecture-based methods. In a medicinal chemistry course, grades moved from a B-C centered distribution to an A-B centered distribution after POGIL was implemented.²⁶ Straumanis and Simons showed in their multi-institutional study of organic chemistry courses that the percentage of unsuccessful students (defined as those receiving D, F, or withdraw) in lecture-based courses was about twice that of POGIL-based courses.²⁰ In the current study, homework assignments were included in determination of the final grades. The final grade distribution, a measure representing the larger body of the students' work, was consistent with the examination data.

Student input on the course was collected using a variety of questions and formats such as Likert-scale ratings of standardized questions and free response to open-ended questions. Overall, students were supportive and positive towards the use of the POGIL strategy. Prior to implementing the POGIL strategy, students indicated that the course provided minimal opportunities to learn from their classmates (Table 5). PostPOGIL, there was a significant increase in those ratings. In the free-response section of the course evaluation, students indicated that the inclass exercises were helpful for 3 main reasons: the activities provided relevant applications of concepts, kept students engaged throughout class, and helped them realize the benefit of group work. This last point was aided by the role of the student assistants, P3 students who had experience in team-based learning and were able to convey to P1 students the importance and need for learning skills associated with effective group work. The students who provided negative or unsupportive comments (10-15%) for using the POGIL strategy focused on their experience as a member of an ineffective group. An ineffective experience involved group members not attending class, being unprepared, or lacking the desire to engage in the exercises. Future efforts to enhance group effectiveness will include providing a structured introduction on how to manage group work effectively, proactive monitoring for poorly functioning groups, and implementation of a peer evaluation system.

When students were asked to rate their perceived progress on attaining course objectives or skills in problem solving and critical thinking, they rated the course favorably (4.3-4.6 on a 5-point scale; Table 4). Traditionally, the course was rated above average (based on IDEA Center comparators) partially because it was the first course in the professional curriculum that had direct relevance and application to drugs. Therefore, the lack of change in course rating postPOGIL was not unexpected as room for improvement was limited. However, one area of change not anticipated was the students' perceptions of the difficulty and the amount of work in the course (Table 5). When the POGIL strategy was fully implemented in 2013, the students' ratings on difficulty and workload decreased significantly. During the period of this study, there were no major changes to the course and no significant changes to the professional curriculum or the preprofessional requirements. It is possible that students perceived a lighter workload because having POGIL activities throughout the course allowed them to become more efficient in their study and work habits. It is also possible that moving from 2 instructors in 2011 and 2012 to 1 instructor in 2013 reduced the perceived workload because students did not need to adjust to a second instructor's teaching style.

The adoption of the POGIL strategy presented some challenges. Converting materials required time to reconfigure the materials, reflection to identify and define the critical concepts, creativity to develop the models, and focus to create guided questions leading to the concept. The prospect of losing content was a minor issue. We continued to use the same syllabus and the same examinations when the course was covered using a lecture format. Any perceived loss of content was information deemed unnecessary for testing as seen by the use of the same examinations prePOGIL and postPOGIL with similar or better outcomes postPOGIL. Engaging students was challenging at times. Setting expectations, creating well-designed exercises, and having a student assistant in the classroom to facilitate discussion were critical components of successful sessions.

CONCLUSION

The use of the POGIL strategy had an overall positive effect on student learning and the classroom environment. Student examination scores improved as a result of increased performance on questions requiring higher-order thinking such as application and analysis. Students stated that their skills in problem solving and critical thinking improved with the use of the POGIL strategy.

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Appendix 1. Example of an Application POGIL Activity

Objectives of the activity

Using a set of data (eg, dose response curves, affinity constants):

- infer the pharmacological actions of a drug at a receptor and
- propose or predict potential therapeutic applications based on these actions.

Background Information

- Nicotine is an agonist at nicotinic receptors in the brain. Nicotine is present in tobacco products and plays an important role in the development of addiction to these products.
- Varenicline (Chantix) also acts at nicotinic receptors and is used as an aid in smoking cessation programs.
- The interaction of a drug with a receptor and subsequent biological effects can be described using various terms such as efficacy, affinity, potency, agonist, and antagonist.

1. Using figure 1, what conclusions can be drawn regarding the actions of varenicline compared to nicotine?
2. Compare the information provided in Figures 1 and 2. What do the curves in Figure 1 measure and what do the curves in Figure 2 measure?

3. The published K_d values of nicotine and varenicline for nicotinic receptors are: Nicotine: $K_d=1.0$ nM and Varenicline: $K_d=0.1$ nM. Based upon the K_d values, identify which curve in Figure 2 corresponds to varenicline and which curve corresponds to nicotine.

Dopamine is a neurotransmitter. Its release in an area of the brain called the nucleus accumbens is associated with producing a pleasurable or rewarding effect.

4. Explain the effects of nicotine and varenicline on the release of dopamine when each drug is administered alone.
5. Are the results depicted in Figure 3 consistent with results in Figures 1 and 2? That is, how do the data from Figures 1 and 2 explain the results in Figure 3?
6. When nicotine and varenicline are administered together, why isn't the response greater than when nicotine is administered by itself?
7. How or why is varenicline beneficial as an aid in smoking cessation?

Figure 1^a

Figure 2^b

Figure 3

^aReprinted with permission from: Rollema H, et al. *Neuropharmacology*. 2007; 52(3):985-994.

^bReprinted with permission of Rollema H, et al. *Trends Pharmacol Sci*. 2007; 28(7): 316-25.