Process-oriented guided-inquiry learning in an introductory anatomy and physiology course with a diverse student population

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Brown PJ. Process-oriented guided-inquiry learning in an introductory anatomy and physiology course with a diverse student population. Adv Physiol Educ 34: 150–155, 2010; doi:10.1152/advan.00055.2010.—Process-oriented guided-inquiry learning (POGIL), a pedagogical technique initially developed for college chemistry courses, has been implemented for 2 yr in a freshman-level anatomy and physiology course at a small private college. The course is populated with students with backgrounds ranging from no previous college-level science to junior and senior biology, biochemistry, and forensic science majors. Fifty percent of the lectures in the course were replaced with POGIL activities, performed in class by students working collaboratively in small groups. The introduction of POGIL pedagogy into the second half of a two-semester anatomy and physiology course significantly improved student performance on summative evaluations. Overall course scores increased from a mean score of 76% to 89% in the three semesters after POGIL was introduced. Performance on the same multiple-choice final exam rose from a mean of 68% to 88% over the same time period. Most significantly, the rate of students earning a D or F in the course was halved in the first two semesters after POGIL was introduced and was 0% in the third semester. Student satisfaction with the method was high, and most students perceived the value of this form of instruction.

active learning; student centered; process skills

The last 20 yr have seen a quiet revolution take place in science pedagogy. Beginning with problem-based learning (PBL) in the 1980s (4) and continuing to today, more and more science courses at both the high school and college level are incorporating some degree of active, student-centered learning. The National Research Council has produced statements in the last two decades strongly advocating more wide-reaching incorporation of student-centered teaching methods, especially inquiry-based methods, into secondary and postsecondary science curricula (20, 21). This increased emphasis on student-centered “active learning” is largely in response to the recognition by science educators that only a small fraction of students in introductory science classes are served by a traditional didactic approach (25).

Inquiry-based learning strategies have been widely incorporated into laboratory components of many courses within the biological sciences (3, 6, 12, 16); however, use of more student-centered strategies outside of the laboratory has been primarily within the context of a didactic lecture. Lundsford and Herzog (14) reported success using concept mapping and metacognitive writing within an introductory anatomy and physiology course. McLaughlin (15) found increased student performance upon the introduction of web-based e-learning modules as an addendum to a general biology course. Armbruster et al. (2) dramatically redesigned an introductory biology course to include PBL, group work, and student response systems (among other student-centered innovations) and found a statistically significant improvement in student performance after the incorporation of the student-centered reforms. Finally, Udovic et al. (28) radically redesigned their nonmajor general biology course into a workshop format that improved students’ appreciation for science and critical-thinking skills but was not designed to deliver content needed to perform well in upper-level courses.

There has been a more systematic and wide-reaching incorporation of active learning within chemistry education. Eberlein et al. (8) summed up the three most common and/or effective active learning strategies under the heading PXnL: PBL, peer-led team learning (PLTL), and process-oriented guided-inquiry learning (POGIL). PBL has been around the longest (4) and has been expanded from its original focus in medical education to a variety of subjects in undergraduate education (7). PLTL and POGIL are both effective at delivering content and are more popular with students than traditional didactic approaches (9, 13). These group-based pedagogies, to one degree or another, incorporate noncontent skills and allow more experienced students to mentor their less-experienced colleagues (be they classmates or upperclassmen who have previously taken the course), both assets in my particular course make up. Unfortunately, PBL alone requires more student independence and academic maturity (8) than is common in most introductory anatomy and physiology courses. Of the two remaining PXnL strategies, POGIL is more explicit in the inclusion of process skills and is designed from the outset to replace entire lectures, making it the ideal choice for many introductory anatomy and physiology courses.

POGIL was developed in the mid-1990s in response to the realization among chemistry educators that telling does not necessarily equal teaching (19) and is based on the concept of a three-stage learning cycle (9, 25), which emerged from cognitive research (1). Pedagogies that teach according to the three-step learning cycle take into account a student’s prior knowledge including (mis)conceptions about the material by allowing them to explore a model (data, a graph, an illustration, or text) using carefully crafted questions (the guided inquiry) to lead them to concept invention (25). Finally, students are asked to apply their new understanding of the concept through problems. In addition to delivering content in an effective manner (9, 26), POGIL explicitly incorporates process skills such as management (of time and human resources), information retrieval and processing, critical thinking, and oral and written communication (19). POGIL therefore incorporates aspects of both PBL and PLTL while also incorporating other noncontent skills into a single pedagogical method. POGIL also has an institutional support program through The POGIL...
Project, a federally supported program that trains educators in the POGIL technique, provides guidelines for the development of POGIL activities, and provides financial support to projects that aim to increase the use the POGIL method (19).

Course Description

The Anatomy and Physiology 2 (A&P 2) course at King College is the second half of the introductory level anatomy and physiology course. Unlike some institutions, where A&P 1 is solely an anatomy course and A&P 2 is solely a physiology course, at King College A&P 1 and 2 cover anatomy and physiology of the various organ systems, which are divided between the two courses. A&P 2 at King College covers the anatomy and physiology of the following organ systems: endocrine, blood, cardiovascular, digestive, respiratory, urinary, fluid balance, reproductive, and genetics.

A&P 2 is required of all students majoring in nursing, psychology, neuroscience, physical education, and athletic training. There are also a significant number of biology, biochemistry, and forensic science majors who want to pursue further education in medicine, pharmacy, physical therapy, dentistry, optometry, and other allied-health fields. A&P 2 does not count toward the BS degree in biology, forensic science, or biochemistry, so most of these students who take A&P 2 are seniors who have already completed most of their major requirements. These students are either taking the course to fulfill professional school prerequisites or to prepare them for their admissions tests (e.g., Medical College Admission Test, Pharmacy College Admission Test, or Dental Admission Test). Additionally, there are occasionally students who, because of recognized academic ability, are permitted to take A&P 2 without having the first half of the course. This incredibly varied student population ensures that the students have a very wide range of science coursework before taking A&P 2 (Table 1).

Course Redesign

In fall 2007, the A&P 2 course enrollment was low (n = 9), and assessment was through four in-class exams that contained multiple-choice, fill in the blank, short-answer, and essay questions, three laboratory exams with similar construction (but with a practical component), and a written comprehensive final similar in format to the other exams. In spring 2008, the course was altered to deal with the larger student population. The class was taught using primarily self-developed didactic lectures. Lecture notes, in outline form, were made available to students during class and on request. These outlines also served as study guides, essentially summarizing each chapter of the textbook into key points. Exams were still in class and proctored but were all multiple choice and delivered via an online course management system. There were also four summative quizzes offered between tests. The final exam was formatted and delivered like the regular semester exams.

In fall 2008, 50% of the lectures (Table 2) were replaced with POGIL activities developed over the summer of 2008. The lecture outlines from previous semesters were used to generate a study guide containing explicit learning goals for each chapter. The material available to the students was essentially the same, just formatted differently. The summative quizzes were also replaced with 10 formative quizzes, available online, that covered each of the 10 units in the course. The semester exams and final exam used in the POGIL semesters were the same as those used in the last semester of the lecture-only offering (spring 2008).

POGIL activities are meant to be completed by small groups of 3–4 students/group working collaboratively. Each activity is designed to be completed within the 65-min class period. To make process skill acquisition more effective and explicit, each student was assigned one of four particular roles to play within the group. The manager was responsible for keeping the entire group on time and on task. Students were provided with a set time limit to answer a particular set of questions, and it was the manager’s job to ensure that the group was finished on time. The manager was also the only member of the group allowed to ask the course instructor questions, so all group questions had to go through that person, reinforcing one of the built-in process skills inherent in this pedagogy. The scribe was the official record keeper of the group. As the instructor moved among groups to check on student progress, the scribe’s worksheet was the only one examined. If the group was to turn anything in (e.g., a flow chart or other collaborative product), the scribe’s copy was graded. It was the scribe’s responsibility to ensure that he or she understands the group’s consensus answers to all questions and that those were properly recorded. The spokesperson was the official mouthpiece of the group. When the instructor debriefed the class after each section of the activity, the instructor asked the spokesperson for the group’s answer. It was the spokesperson’s job to ensure that he or she understood the consensus answers for each question and could communicate that answer to the rest of the class either orally or in writing (on the board). Finally, the librarian was the only person in the group permitted to have their textbook open. If the group required information from a previous chapter to answer questions on the assignment (e.g., no one can remember what resting membrane potential is), it was the librarian’s

Table 1. Student population and level of preparation before the beginning of Anatomy and Physiology 2 course

<table>
<thead>
<tr>
<th>Major</th>
<th>Science Courses Typically Taken Before Anatomy and Physiology 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychology</td>
<td>Anatomy and Physiology 1</td>
</tr>
<tr>
<td>Physical Education</td>
<td>Anatomy and Physiology 1, another 4-h laboratory science course (Principles of Biology, Principles of Chemistry, or Astronomy)</td>
</tr>
<tr>
<td>Athletic Training</td>
<td>Anatomy and Physiology 1, Chemistry for Health Sciences</td>
</tr>
<tr>
<td>Nursing</td>
<td>Anatomy and Physiology 1, Chemistry for Health Sciences, Microbiology (often taken concurrently with Anatomy and Physiology 2)</td>
</tr>
<tr>
<td>Neuroscience</td>
<td>Anatomy and Physiology 1, General Chemistry 1, General Chemistry 2</td>
</tr>
<tr>
<td>Biology, Biochemistry, and Forensic Science</td>
<td>General Biology 1, General Biology 2, General Chemistry 1, General Chemistry 2, Organic Chemistry 1, Organic Chemistry 2, and usually 1 full year of upper-level biology coursework</td>
</tr>
</tbody>
</table>
task to find that information in the textbook and effectively communicate it to the rest of the group. Each POGIL activity contains numerous models that the students explore through a series of critical-thinking questions. Models include flowcharts, feedback diagrams, illustrations from the textbook, simulated patient charts, and graphs. For example, Physioactivity 8 (appendix) begins with a cardiological history of a make-believe patient, including a health assessment, mild stress test, and hospitalization records including a hemorrhage and a diagnosis of atherosclerosis. From these data, students are asked to determine the relationship between various hemodynamic factors (i.e., when heart rate goes up, what happens to blood pressure?). From this exploration, they are then asked to come up with a definition, in their own words, of cardiac output. They also derive the equation cardiac output = heart rate × stroke volume solely from exploration of the model. After the critical-thinking questions, which apply the first two stages of the learning model (exploration and concept invention), the students are then prompted to answer one or more application questions. Application questions cannot be directly answered from the data but rather must be based on a student’s application of the concepts discovered/invented in the first two stages. Finally, students are challenged with exercises and/or problems to reinforce the concepts discovered during the class.

A typical class period begins with a very short (no more than 1–2 min) introduction to the day’s activity. The instructor then sets a timer on the classroom computer and projects it onto the screen while the students begin exploring the day’s first model. As they work, the instructor walks among groups, checks the students’ progress, and provides direction, if needed, without divulging any answers. The whole point of using the learning cycle is that students are encouraged to invent concepts by themselves, using their own vocabulary and integrating them into their own knowledge base. Any questions asked are answered with leading questions meant to guide the student to the answer they seek, thus making instructor facilitation a vital component of the guided-inquiry process. After the time has elapsed, the instructor asks the spokesperson to share answers with the entire class. The instructor asks the spokesperson to put answers to certain key questions on the board. If a new term or concept is defined, the instructor has the students write their own definition on the board, and the class works together to come to a consensus definition of the concept. This is a vital component of facilitation because it ensures that the students are understanding the concept at the level appropriate to the question being asked. Exercises and/or problems are meant to be completed individually and are usually completed as homework, before the beginning of the next class. Many students, however, finish the activity proper with enough time remaining to work on the exercises/problems before they leave the classroom.

The first year POGIL was used in the course, the activities themselves were not graded, only casually checked for accuracy. To increase student “buy-in,” the instructor began assigning grades to the POGIL activities after the first semester. Each activity is now graded for accuracy, completeness, and whether or not it was completed in class. If the activity is performed

![Fig. 1. Mean final scores in the Anatomy and Physiology 2 (A&P 2) course from spring 2008 (SP08), fall 2008 (FA08), spring 2009 (SP09), and fall 2009 (FA09). Values are means ± SD. NS, not significant (P ≥ 0.05). *P < 0.01 as measured using a two-tailed Student’s t-test.](http://advan.physiology.org/)

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**Table 2. Physiology POGIL activities used in the redesigned course**

<table>
<thead>
<tr>
<th>Physiology POGIL Activities</th>
<th>Material/Concepts in the Activity</th>
</tr>
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<tbody>
<tr>
<td>Endocrine system 1</td>
<td>Endocrine versus exocrine glands, steroid versus nonsteroid hormones, and hormone mechanisms of action</td>
</tr>
<tr>
<td>Endocrine system 2</td>
<td>Control of endocrine secretions, tropic hormones, and negative feedback loops</td>
</tr>
<tr>
<td>Red blood cells</td>
<td>Hematocrit, erythrocyte morphology and function, hemopoiesis, and hemoglobin recycling</td>
</tr>
<tr>
<td>Hemostasis and blood type</td>
<td>Extrinsic clotting mechanism, ABO blood groups, Rh factors, and erythroblastosis fetaalis</td>
</tr>
<tr>
<td>Cardiac cycle 1</td>
<td>Systole versus diastole, cardiac muscle physiology, and the cardiac conduction system</td>
</tr>
<tr>
<td>Cardiac cycle 2</td>
<td>ECG, heart sounds, and cardiac fluid dynamics</td>
</tr>
<tr>
<td>Capillary exchange</td>
<td>Introduction to hemodynamics, capillary exchange mechanisms, and colloid osmotic pressure</td>
</tr>
<tr>
<td>Hemodynamics</td>
<td>Systolic and diastolic pressure, cardiac output, stroke volume, mean arterial pressure, and peripheral resistance</td>
</tr>
<tr>
<td>Innate immunity</td>
<td>Barrier defenses, second line defenses, and inflammation</td>
</tr>
<tr>
<td>Cellular adaptive immunity</td>
<td>T cell maturation and self-inventory, antigen presentation and T cell activation, role of the major histocompatibility complex, T cell types and functions, and cytokines</td>
</tr>
<tr>
<td>Humoral adaptive immunity</td>
<td>B cell activation, proliferation, and differentiation; antibodies and Ig classes; and classification of immunity</td>
</tr>
<tr>
<td>Anatomy of ventilation</td>
<td>Pressures driving tidal and maximal inspiration and expiration, the pneumothorax, and respiratory distress syndrome</td>
</tr>
<tr>
<td>Renin-angiotensin-aldosterone system</td>
<td>Role of all components and effector sites of the renin-angiotensin-aldosterone system in the regulation of electrolytes and blood pressure</td>
</tr>
<tr>
<td>Water homeostasis</td>
<td>Distribution of body water, water of metabolism, and excretion mechanisms</td>
</tr>
<tr>
<td>pH homeostasis</td>
<td>pH, buffers, chemical buffering systems, and physiological buffering systems</td>
</tr>
<tr>
<td>Metiosis</td>
<td>Meiosis versus mitosis and germ cell development</td>
</tr>
<tr>
<td>Mendelian genetics</td>
<td>Heredity, genes, alleles, dominance, incomplete dominance, and Punnett squares</td>
</tr>
<tr>
<td>More complex forms of inheritance</td>
<td>Sex-linked loci, codominance, and polygenic traits</td>
</tr>
</tbody>
</table>

POGIL, process-oriented guided-inquiry learning.
outside of class, the most a student can earn on that particular activity is four points of the possible six points. This provides an incentive for class attendance and participation. Currently, POGIL activities account for 10% of the total course grade, enough to adversely affect a student who never completes them but not enough to overcompensate for poor performance on summative assessments.

Introducing POGIL to Students for the First Time

Although POGIL has been demonstrated as a highly effective means of teaching content and process skills, implementation of POGIL into a course is not, however, an effortless proposition. Dee Silverthorn (23) noted that “there are always a few students who never make the transition [to an interactive classroom] and fail.” Walker et. al. (29) also noted that “student concerns about instructor expectations indicate that a judicious balance of student-centered activities and presentation-style instruction may be the best approach.” Lundsford and Herzog (14) also expressed difficulty with student “buy-in” into an active-learning student-centered class.

Silverthorn (23) and Wood (30) noted that making the pedagogy explicit from day 1 goes far toward getting the students to “buy-in” to what is, for them, something very new and perhaps a little bit frightening. In fact, Silverthorn (23) equated student responses to a student-centered pedagogy as similar to those experienced by people coping with catastrophe. Many instructors might laugh at such a comparison, but we must remember that our students have, by and large, been fed content through didactic means for most of their lives. They are comfortable with the notion that “good teaching is the efficient delivery, from professor to student, of such [unambiguous] facts…” (29), and any departure from this “efficient delivery” isn’t really teaching. Thus, the entire first day of the course is spent introducing the POGIL model and encouraging students to get “on board.” This involves a 10-min activity that imparts the benefits of working in groups. This activity is actually a modification of one of the first activities in which attendees of a 3-day POGIL seminar will participate. On day 1, the instructor gives the students a blank note card and has them, working by themselves, complete the following: 1) draw a parallelogram 1 in. high and 3 in. on the long axis; 2) if this is the state of Tennessee, place “/H9004” where Nashville should be; 3) place, in Roman numerals, the number of players on a side on an American football team; 4) draw a 1-in. high caduceus above the parallelogram; and 5) write the Latin motto of King College beneath the parallelogram. The instructor then has the students rate their confidence in the correctness of their drawing on a scale of 1–5. The instructor then puts the students into groups of four and has them repeat the exercise, again rating their confidence in their drawing at the end of the exercise.

Very few students possess all of the somewhat obscure knowledge needed to successfully draw the picture described, but most students possess some of that knowledge. Students see quickly that although a person rarely has all the answers,
people often do. This not only adds something fun to the first
day of class but also demonstrates unequivocally the benefits of
group learning. After this exercise, students are shown scient-
ific data of student performance from a chemistry course (9)
after the implementation of POGIL. This again shows students
verifiable evidence that what is being done works. Finally, a
lecture approach is used for some topics. Some material in
A&P 2 is largely factual and does not lend itself readily to a
guided-inquiry activity. Also, the use of lecture in about half of
the class meetings reassures those students who, for one reason or
another, are simply unconvincing of the utility of the POGIL
approach.

RESULTS

The last semester that was taught using lecture was spring 2008
(n = 25). POGIL was introduced in fall 2008 (n = 18) and
continued through spring 2009 (n = 31) and fall 2009 (n = 17).
The statistical significance of mean scores was determined using
a two-tailed Student’s t-test in all cases. Results were considered
significant if P values were below 0.05.

The last semester the course was taught using lecture only
(spring 2008); the mean final score was 76.04 ± 16.16. In the first
semester of the redesigned course (fall 2008), the mean final grade
was not significantly different (77.79 ± 16.11). During the
next two semesters, the mean final score rose significantly to
86.89 ± 12.16 in spring 2009 and 89.25 ± 8.72 in fall 2009
(Fig. 1).

Although the mean score was not significantly different be-
tween the lecture-only section and the first semester of POGIL,
the difference in the grade distribution was striking. In spring 2008,
The D/F rate for the course overall was 16% with an A/B rate of 52% (Fig. 2), but during the first semester of POGIL, the
D/F rate fell to 5.88% but the A/B rate did not rise; in fact, it fell
to 41.17%. The number of B grades rose from 32% to 52.94% in
class. The percentage of students earning an A in the
course remained steady across all four semesters (Fig. 3).

There is a laboratory component to the course, which accounts
for 30% of the final grade. The laboratory grade is, however,
based solely on examinations, which contain both written compo-
nents and a practical. Since the laboratory grade is based solely on
summative assessment and there is considerable overlap between
the concepts and material covered in POGIL and in the laboratory,
it was felt that reporting total course grades has value; however, to
more accurately assess the influence of the course redesign, it is
necessary to examine performance on the comprehensive final
exam. The same final exam was used in all four semesters of this
study and was administered via the online course management
system Blackboard as a proctored, in-class exam. In the lecture-only
semester, the most common grade on the final exam was an F, and
more students earned a C or D than earned an A or a B (Fig. 4). The
distribution moved steadily away from the C/D/F distribution
and toward an A/B/C distribution after the introduction of
POGIL, with no students failing the final exam in fall 2009 (Fig. 4).
The mean score on the final exam rose from 68.08 ± 16.21 in
spring 2008 to 79.88 ± 14.48 in fall 2008, 86.22 ± 11.83 in
spring 2009, and 88.33 ± 12.16 in fall 2009 (Fig. 5).

Student perceptions of the course overall showed little differ-
ence between the lecture-only semesters and POGIL semesters.
Using IDEA (11) evaluations of instruction, students in the pre-
POGIL classes were not significantly different (P = 0.56 using a
two-tailed Student’s t-test) from those in the POGIL classes with
regard to their perceptions of how clearly the content was deliv-
ered, how well the material was related to real-life situations, or
how well the material was communicated to them (Table 3).
Unsurprisingly, however, there was an increase in student percep-
tions of the importance of group work, although it was not
statistically significant (Table 3). Student perceptions of the
importance of their peers in helping them to understand ideas and
concepts did increase significantly (P = 0.015) after the introd-
uction of POGIL. Qualitative data regarding student perceptions of
POGIL were overwhelmingly positive (see Table 4 for a selec-
tion) and seemed to indicate that students not only enjoyed the
POGIL activities but perceived their benefit.

Conclusions

Active learning methods are becoming more prevalent in
science education as the verifiable evidence of their success
becomes apparent to more educators (17). POGIL has been
implemented with great success in general chemistry (9),
organic chemistry (24), physical chemistry (27), biochemistry

Table 3.  Selected items from IDEA (11) student evaluations of instruction

<table>
<thead>
<tr>
<th>Evaluation Question</th>
<th>Pre-POGIL Score</th>
<th>Post-POGIL Score</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Instructor demonstated the importance and significance of the subject matter</td>
<td>4.65 ± 0.07</td>
<td>4.63 ± 0.06</td>
<td>0.807</td>
</tr>
<tr>
<td>5. Instructor formed teams or discussion groups to facilitate learning</td>
<td>4.00 ± 0.42</td>
<td>4.9 ± 0</td>
<td>0.205</td>
</tr>
<tr>
<td>6. Instructor explained course material clearly and concisely</td>
<td>4.5 ± 0.57</td>
<td>4.6 ± 0</td>
<td>0.844</td>
</tr>
<tr>
<td>11. Related course materials to real-life situations</td>
<td>4.55 ± 0.21</td>
<td>4.6 ± 0.26</td>
<td>0.830</td>
</tr>
<tr>
<td>18. Instructor asked students to help each other understand ideas or concepts</td>
<td>4 ± 0</td>
<td>4.53 ± 0.12</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Values are means ± SD. Results are based on a Likert scale, where 1 = strongly disagree and 5 = strongly agree. P values are based on a two-tailed Student’s t-test.

Table 4.  Selected student comments from IDEA student evaluations

• “I really liked the POGILs. They really helped me understand things rather than have them memorized to regurgitate on the test.”
• “I liked the POGIL activities, not only because they helped me learn, but I gained experience with working as a team.”
• “I really liked the POGILs. They really helped me understand ideas or concepts did increase significantly (P = 0.015) after the introduction of POGIL. Qualitative data regarding student perceptions of POGIL were overwhelmingly positive (see Table 4 for a selection) and seemed to indicate that students not only enjoyed the POGIL activities but perceived their benefit.

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organic chemistry (24), physical chemistry (27), biochemistry
(18) medicinal chemistry (5), mathematics (22), and even business marketing (10), as it has in our introductory A&P 2 course. Student performance on lecture exams, the comprehensive final, and the course overall was significantly higher in the POGIL sections than in the final lecture-only offering of the same course. Although POGIL requires a great deal of effort and a careful introduction to students who might be skeptical of a novel and unfamiliar classroom experience, its benefits cannot be easily disputed.

DISCLOSURES

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REFERENCES