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Developing POGIL Materials: Writing and Refining Activities for a Spectrum of Content Areas

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***P**rocess **O**riented **G**uided **I**nquiry **L**earning (POGIL) is an active-learning pedagogy that emphasizes content mastery as well as the development of process skills like critical thinking and problem solving. Although published POGIL materials are available in several STEM disciplines, there are still a number of courses within a variety of disciplines for which materials have not been written. The authors describe how to write POGIL activities, including details on the learning theories behind POGIL, how to develop a model, how to write guiding questions that scaffold content mastery and development of process skills, and how to refine an activity based on feedback.*

Introduction

Process **O**riented **G**uided **I**nquiry **L**earning (POGIL) is an active-learning pedagogy that has been adopted in a variety of STEM disciplines, including chemistry, mathematics, biology, psychology, and computer science at the secondary and post-secondary level (Moog & Spencer, 2008). POGIL has also been used in non-STEM disciplines such as information literacy, business marketing, financial literacy, aviation law, and instrument flight rules (Hale & Mullen, 2009; Maurer, 2014; Mitchell & Hiatt, 2010; Vacek, 2011). A variety of other pedagogies have been developed to encourage active learning in the classroom, including, but not limited to, peer-led team learning (PLTL) (Gafney & Varma-Nelson, 2008; Gosser Jr, 2015; Gosser Jr., Kampmeier, & Varma-Nelson, 2010), peer instruction (Crouch & Mazur, 2001; Turpen & Finkelstein, 2009), flipped classrooms (Bishop & Verleger, 2013), problem-based learning (PBL) (Savery & Duffy, 1995), and student-centered active learning environment with upside-down pedagogies (SCALE-UP) (Beichner et al., 2007). All of these pedagogies aim to engage students in meaningful learning using a variety of active individual or group tasks along with formative assessment. Generally, these active learning pedagogies require instructors to change how they facilitate their classroom environments, and several of these pedagogies require specifically designed course materials to guide student learning.

The POGIL pedagogy is one that requires developing specific materials and activities. A unique aspect of POGIL activities is that they are based on the learning cycle of exploration, concept invention, and application (Abraham, 2005; Lawson, 1995; Lawson, Abraham, & Renner, 1989). In a POGIL classroom, students work in teams on POGIL activities that guide them to discover new concepts. Implementation of POGIL can be customized to the classroom environment; activities can be completed every class, once a week, or every other week. POGIL materials (the in-class activities as well as supplemental documents like implementation guides, and answer keys) for some introductory level courses, have been published and approved by the POGIL Project (www.pogil.org). However, activities for many advanced courses or other disciplines are not available. Thus, instructors interested in adopting POGIL in courses without published materials must write their own activities to use in their classrooms.

Another common active learning pedagogy, PLTL typically occurs in a recitation session or optional study session outside the regular classroom (Hockings, DeAngelis, & Frey, 2008; Preszler, 2009). The fundamental difference between activities for PLTL and POGIL is that PLTL activities are not meant to introduce new concepts; rather, they are prepared to enrich content acquired in another manner. PBL (Eberlein et al., 2008) activities can take many forms, but they always begin with an open-ended problem for students to solve. PBL activities can be collaborative like POGIL, or they can be solved individually (Davis, 2009). Unlike POGIL, where the guided inquiry is a part of the written activity, guidance in PBL is often solely through facilitation and requires considerable flexibility and subject area expertise on the part of the instructor (Davis, 2009). SCALE-UP is a

strategy that combines a studio pedagogy with classroom design (Handelsman et al., 2004). It combines a "flipped" approach, meaning that students do some preparation outside of class and engage in an application of what they've learned during the class meeting. Beichner and Saul (2003) describe activities employed in a SCALE-UP physics classroom that they refer to as "tangibles and ponderables"—both of which incorporate elements of what would normally be a lab activity into the classroom setting. The majority of other common active-learning strategies are even less reliant on the written materials used, so they will not be discussed further in this article.

A recent chapter on authoring POGIL activities describes the elements of POGIL activities, suggests how to select and use activities, and offers tips for how to start writing POGIL activities (Kussmaul & Sullivan, 2019). However, the authors do not provide a step-by-step process highlighting how to convert lecture materials into POGIL activities. This article is designed to help instructors interested in writing POGIL activities learn about the theory behind POGIL, determine how to transform lecture notes into a POGIL activity, and use feedback from students and other faculty users to refine the activity.

Background

The Theory Behind POGIL Pedagogy

POGIL is a classroom and laboratory instructional technique based on theories of constructivism (Piaget, 1977; Vygotsky, 1978, 1986) and the learning cycle (Lawson, 1995; Lawson et al., 1989). In the POGIL classroom, students are actively engaged in the development of process skills, construction of knowledge, and social interactions to help them gain a deep understanding of content and achieve long-term retention of concepts (Piaget, 1977; Vygotsky, 1978, 1986). This is accomplished though facilitation of specially designed course materials (POGIL activities). Regardless of discipline, the two primary objectives of teaching using the POGIL pedagogy are as follows:

- mastery of content, where students construct their own understanding of the concepts; and
- development of process skills such as information processing, communication, critical thinking, problem solving, and metacognition (Moog & Spencer, 2008).

All POGIL activities must include questions that allow students to explore new information in order to develop a concept. Additionally, the sequencing of these guiding questions must be carefully considered so that students reach the appropriate conclusions as well as develop process skills (Kussmaul & Sullivan, 2019).

The Learning Cycle

Providing assistance to learners as they develop new knowledge can be accomplished by following the learning cycle. The learning cycle is an inquiry strategy for teaching and learning grounded in the constructivist principles of Abraham and Lawson (Lawson, 1995; Lawson et al., 1989). POGIL activities are designed using questions that guide students through the three phases of the learning cycle: exploration, concept invention, and application. Each phase of the learning cycle serves a different purpose in the learning process, as shown in Table 1.

Table 1
Phases of the Learning Cycle

Learning Cycle	*Definition*
Exploration	Questions that require students to collect information and examine data in the models, students can these questions from the information provided or from prior knowledge.
Concept Invention/Term Introduction	Questions that require students to find patterns in the data and converge on a concept by having students analyze, compare, and contrast concepts. Terms are typically introduced after a concept has been developed.
Application	Questions that require students to test their understanding of concepts by applying them in new contexts.

In the first, exploration phase, students are asked to analyze information provided in a model. A model can include a table, chart, diagram, or scheme—any form of information relevant to the topic under discussion. Students answer exploration questions that allow them to evaluate a model, interpret the information in the model, and search for patterns within it. In the second, concept invention phase, questions guide students

to combine multiple pieces of data identified in the exploration phase to help them construct and develop a particular concept. Once the concept is developed, then the term or the name for this concept is introduced. The strategy is to get the students to explore a concept, summarize in their own words then tell them what it is called so they are not encumbered by the terminology at the beginning. In the final, application phase, students solidify their understanding of the newly constructed concepts by applying them to new situations. The learning cycle provides important scaffolding, or structure, to guide students, in constructing and refining new concepts; this scaffolding helps promote a sense of ownership of the content knowledge.

Question Types

Every POGIL activity follows the learning cycle, and there may be more than one learning cycle per model. Scaffolding within the learning cycle may be further delineated with three question types: directed, convergent, or divergent (Hanson, 2006). Each type of question is designed to serve a different purpose, as detailed in Table 2. Developing POGIL activities using the different question types, provides a framework to structure questions that build upon the provided information and previous questions.

Table 2
Types of POGIL Questions

Question Type	*Definition*
Directed Questions	Questions that can be answered directly from provided information or previous knowledge and provide a foundation for later parts of the activity.
Convergent Questions	Questions that may have single or multiple answers and generally require more than one piece of information to synthesize a conclusion.
Divergent Questions	Questions that are open-ended, do not have specific answers and may lead individual learners in different directions.

Directed questions are frequently used in the exploration phase of the learning cycle, because these questions help students navigate the various information provided in the models. Although directed questions may seem obvious to the instructor, they are a critical component of the exploration phase of the learning cycle because they help organize and direct student inquiry. Convergent questions are generally used in the concept invention and application phases. These questions require that students combine multiple pieces of information to help them develop or apply the new concept. Divergent questions, not as common as directed or convergent questions, are designed to promote discussion due to their open-ended nature, and they are most often used in the application phase of the learning cycle.

Process Skills

The POGIL pedagogy also emphasizes development of key process skills. Most employers emphasize that skills such as problem solving, management, creative thinking, leadership, communication, teamwork, and metacognition (Carnevale, Gainer, & Meltzer, 1990) are critical to success in the workplace. The POGIL Project refers to these skills as process skills, but they are also known by various other names, including workplace skills, professional skills, personal skills, lifelong learning skills, soft skills, and transferable skills. Students need to develop these key skills in order to optimize their education in active learning environments and to prepare them to be successful in the workplace. The POGIL Project has developed standard definitions for these process skills, as shown in Table 3 (The POGIL Project, 2015). These definitions provide a common language for each skill, are designed to be used across different disciplines, and can be utilized in writing activities and facilitating the POGIL classroom.

Connections Between the Learning Cycle, Question Type, and Process Skills

POGIL activities are designed to follow the learning cycle, incorporating different question types to provide scaffolding and ensuring that questions involve the development of process skills. These factors are interwoven throughout an activity and integrated into questions to ensure that students develop disciplinary concepts and process skills concurrently (see Figure 1). The learning cycle, shown on the left side of Figure 1, is the foundation of every POGIL activity. The exploration phase of the learning cycle generally employs directed questions to help students process information contained in the models. These questions prompt students to evaluate the relevance of the information and to interpret the data provided, a key aspect of information processing. Directed questions

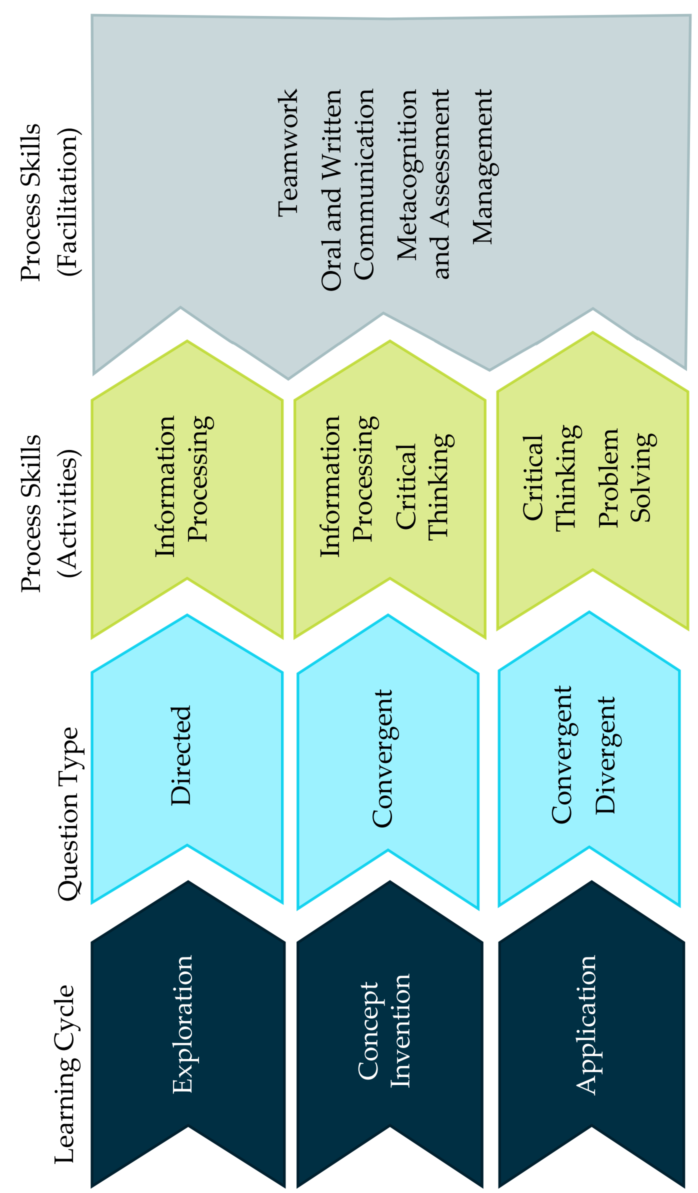
Table 3
POGIL Process Skills (The POGIL Project, 2015)

Oral & Written Communication	Oral Communication: Exchanging information and understanding through speaking, listening, and non-verbal behaviors. Written Communication: Conveying information and understanding to an intended audience through written materials (paper, electronic, etc).
Teamwork	Interacting with others and building on each other's individual strengths and skills, working toward a common goal.
Information Processing	Evaluating, interpreting, and manipulating or transforming information
Critical Thinking	Analyzing, evaluating, or synthesizing relevant information to form an argument or reach a conclusion supported with evidence.
Problem Solving	Identifying, planning, and executing a strategy that goes beyond routine action to find a solution to a situation or question
Management	Planning, organizing, directing, and coordinating one's own and others' efforts to accomplish a goal.
Assessment (Self-Assessment, Peer Assessment, and Metacognition)	Self- and Peer Assessment: Gathering information and reflecting on experiences to improve subsequent learning and performance. Metacognition: Thinking/reflecting about one's thinking and how one learns, and being aware of one's knowledge.

are a critical component of the learning cycle, because they provide the foundation for development of critical thinking and problem solving.

The concept invention phase employs convergent questions to encourage students to transform the given information and to begin synthesizing relevant information to form an argument about the concept they are developing, using critical-thinking skills. The application phase uses both convergent and divergent questions to allow students to

Figure 1
Connections Between the Learning Cycle, Question Types, and Process Skills



apply a concept in different contexts. The application questions require higher levels of critical thinking, wherein students must support their conclusion with evidence and develop and execute strategies to solve new problems. While some process skills are emphasized in different phases of the learning cycle, all of the questions in an activity are written to support the development of students' communication and teamwork skills. Furthermore, while written POGIL activities may direct students to *explain* concepts to their teammates, further encouragement by the instructor during classroom facilitation will ensure that students *practice* skills such as teamwork, communication, metacognition and assessment, and management. These features, woven together through the activity, build student understanding, develop key process skills, and promote scientific argumentation (Kulatunga, Moog, & Lewis, 2014).

Rationale

An active learning POGIL classroom must include learning cycle activities that students complete during class time. Although a number of published POGIL activities are available, they are mostly in chemistry and biology. There are still courses within a variety of disciplines for which no published POGIL activities exist. A specific guide for how to develop and refine POGIL activities would be an important resource for potential authors of POGIL activities. Herein, we outline key steps for how to write effective POGIL activities for any discipline. We include an example of a simple POGIL activity on geometry so that the structure of a POGIL activity can easily be followed by those from different disciplines. In particular, we focus on the following key POGIL decisions and actions:

1. Deciding upon key concepts and what information is needed to make an effective activity.
2. Writing questions that allow students to construct a concept.
3. Writing questions that encourage discussion and development of process skills.
4. Testing and revising an activity based on feedback.

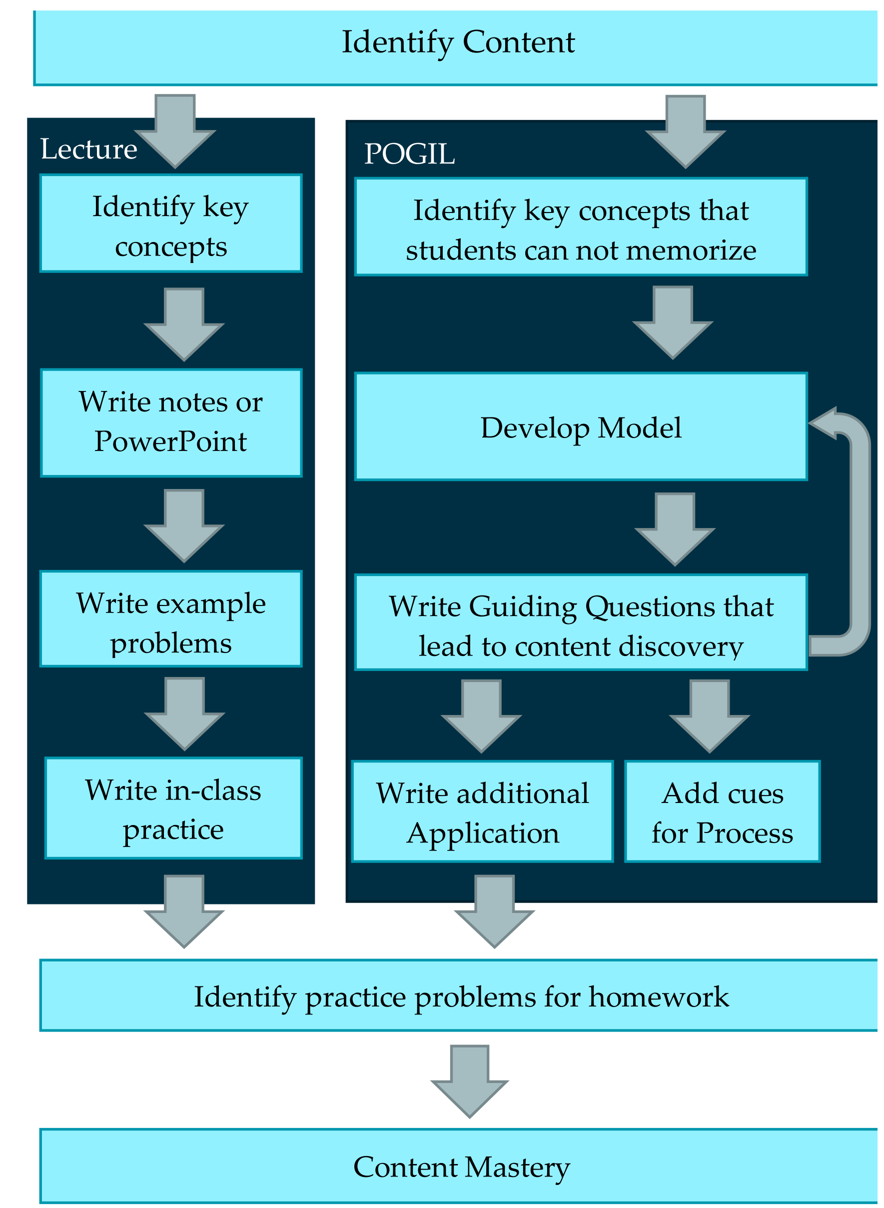
Overview of Preparation for Lecture vs. POGIL Classrooms

In a traditional lecture setting, instructors typically prepare for class by selecting a book, determining what order to present key topics, and preparing materials to use in the classroom. In an active learning setting such as POGIL, instructors follow a similar pathway, except the types of materials prepared are different. A comparison of these general processes is shown in Figure 2. For a lecture, the instructor typically prepares notes, presentations, and examples of concepts and solved problems. Generally, these materials explain concepts and provide examples. In contrast, for a POGIL lesson, the instructor prepares activities that consist of data or information in the form of a figure or diagram (the model), followed by questions that allow students to invent the concept. Since students work in teams on the activities, cues for key process skills can also be imbedded in the activities. Typically, each new concept to be developed will include a new model of information, so that iteration of this approach is necessary.

Consider the lecture preparation pathway shown on the left in Figure 2. To prepare a lecture, instructors identify a topic and the key concepts that will be presented to the class. Then they prepare notes and/or presentations to deliver the information in the form of a presentation or a "chalk talk." Once the content, examples, and practice questions are determined, instructors then decide what to assign for homework, drawing either from the course textbook or an online homework program. Together, the lecture presentation and homework assignments ideally lead to content mastery.

In comparison, consider the POGIL preparation pathway shown on the right side of Figure 2. If a POGIL activity is not available for a particular concept, then it must be developed. Much like a typical lecture preparation, instructors decide what content will be taught and identify key concepts. These concepts should not be information that can be easily memorized. Once a key concept has been selected, a model needs to be designed around that concept. Models consist of information that students explore to construct the concept, in the form of a graph, table of data, figure or diagram that illustrates a topic. Questions about information in the model are then written to help students develop the key concept. Additionally, cues can be included in the questions to help students engage and develop process skills. For example, the direction "Discuss with your team" prompts students to engage in oral communication and teamwork, while "Justify your answer" is used to elicit critical thinking by asking students to construct scientific arguments to support their claim. The process of choosing a model and writing guiding questions is repeated until all pieces of a key concept are developed. Finally, additional application questions or exercises at the end of the activity are added to help students practice applying the newly developed concept in a different context. As with instructors that lecture, practice problems are selected for homework to help lead to content mastery.

Figure 2
General Process for Preparing a Lecture Presentation vs. a POGIL Activity



Identifying Learning Objectives and Key Concepts

Identifying Key Concepts

In considering which key concepts to focus on for a POGIL activity, a quick look at existing lecture notes or course outline can act as a guide. Concepts that require simple rote memorization are not ideal for writing POGIL activities and are often better assigned as homework. Concepts that require a deeper conceptual understanding, especially if they are prerequisite concepts for later key ideas in the course (such as pKa in chemistry or diffusion in physiology), are ideal for creating a POGIL activity. Additionally, concepts that facilitate higher-order skills like problem solving and critical thinking make good topics for a POGIL activity. In addition to lecture notes, the table of contents of a course textbook can also help an instructor determine the concepts to be developed in a POGIL activity. Chapter titles and subtitles usually contain one or two key concepts that provide a broader context for the topic of the chapter.

Determining Learning Objectives

Once a key concept is chosen for development into a POGIL activity, it is helpful to delineate the learning objectives for this activity. Activities typically cover one major concept, consist of two to three models used to develop various aspects of the concept, and typically take about 50 to 100 minutes for students to complete depending on the length or complexity of the activity. Generally, an activity should have no more than three main learning objectives. A single learning objective may be assigned to each model and should reflect the main ideas intended for students to master. These learning objectives can then be used to develop guided inquiry questions that help students discover these concepts on their own. Inclusion of the prior knowledge needed to complete the activity is also helpful. With this information, students can review any important concepts before they attempt to complete the activity. A sample title page for one model in the example Geometric Shapes activity is shown in Figure 3.

Developing a Model

After key concepts for a POGIL activity are chosen, the next step is to decide on models that will enable students to acquire these concepts through guided inquiry. A model often consists of information that students explore, in the form of a graph, table of data, short reading passage, or a figure or diagram that illustrates a topic. Models can also include live demonstrations (such as dissections), exhibits (for example, paintings), or short videos. The model chosen should contain enough depth to allow students to discover the intended concepts without being so detailed that the answer is simply provided with no discovery needed. It is important that each model facilitate students' acquisition of the learning objective and that a sufficient number of questions can be constructed in order to move through a full learning cycle.

POGIL activities are well-suited for allowing discussion of common misconceptions. Addressing misconceptions head-on in a POGIL activity can allow students to gain a more accurate understanding of the concepts as well as to integrate the concepts within their own cognitive schema so that the misconception does not persist. Misconceptions are likely to persist if not addressed directly, and the model of a POGIL activity provides an excellent opportunity to do this. In the geometry activity used as an exemplar throughout this article, the third part of the model contains squares that have been halved on the diagonal to address a potential expectation that the diagonal will be the same length as the sides and to

Figure 3
Title Page Stating Necessary Prior Knowledge and Learning Objectives for the Geometry Activity

Activity: Geometric Shapes

<u>Prior Knowledge</u>

Before beginning this activity, students should be familiar with the following concepts:
- Length and width
- Inches
- Basic Shapes

<u>Learning Objectives</u>

Content Learning Objectives:
After completing this activity, student should be able to:
- Determine the perimeter of a shape

Process Learning Objectives:
- Information Processing: Students interpret information about the perimeter of a shape.
- Critical Thinking: Students analyze and synthesize information to predict and compare perimeters of multiple shapes.

Note. The targeted process skills are also listed for the activity. These skills are the ones that are most likely to be developed by completing provide an entry into trigonometry concepts. Incorporation of anything that directly challenges common pre-conceived notions into the model allows authors to give students the opportunity to engage with any cognitive dissonance from the beginning.

As shown in Figure 3, the learning objective for the Geometric Shapes activity is to determine the distance around a shape, the perimeter. Figure 4 shows the first model from the activity, where students explore different shapes in order to discover the concept of perimeter. The model includes three different shapes drawn as a series of squares on the activity. Alternative suggestions for a model for this learning objective could be to use materials like blocks or paper squares to replicate the shapes, or even to have students watch a video presentation of shapes reforming with the same, and then with different, perimeters.

Writing Guiding Questions

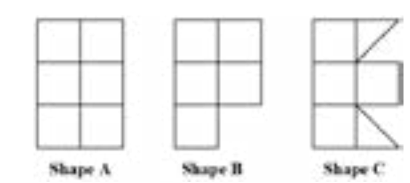
Once a model is in place, questions can be crafted that follow the learning cycle. Initial questions should allow students to explore the content provided in the model, and subsequent questions should guide them through concept invention and, ultimately, application. Typically, these questions follow a progression from directed questions, to convergent questions, and, finally, to divergent questions. In the Geometric Shapes activity example shown in Figure 5, each question is labeled with respect to the stage of the learning cycle (exploration, concept invention, application) in bold and type of question (directed, convergent, divergent) in italics.

Exploration Phase

The exploration phase of the learning cycle allows students to answer questions that engage with the model, determine what information is present in the model, and discover how information in the model is connected. Consider the Geometric Shapes activity shown in Figure 5. The model consists of a series of different shapes made from squares. The questions start with having the students explore these shapes. The first question (1a) is a directed question whose answer is found directly in the model by counting the squares. This exploration phase is repeated each time a new shape in the model is explored. Exploration questions could be grouped together at the start of each model, or separated based on what is being explored from the model, as in this example. Exploration questions are important so that students can become familiar with the information in the model and provide the foundation for the discovery aspect. Although these directed questions may seem obvious to an instructor familiar with

Figure 4
Activity: Geometric Shapes

Model 1: How can the distance around a shape be measured?



Questions:

1. a. How many squares make up **Shape A**? *6 squares*
   b. If each square shape is 3 inches in length, what is the distance around the outside of **Shape A** in inches? Discuss as a team, how you came to this conclusion. Write down your team's best strategy.
   Outside of Shape A is 30 inches. Count how many edges of each square make up the outside of Shape A. There are 10 edges that form the outside of Shape A and each edge is 3 inches
   c. The distance around a shape is called the perimeter. Write a process for calculating perimeter that works for **Shape A**.
   length of edge x # of edges = perimeter
   3 inches x 10 edges = Outside edge is 30 inches
2. a. How many squares make up **Shape B**? *5 squares*
   b. Compare **Shape A** and **Shape B** without measuring. Would you predict the perimeters to be the same or different? Explain.
   The perimeters should be the same because there are still 10 edges of the 5 squares that make up the outside of Shape B.
   c. If each square shape is 3 inches in length, what is the perimeter of **Shape B** in inches?
   Perimeter of Shape B is 30 inches
   d. Does your prediction from question #2b match the actual perimeters calculated for **Shape A** and **Shape B**? Discuss as a team why your prediction was correct or not. Explain.
   Yes, the prediction that the two shapes have the same perimeter is true. This prediction was correct because the outside of both shapes is made up of the same number of edges (10) there when you add up the lengths of each edge you still get 30 inches.
3. a. How many squares make up **Shape C**? *4 squares and 2 halves of a squares (triangle) = 5 squares total*
   b. Estimate the length of the inside edge of the triangle shape. Compared to the outside edges, the distance of the inside edge is *(circle one)* *longer* / shorter / same.

Figure 4 (*continued*)
Activity: Geometric Shapes

3. (*continued*)
   c. How did you determine the distance of the inside edge of the triangle?
      Traced triangle on to another piece of paper and put next to edge of square to compare lengths.
   d. Would the perimeter of **Shape C** be larger or smaller than the perimeter of **Shape B**? Explain your strategy.
      Larger. There are 10 square edges plus the longer edges of 2 triangles.
   e. Recall your process for calculating the perimeter from question #1c. Does this process work for **Shape C**? If not, rewrite your process for perimeter so that it will work for all three shapes.
      No, it does not account for the longer edges of the triangles. (length of square edge x # of edges) + (length of triangle edge x # of edges) = perimeter
4. Recall that the area of an object is defined as the number of square units that covers up the object. Using complete sentences, support or refute this claim: **as perimeter increases, area increases**.
   This claim is false. Shape A and B both have the same perimeter but Shape A has a great area because it has 6 squares as opposed to 5. Furthermore, when comparing Shape B and Shape C, Shape C has a larger perimeter but both Shapes have the same area because they both comprised of 5 squares.

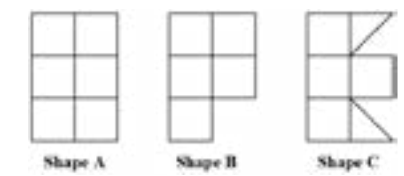
the material, they often do not appear simple to novice learners. Sometimes adding an additional exploration question helps students bridge a gap that may cause them to get stuck on a concept.

Concept Invention/Term Introduction Phase

In the concept invention phase, students develop the concepts that are the intended learning outcomes of the activity. A key component of the POGIL pedagogy (and of constructivist theory in general) is that concept invention should precede term introduction. The goal is to allow students to integrate the new knowledge/concept with their existing schema to construct their own understanding of the concept using their own words and explanations. Only after this discovery has occurred are they supplied with the technical terms to explain that new concept more fully. Questions in the concept invention phase require more cognitive effort on the part of students.

Figure 5
Example of a POGIL Activity About Perimeter With Each Question Annotated for the Learning Cycle Stage and Question Type

Activity: Geometric Shapes
Model 1: How can the distance around a shape be measured?



Questions:

1. a. How many squares make up **Shape A**?
      Learning Cycle – Exploration: Students are asked to examine Shape A in Model 1.
      Question Type – Directed: *The number of squares can be determined by counting.*
   b. If each square shape is 3 inches in length, what is the distance around the outside of **Shape A** in inches?
      Discuss as a team, how you came to this conclusion. Write down your team's best strategy.
      Learning Cycle – Concept Invention: Students calculate the perimeter of Shape A, using the information they determined in Q1a and information provided in Q1b.
      Question Type – Convergent: *There are several correct approaches students can use to determine the distance around Shape A, and they need to combine multiple pieces of information to arrive at the answer.*
   c. The distance around a shape is called the <u>perimeter</u>. Write a process for calculating perimeter that works for **Shape A**.
      Learning Cycle – Concept Invention/Term Introduction: Students are introduced to the term perimeter after calculating it and taking the strategy they previously developed and turning it into a mathematical equation.
   Question Type – Convergent: *There are several correct approaches students can use to determine the distance around Shape A, and they need to combine multiple pieces of information to arrive at the answer.*

Figure 5 (*continued*)
Example of a POGIL Activity About Perimeter With Each Question Annotated for the Learning Cycle Stage and Question Type

2. a. How many squares make up **Shape B**?
Learning Cycle – Exploration: Students are asked to examine Shape B in Model 1.
Question Type – Directed: *The number of squares can be determined by counting.*
b. Compare **Shape A** and **Shape B** without measuring. Would you predict the perimeters to be the same or different? Explain.
Learning Cycle – Concept Invention: Using the information they determined in Q1 and Q2a students compare the perimeter of Shape A to Shape B based on the number of square sides.
Question Type – Convergent: *Students need to combine multiple pieces of information to compare the shapes and arrive at an answer.*
c. If each square shape is 3 inches in length, what is the perimeter of **Shape B** in inches?
Learning Cycle – Application: **Students calculate the perimeter of Shape B using the process they determined in Q1 to calculate the perimeter of Shape A.**
Question Type – Convergent: *There are several correct approaches students can use to determine the perimeter.*
d. Does your prediction from question #2b match the actual perimeters calculated for **Shape A** and **Shape B**? Discuss as a team why your prediction was correct or not. Explain.
Learning Cycle – Application: Students compare the two calculated perimeters, then evaluating their prediction.
Question Type – Convergent: *Students need to combine multiple pieces of information and there are several correct approaches students can use to evaluate their process for predicting perimeter.*
3. a. How many squares make up **Shape C**?
Learning Cycle – Exploration: Students are asked to examine Shape C in Model 1.
Question Type – Directed: *The number of squares can be determined by counting.*
b. Estimate the length of the inside edge of the triangle shape. Compared to the outside edges, the distance of the inside edge is *(circle one)* longer / shorter / same.
Learning Cycle – Concept Invention: Students need to determine a way to estimate the length of the triangle's edge and compare it to the known length of the square's edge.
Question Type – Convergent: *There are several correct approaches students can use to determine the length of the inside edge of the triangle.*

3. (*continued*):
c. How did you determine the distance of the inside edge of the triangle?
Learning Cycle – Concept Invention: Students explain the process for determining the distance of the inside edge of the triangle.
Question Type – Convergent: *There are several correct approaches students can use to determine the length of the inside edge of the triangle.*
c. Would the perimeter of **Shape C** be larger or smaller than the perimeter of **Shape B**? Explain your strategy.
Learning Cycle – Application: Students compare their known and estimated perimeters for Shape B and C to determine which is larger.
Question Type – Convergent: *There are several correct approaches students can use to determine the perimeter and they need to combine multiple pieces of information to arrive at the answer.*
e. Recall your process for calculating the perimeter from question #1c. Does this process work for **Shape C**? If not, rewrite your process for perimeter so that it will work for all three shapes.
Learning Cycle – Application: Students review their previous process of calculating the perimeter of Shape A and try to determine if this same process works for Shape C. If it does not they must develop a new strategy.
Question Type – Convergent: *There are several correct approaches students can use to determine the perimeter and they need to combine multiple pieces of information to arrive at the answer.*
4. Recall that the area of an object is defined as the number of square units that covers up the object. Using complete sentences, support or refute this claim: **as perimeter increases, area increases**.
Learning Cycle – Application: Students apply their definition of perimeter and comparing it to the definition of area. Students can use the three Shapes in Model 1 to compare the perimeters and areas for each shape.
Question Type – Convergent: *There are several correct approaches students can use to determine the perimeter and they need to combine multiple pieces of information to arrive at the answer.*

These questions also tend to be convergent questions: There is one solution or answer, but the path each student takes to get there may be quite different. For example, questions 1b and 1c in the Geometric Shapes activity (Figure 5) are part of the concept invention phase of the learning cycle. After exploring the shapes, students are asked to determine the distance around the shape. There are several ways that the distance can be determined, all of which lead to the same correct answer. Students could count the number of edges in the shape and multiply by the length of each edge (10 x 3 = 30 inches) or determine the length of each side and add them together (9 + 9 + 6 + 6 = 30 inches). Only after students have decided on a method for how to calculate the distance around a shape is the term *perimeter* introduced. The concept of perimeter is further developed after exploring the different shapes, and students are asked to develop a definition that works for all the shapes given.

Application Phase

In this final phase of the learning cycle, students apply the concepts they have developed to new questions. These questions are either convergent or divergent, and they may have more than one correct answer. In the Geometric Shapes activity (Figure 5), after developing the concept of perimeter in question 1, students apply this concept to a different shape in question 2c. In question 2d, students compare their answers for Shapes A and B and determine if their predictions are correct. This type of application question depends on students' predictions, so there may be multiple answers. Questions 3d, 3e, and 4 are also examples of application where the concept of perimeter is reinforced by determining the perimeter of different shapes.

Incorporating Process Skills

The POGIL pedagogy was designed to help students develop process skills such as teamwork (TW), critical thinking (CT), and problem solving (PS). Although some skills may be readily prompted through classroom facilitation, others are more likely to be developed through completion of the written POGIL activities. For example, skills like teamwork, management (MG), and oral communication (OC) can be called out during class time by asking the manager of the group to complete a task, or by asking the presenter to present the information orally. Sometimes these tasks can be embedded within the activity as well. Other skills, such as information processing (IP), critical thinking (CT), and problem solving (PS), are generally developed by working through the learning cycle questions. In order to develop process skill growth, the questions should aim to meet the level of the students completing the activity. If the questions are too difficult without appropriate scaffolding, students may give up and not progress through the activity. On the other hand, if the questions are too simple, students may be more inclined to work alone rather than discuss the concepts within their groups. Development of process skills is best accomplished when students work collaboratively.

Figure 6 shows the geometry activity that has been annotated to reflect the process skills that have been integrated into the activity. Identifying the process skills utilized for each question, using the definitions listed in Table 3, is helpful to ensure that the written activities integrate the development of students' process skills as well as content. Although some skills may be developed more readily within the context of completing content-rich questions (for example, IP, CT, PS, as used above), others can be developed more through facilitation prompts (TW, OC, MG). Both types of process skills can be developed within the written aspect of an activity. For example, the process of exploring a model and finding relevant information develops students' information processing skills. Question 1a asks students to determine the number of squares in Shape A, which requires counting and reporting the answer. Critical-thinking questions require students to construct an argument using data often provided in the model. In question 1b, students are using critical thinking to determine the perimeter of the shape. Additionally, they are prompted to discuss in their groups and write down the team's strategy, which requires oral communication and teamwork skills. These process skills also can be reinforced by verbal prompts from the instructor while students are working through the activities. Each question from the geometry activity has been annotated with respect to the process skills used (see Figure 6). The annotations in bold indicate process skills generally developed by completing the questions on content. The annotations in italics indicate process skills that can be prompted in both the written activity as well as with verbal cues from the instructor. In general, it is helpful to annotate every activity with respect to the process skills used to complete the work. This process helps ensure that process skills are adequately represented in every activity.

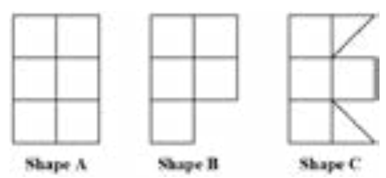
Examples: From Lecture Notes to POGIL Activity

The preceding sections delineate the process of writing POGIL activities based on a simple geometry activity. Next, we provide examples of this process for two subject areas: organic chemistry and

Figure 6
Example of a Model for a Geometry POGIL Activity About Perimeter and an Explanation Detailing How Each Question Aligns With the Process Skills

Activity: Geometric Shapes

Model 1: How can the distance around a shape be measured?



Questions:

1. a. How many squares make up **Shape A**?
   Process Skill - Information Processing: *Students interpret the information contained in Shape A to determine the number of squares.*

   b. If each square shape is 3 inches in length, what is the distance around the outside of **Shape A** in inches? Discuss as a team, how you came to this conclusion. Write down your team's best strategy.
   Process Skills – Critical Thinking/Problem Solving: Students must construct an argument using the data they know from Model 1, detailing what the perimeter of Shape A is, and support their answer by explaining the strategy they used to calculate the perimeter.
   Process Skills – Oral Communication/Teamwork: *The question prompts students to orally communicate between the members of their group to determine the best strategy.*

   c. The distance around a shape is called the <u>perimeter</u>. Write a process for calculating perimeter that works for **Shape A**.
   Process Skill - Information Processing/Critical Thinking: Students synthesize different types of information to transform the information into an equation for calculating the perimeter of Shape A.

2. a. How many squares make up **Shape B**?
   Process Skill - Information Processing: Students interpret the information contained in Shape B to determine the number of squares.

2. (*continued*):

   b. Compare **Shape A** and **Shape B** without measuring. Would you predict the perimeters to be the same or different? Explain.
   Process Skills – Critical Thinking: Students must synthesize multiple pieces of information to make a prediction, and then construct an argument explaining what data they used to make their prediction.

   c. If each square shape is 3 inches in length, what is the perimeter of **Shape B** in inches?
   Process Skills - Information Processing: Students evaluate the information they have and determine what is needed to use the equation they came up with in Q1c to calculate the perimeter of Shape B.

   d. Does your prediction from question #2b match the actual perimeters calculated for **Shape A** and **Shape B**? Discuss as a team why your prediction was correct or not. Explain.
   Process Skills – Critical Thinking: Students must analyze their previous prediction and critique the argument they previously made. If necessary they create a new argument to explain why their prediction was incorrect.
   Process Skills – Oral Communication/Teamwork/ Metacognition: *The question prompts students to orally communicate between the members of their group to reflect on their answer to a previous question and assess its correctness.*

3. a. How many squares make up **Shape C**?
   Process Skill - Information Processing: Students interpret the information contained in Shape C to determine the number of squares.

   b. Estimate the length of the inside edge of the triangle shape. Compared to the outside edges, the distance of the inside edge is *(circle one)* longer / shorter / same.
   Process Skill - Information Processing: Students interpret the information contained in Shape C to determine the distance of the inside edge of the triangle.

   c. How did you determine the distance of the inside edge of the triangle?
   Process Skills – Critical Thinking: Students must construct an argument explaining what data they used to determine if the distance of the inside edge is longer/shorter/same compare to the outside edges.

   d. Would the perimeter of **Shape C** be larger or smaller than the perimeter of **Shape B**? Explain your strategy.
   Process Skills – Critical Thinking/Problem Solving: Students must construct an argument detailing what strategy and data were used from the previous questions to determine which shape has the larger perimeter.

Figure 6 (*continued*)
Example of a Model for a Geometry POGIL Activity About Perimeter and an Explanation Detailing How Each Question Aligns With the Process Skills

3 (*continued*):

e. Recall your process for calculating the perimeter from question #1c. Does this process work for **Shape C**? If not, rewrite your process for perimeter so that it will work for all three shapes.
Process Skills – Critical Thinking/Problem Solving: Students must analyze their previous process for calculating perimeter, and determine if it works for calculating the perimeter of Shape C. If their previous process does not work, students must evaluate all their data and devise a new strategy for calculating the perimeter of Shape C.

4. Recall that the area of an object is defined as the number of square units that covers up the object. Using complete sentences, support or refute this claim: **as perimeter increases, area increases**.
Process Skills – Critical Thinking: Students must construct an argument using the data they learn from this activity on perimeter and the definition of area to critique the given statement.
Process Skills – Written Communication: The question prompts students use complete sentences when constructing their argument.

anatomy and physiology. These graphics show original lecture notes, followed by a POGIL activity using the processes described above.

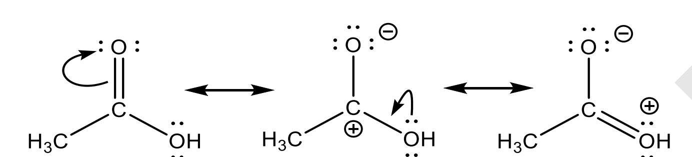
An example of how lecture notes were converted to a POGIL activity for an organic chemistry course is outlined in Figures 7 and 8. A portion of the lecture notes for drawing resonance structures is shown in Figure 7. During class, the notes were transcribed onto a white board, and verbal explanations describe how the structures were drawn. The descriptions in the grey box in Figure 7 show how the lecture notes were converted to the POGIL activity. Instead of *telling* students the rules, the questions were written to get students to *discover* the rules. The example used in the lecture to explain the rules was used as the model in the POGIL activity. The resulting POGIL activity is shown in Figure 8. The model is similar to the scheme from the lecture notes, but it is slightly less complex. The

Figure 7
Example of Lecture Notes for an Organic Chemistry Topic on Resonance

Class Notes:
Resonance structures are two or more Lewis structures that differ only in the placement of electrons. These structures should all have the same number of electrons.
Rules for drawing resonance structures include:

a. only lone pair and pi electrons are moved
b. no single bonds are broken
c. net charge must be the same
d. a double headed arrow is used to indicate resonance

Questions should allow students to invent these concepts



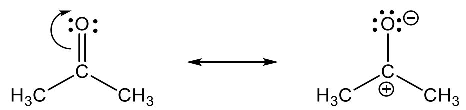
Ask questions about this scheme

Note: In the lecture the rules would be written out in a presentation and described. Then the instructor would draw out the above scheme, and while drawing it, describe how to form each structure by moving electrons and what the arrows mean.

different questions follow the learning cycle (exploration, concept invention, application) to have students construct their own knowledge of the rules for drawing resonance structures, the topics that they would have been told during lecture.

An example of how lecture notes were converted to a POGIL activity for an anatomy and physiology course is shown in Figures 9 and 10. The notes in the grey boxes outline the process envisioned to transition from telling students what affects blood pressure in lecture, to allowing them to discover the effects by exploring simulated patient information and using newly acquired concepts in a POGIL activity. The lecture outline for factors affecting blood pressure is shown in Figure 9, with notes to

Figure 8
Example of a POGIL Activity
That Was Written Based on Lecture Notes



1 **2**

Model

1. (a) Count the electrons in each bond and lone pair to determine the total electrons are in structures **1** and **2.** Are they the same? *(Circle)* yes / no.

Explore

   (b) How many single (sigma) bond electrons are in structures **1** and **2**? Are they the same in each structure? *(circle)* yes / no.

   (c) How many lone pair electrons are found in structures **1** and **2**? Are they the same in each structure? *(circle)* yes / no.

   (d) How many double (pi) bond electrons are found in structures **1** and **2**? Are they the same in each structure? *(circle)* yes / no.

Invent

   (e) Based on the answers above, describe what is different between structures **1** and **2** (in terms of electrons)?

Explore

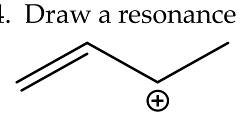
2. Is the total net charge of structures **1** and **2** the same? *(Circle)* yes / no.

Invent

3. In your teams come to an agreement about what the curved arrow on structure **1** represents.

4. Draw a resonance structure for the following structure:

Apply



Note: In the POGIL activity, the questions ask the students to look at the model (Explore) to come to conclusions (Invent) about the items that would have been described in the lecture from class notes.

work practice problems that typically would be created *ad hoc*. The POGIL activity created from these notes is shown in Figure 10. The model con-

Figure 9
Example of Lecture Notes
for an Anatomy and Physiology Topic on Blood Pressure

Class Notes:
Blood Pressure is affected by
1. Heart action (Cardiac Output)
   a. Normal CO = 5 L/min
   b. CO = Heart Rate X Stroke Volume
2. Blood Volume (fairly constant)
3. Peripheral Resistance = opposition to blood flow normally caused by friction
   a. 3 factors that affect PR
      - Viscosity – Fairly constant
      - Blood vessel length – fairly constant
      - Blood vessel radius = most significant factor for determining BP

Use patient data to allow students to invent concepts of cardiac output, peripheral resistance, and blood volume as they relate to blood pressure

Control of BP
1. Mean Arterial Pressure (MAP) = $P_D + (P_S - P_D)/3$
   MAP = Cardiac Output X Peripheral Resistance
   a. To alter CO – change either Stroke Volume or Heart Rate
   b. To alter Peripheral Resistance – change radius of arterioles

Give students the opportunity to apply these concepts/ equations themselves

Note: Several practice problems would be worked on the board for students to see application of these concepts in a clinical framework

sists of data from a hypothetical patient that allows students to explore the relationships between the different variables and come to their own conclusions about how they are related. A complete activity is provided in the supplementary materials for both organic chemistry and anatomy.

Integrating Feedback Into an Activity

Using feedback to refine the activities is an important process to

Figure 10
Example of a POGIL Activity
That Was Written Based on Lecture Notes

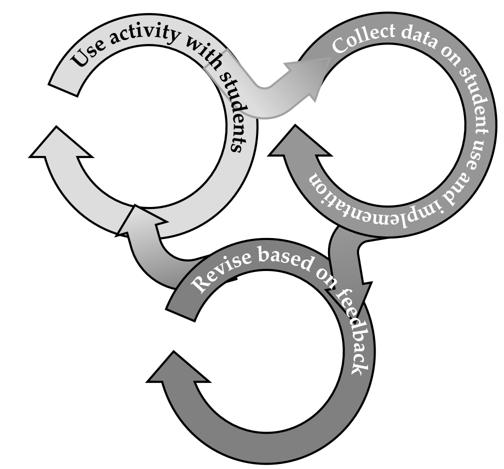
POGIL Activity: Model

Cardiac Health Assessment: Conducted 09/18/1979 Observations: Patient in good health, age 22, height 178 cm, weight 82 kg		
Resting Values HR: 70 bpm SV: 0.071 Lpb CO: 5.0 Lpm BV: 5.0 L PR: 18.66 mmHg/L BP: 120/80 mmHg	After walking for 1 min HR: 75 bpm SV: 0.071 Lpb CO: 5.5 Lpm BV: 5.0 L PR: 18.66 mmHg/L BP: 138/85 mmHg	After walking for 10 min HR: 85 bpm SV: 0.079 Lpb CO: 6.1 Lpm BV: 5.0 L PR: 18.66 mmHg/L BP: 162/90 mmHg
Patient Hospitalization Records		
Date: 01/01/1981 Diag: MVA w/ hemorrhage HR: 70 bpm SV: 0.071 Lpb CO: 5.5 Lpm BV: 4.2 L PR: 18.66 mmHg/L BP: 90/64 mmHg	Date: 11/27/2007 Diag: Atherosclerosis HR: 70 bpm SV: 0.071 Lpm CO: 5.0 Lpm BV: 5.0 L PR: 21.33 mmHg/L BP: 140/90	HR (heart rate: beats per minute) SV (stroke volume: liters per beat) CO (cardiac output: liters per minute) BV (total blood volume: liters) PR (peripheral resistance) BP (blood pressure)

1. Examine the health assessment data for Mr. Fields: Explore
   a) What is the relationship between heart rate and blood pressure?
   b) What is the relationship between stroke volume and blood pressure?
2. a) In the space below write the **units** for heart rate, stroke volume, and cardiac output in that order. Write them as fractions, e.g. heart rate would be beats / minute Invent
   b) Just looking at the units, devise an equation that explains the relationship between heart rate, stroke volume, and cardiac output.
3. Write a consensus definition of cardiac output. Be able to explain your definition.
4. What is the relationship between cardiac output and blood pressure?
5. There are three factors that influence blood pressure. We have established that cardiac output is one. What are the other two? Explore
6. When Al Fields was admitted in 1981, the first thing the ER team did was push 1 liter of IV saline. Why? Apply
7. Atherosclerosis is the narrowing of the arteries due to build up of plaques on the artery walls. Explain why people with atherosclerosis have elevated blood pressure.

ensure that students meet the learning objectives and develop process skills after completing the activities. A typical feedback loop is represented in Figure 11. Initial written activities should be classroom tested in multiple classrooms, preferably at different institutions. This allows the author to see if there are gaps hindering students' understanding of the material. With feedback from students and instructors, questions can be reworded, or additional questions can be added so that there is a natural progression from one question to the next. Often, adding another question that helps bridge a gap is enough to allow students to get past an otherwise-confusing section. Once feedback is obtained, the activities can be refined and tested further for improvement.

Figure 11
Three Phases of the Feedback Loop



When first starting to write POGIL activities, typically when developing activities from lecture notes, authors tend to include more information than necessary. If the activity involves description of a concept, followed by questions about that topic, then it is not a guided inquiry activity. For example, consider how the geometry activity on perimeter would look if it were not using guided inquiry. A non-guided inquiry approach might begin with a picture of Shape A, a definition of perimeter, and a description of how to calculate perimeter, followed by a question about finding perimeter in a different shape. This activity does not involve concept discovery, because the description gives away the answer. A revision of this non-guided inquiry example would involve deleting the description and adding questions that prompt students to describe the concepts in their own words and discover the concepts more thoroughly. Examples of an initial version and finalized activity for anatomy and physiology and organic chemistry can be found in the "Supplemental Information section."

Feedback from students can also pinpoint issues with the language used in the activities. Are students getting derailed because they do not understand the question or some of the terminology? It is important to use language suitable for the level of the intended audience, novice learners. In classes with students whose native language is not English, it may be useful to include parenthetical descriptions of technical or less familiar terms. This simple addition may be enough to help students understand the question and move on in the activity instead of creating a roadblock to their understanding. Obtaining feedback from students and other instructors allows the author to continuously revise and improve the activities so that students are able to master the content and process the objectives for each activity.

Getting the POGIL Stamp of Approval

Activity Feedback Process

Obtaining feedback on new activities from both students and instructors is an important part of refining the activities. After developing a POGIL activity, an author can submit the activity to the POGIL Project for feedback. The activity is then sent to experienced authors and practitioners, who will provide feedback on content learning objectives and process skill objectives using a specially designed rubric. The new author can then use this feedback to improve the activity.

Endorsement and Publication

The POGIL Project has a program in which authors can have their collection of activities endorsed. Endorsement permits the author to use the trademarked POGIL acronym and to pursue publication of their materials through the POGIL Project's agreements with various publishing firms. (For more information about endorsement and publication, visit the POGIL Project website at www.pogil.org.)

Conclusions

Writing POGIL guided inquiry activities can seem to be a daunting task at first. By following the process discussed here, however, POGIL activities

can be generated readily using lecture notes as a guide. It is important to begin by identifying key concepts, followed by developing models and questions that guide learners to discover each topic. Integrating process skills within the activity helps students improve their critical workplace skills. Writing effective POGIL materials is a process that takes practice to determine exactly how much information to supply and to write guided inquiry questions that provide adequate scaffolding to help students develop their understanding of a concept. By following this process, instructors can more easily begin to write their own POGIL activities. Connecting with the POGIL community will also enable them to receive support from other POGIL authors and receive feedback on their materials.

Acknowledgments

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