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Reflection on the Use of Process Oriented Guided Inquiry Learning in Science-focused English Classes

James Ellinger

The University of Tokyo, Center for Global Communication Strategies
ALESS Program

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Abstract

The Process Oriented Guided Inquiry Learning (POGIL) framework is a student-centered teaching method that has been used extensively to teach core science content while simultaneously developing process skills such as teamwork, critical thinking, and oral communication. The activities used in this approach follow a learning cycle that begins with exploration of a model, proceeds to concept or term invention, and is followed by application of the newly acquired knowledge. More than 15 years of research has validated the effectiveness of this method for improving student outcomes. The use of POGIL as a mode of instruction in science-focused English courses has not been directly investigated. This paper describes the observations of student engagement with class materials and learning outcomes following introduction of POGIL activities into two courses: a compulsory academic writing course for first year undergraduate students and an elective science-based Content Language and Integrated Learning (CLIL) course taken by first- and second-year undergraduate students at a national university in Japan.

Keywords: *POGIL, inquiry-based learning, CLIL, student-centered science learning, English for specific purposes, Japanese higher education*

1 A brief introduction to POGIL

Process Oriented Guided Inquiry Learning (POGIL) is a student-centered framework in which students work cooperatively in self-managed teams and the instructor acts as facilitator. This approach was founded on constructivist principles and puts students in the position of taking an active role in their learning. The POGIL framework has been implemented primarily in high school and undergraduate science classrooms, in place of lecture, although guided laboratory activities following the same principles are currently being developed in the United States. The POGIL Project (http://pogil.org) is the official organization responsible for disseminating POGIL material and provides a significant amount of resources and training geared towards implementing the framework in the classroom, including creating activities for specific subjects in biology and chemistry. Furthermore, the POGIL Project has developed a network of experienced POGIL practitioners who can provide peer feedback for instructors who create their own activities.

In this manuscript, I will briefly discuss the principles of the POGIL framework and some of the data supporting its success. Then I will discuss the applicability of POGIL toward a language learner context. Finally, I will provide a reflection of my experience using POGIL in two classes: Active Learning of English for Science Students (ALESS) and a science-based Content Language and Integrated Learning (CLIL) class. For a more detailed reading of the principles and the constructivist theories on which POGIL is based, readers are encouraged to see descriptions in previous publications (Hanson, 2006; Moog, 2014; Moog, Spencer, and Straumanis, 2006).

In the POGIL framework, *Process Oriented* means that the learning environment is structured so that students will develop important process skills, or so-called life skills, such as critical thinking, oral communication, and metacognition (Figure 1). This happens through a cooperative learning environment where students work in teams of three or four and each member is assigned a specific role, thereby giving them responsibilities that ensure the success of the team. For example, a team of 4 students might include a *manager*, a *time-keeper*, a *recorder*, and a *reporter*. The *manager* is responsible for ensuring that each team member is participating in discussion and that the team reaches consensus for each question answered in the activity. The *time-keeper* watches the time and ensures that the team can complete the activity within any stated time limits. The *recorder* is responsible for writing the final, agreed upon answer, and the *reporter* acts as the spokesperson for the team when speaking with the teacher or another team.

The definitions I have provided are not fixed, and roles can be defined flexibly depending on the instructor's preferences. For instance, in a three-member team, the manager may need to take on the role of time-keeper. Depending on how the facilitator has designed the course, teams often contain the same members for multiple sessions or throughout the entire semester. As a result, team members rotate through the roles, providing each member opportunities to develop various process skills. Other roles exist as do other modes of implementing them, which I discuss below.

Guided Inquiry refers to the use of a three-phase learning cycle and carefully scaffolded questions to guide the students through an activity (Figure 1). Central to the effectiveness of these activities is the use of models, typically diagrams, graphs, or other graphic representations of the information or data that students need to complete the activity. In a typical POGIL learning cycle, students begin in the exploration phase, during which they are directed to the relevant parts or information contained in the model. Next, students enter the concept invention or term introduction phase. During this phase, students use the information gathered in exploration to form a generalized concept. This often involves defining a vocabulary term or a set of rules. Finally, students enter the application phase, in which students' understanding of the concept is tested by applying the knowledge to new contexts. A complete POGIL activity will often entail multiple rounds of the learning cycle. For a complete example of an activity I have used in my own classes, and to which I will refer later in this manuscript, please see the *POGIL Sample*[1].

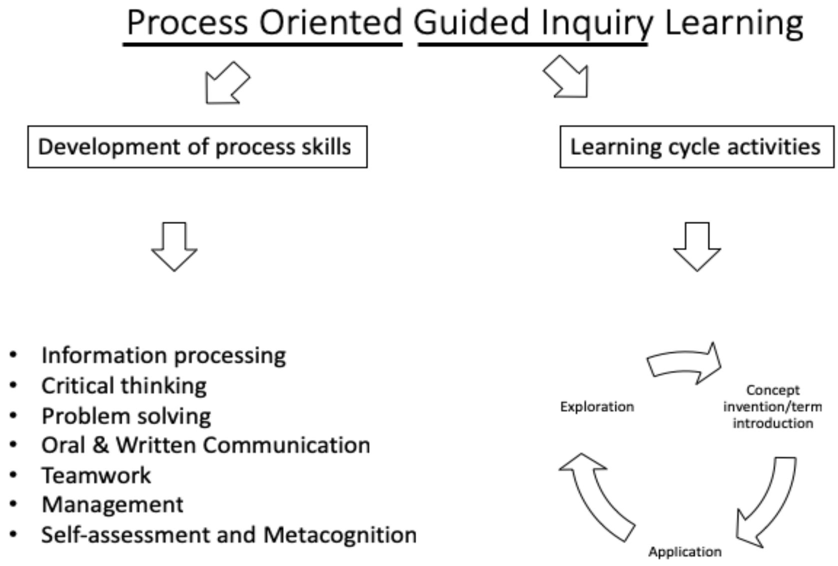

Figure 1. Schematic diagram representing the various dimenions of POGIL.

Because this framework is student-centered, the instructor's role is that of facilitator. While students work through an activity, the instructor provides guidance and support as needed. For example, when a team is struggling to find an answer, the instructor asks guiding questions to help orient students instead of simply providing them the answer. The instructor also plays an important role encouraging students to reflect on their own

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[1] https://pogil.org/educators/become-a-pogil-practitioner/curricular-materials/biology/pogil-activities-for-high-school-biology - the link to a PDF file is labeled as "STUDENT VERSION OF PROKARYOTIC AND EUKARYOTIC CELLS ACTIVITY", which is found below the words "Sample Activities".

learning. Through these interactions, the instructor is able to actively monitor student progress, focus, and understanding of key concepts.

A number of studies have shown that classes taught using the POGIL framework improved student performance. For example, courses taught with POGIL are associated with lower student attrition rates and higher grades (Farrell, Moog, and Spencer, 1999; Straumanis and Simons, 2008; Walker and Warfa, 2017). Additionally, students enrolled in large lecture courses achieved higher scores when POGIL was incorporated as a component of the course (Hanson and Wolfskill, 2000; Lewis and Lewis, 2005). Furthermore, student responses gathered in these studies indicated a preference for POGIL classes compared to traditional methods.

2 Science students are language learners and POGIL helps overcome this hurdle

For students to become experts in any field, they must master the vocabulary, phrases, and collocations associated with that field. Without this knowledge, they are unable to actively participate in the conversation. This is certainly true of science, which is riddled with an intractable amount of specialized terms. A pair of studies has shown that the amount of new vocabulary found in secondary level science textbooks is greater than what is recommended for middle and high school foreign language courses (Groves, 1995; Yager, 1983). The seventh edition of the *Oxford Dictionary of Biology* (Hine and Martin, 2016) includes more than 4500 entries specific to biology, biochemistry and biophysics. Furthermore, 250 new terms were added since the sixth edition of the *Oxford Dictionary of Biology* published in 2008, demonstrating the constantly evolving nature of scientific language.

While the sheer number of terms students must learn is already a formidable challenge, it is compounded by the fact that some scientific terms known as multivalent terms, have multiple meanings. For example, the word *cell* in biology refers to the most basic form of life, whereas in chemistry and physics a *cell* refers to a battery. Yet, in meteorology, a *cell* is a part of a weather pattern (Ryan, 1985). Therefore, it is crucial that when terms are introduced, they are presented with clear reference to the appropriate context and with guidance so that students can properly connect the vocabulary to the underlying concept. Furthermore, it is essential that students have time to incorporate these terms into their lexicon, namely through practice by discussion with peers and the instructor. Indeed, focusing first on the concepts and then on the technical terms and jargon may be a more efficient route (McDonnell, Barker, and Wieman, 2016).

English-language learners (ELLs) who are enrolled in science courses where the language of instruction is English face an additional burden in that they must learn the language of science using their non-native language. For example, a case study of Spanish-speaking English-language learners enrolled in high school chemistry in the United States reported that the challenge of understanding the content was impacted by a lack of competence of content-specific vocabulary (Flores and Smith, 2013). The authors of the study concluded that real-world examples or scenarios, which serve the same purpose as the model used in POGIL activities, would provide helpful guidance for students to become more familiar with the vocabulary.

It has been suggested that in order for scientific terms to be learned meaningfully, they should be connected to what the learner already knows (Wandersee, 1988). As mentioned above, the POGIL approach promotes student understanding by first having students explore a well-designed model. Students make observations, collect information, and finally use the acquired knowledge to define a concept or term through discussion with their team members.

For example, in a biology class that aims to teach students the key differences between prokaryotic and eukaryotic cells, students must first master the vocabulary and concepts related to cell structure and components in order understand the differences and eventually discuss more advanced topics in biology. Understanding the differences requires mastery of vocabulary and concepts that students will eventually need in order to discuss more advanced topics in biology. A typical teacher-centered lecture session might begin with the lecturer outlining the agenda and then displaying two cells, a prokaryote and eukaryote, on a PowerPoint slide. The lecturer will then proceed to describe the various parts of each cell while explicitly noting which parts are shared and which parts are unique to each type of cell. Along the way, the lecturer is introducing and defining even more new terms. This becomes an exercise in which students race to write down as much as they can before the lecturer moves to the next term. During this interval students have little time to process the information. Ultimately, copious information is presented to make a few key points to the students, namely that eukaryotic cells are considered to be structurally more complex than prokaryotes and that their DNA is contained in a nucleus. At this point, the definitions of cell parts are not as important as helping the student arrive at a conceptual understanding of the differences between eukaryotic and prokaryotic cells.

The same topic, as taught using a well-designed POGIL activity, follows a different path (Figure 2). Model 1 of the *POGIL Sample* presents students with different types of bacterial cells. These cells are classified as prokaryotic cells, although students are not yet made aware of this fact. The activity instructs students to make observations about the different cells and draws their attention to various structures and the location of DNA within the cells. Model 2 of the *POGIL Sample* repeats a similar process using plant and animal cells. These cells are examples of eukaryotic cells, but as with Model 1 students are not made aware of this fact. Again, the scaffolding of the activity's questions is designed to specifically draw the students' attention to the location of the DNA. Furthermore, students are asked in an extra step to compare the types of cells in Model 1 and Model 2 with respect to their complexity. Next, Model 3 of the *POGIL sample* uses a small language lesson to introduce students to the terms prokaryote and eukaryote which leads students to describe the differences between the two types of cells. Finally, students are asked to provide definitions for the two cell types. At this point, students have acquired the necessary vocabulary to provide a simple definition written in complete sentences.

Model	Primary goal of the questions	Phase of learning cycle
1 – Three types of bacterial cells	• Identify structures found in the cells • Locate DNA	Exploration
2 - Animal and plant cells	• Identify structures found in the cells • Locate DNA • Discuss complexity of cells as shown in Models 1 and 2	Exploration
3 – Structural comparisons	• Using information from all models, define the terms prokaryote and eukaryote	Concept invention/ term introduction (language building)
	• Describe how the analogy of an efficiency apartment and mansion applies to prokaryotes and eukaryotes	Application (language use)

Figure 2. Structural summary of the POGIL Sample. *The phases of the learning cycle as shown in Figure 1 have been mapped onto each model.*

Upon completing the *POGIL Sample* students will likely have many questions about the definitions of each part of the cells. Although this is natural, it is important to note to the students that defining the parts of the cells was not an objective of the lesson. The learning objectives for the lesson were not included in the *POGIL Sample*, but as written in *POGIL Activities for High School Biology* (Trout, 2012b, p. 51), they are:

> "1. Identify the essential components of prokaryotic and eukaryotic cells.
> 2. Identify the major structural differences between an animal and a plant cell.
> 3. Compare and contrast the structure of prokaryotes and eukaryotes."

Defining the cell parts is the topic covered in the subsequent lesson and is achieved through a similar pattern of inquiry (Trout, 2012b, pp. 53-61).

The POGIL approach as demonstrated in these activities does not assume the students' knowledge of the key scientific vocabulary. Instead, the students acquire the necessary vocabulary through exploration of the models and discussion guided by carefully scaffolded questions. They then use the acquired knowledge to define the concepts and terms. The team-based learning environment gives students an opportunity to repeatedly practice using the terms in the proper context.

There are currently a number of well-constructed POGIL activity books, such as *POGIL Activities for High School Biology* (Trout, 2012b) and *POGIL Activities for AP Biology* (Trout, 2012a), that follow a scaffolded structure throughout the entire book. Activities found later in the books often require students to use vocabulary acquired in previous activities. A good example is the acquisition and repetition of the terms initiation, elongation, and termination, which are used to describe nearly identical processes in the three topics of DNA replication, RNA transcription, and protein translation. These topics are traditionally taught sequentially, therefore the opportunity for repetition is tremendous.

3 POGIL as a framework for teaching science-focused English courses in Japanese higher education

The POGIL Project provides training workshops and opportunities to learn about other teachers' experiences. While attending such a workshop, I learned that POGIL has had positive effects on their students' spoken English in science content courses, even in settings where ELLs are mixed with native English speakers (personal communication). Furthermore, a recent study on the use of guided inquiry learning in an ELL classroom indicated that this method has potential for promoting students' use of English during the study of chemistry (Adams, Jessup, Criswell, Weaver-High, and Rushton, 2015). The aforementioned information and an understanding of the structure of POGIL activities provided motivation to investigate if this method could be useful for teaching science-focused English courses in Japanese higher education.

In the Autumn of 2017, I began introducing POGIL activities into my classes. Specifically, in Active Learning of English for Science Students (ALESS), I used a POGIL activity to teach students about experimental design. Students enrolled in this compulsory course are first-year science students. In ALESS class, students design and conduct a scientific experiment, which serves as the motivation for writing a scientific paper in the Introduction-Methods-Results-Discussion format. Through this course, students improve written scientific English communication. Furthermore, the course is taught using English as the medium of instruction.

I have also used POGIL to teach a CLIL course focused on molecular biology, genetics, and evolution. This course is part of the intermediate level of English series in the University of Tokyo's Junior Division. Enrollment in this course series is compulsory during the first or second year, however students may elect a specific course based on descriptions found in the university's course catalogue. It should be noted that not all students receive their first choice. Indeed, the CLIL course I taught was a mixture of science and humanities students as well as a mixture of first- and second-year students. Among the science students, most indicated that they elected this class. Among the humanities students, one specifically chose this course as the student was planning to switch to the sciences. Based on an in-class survey I conducted, students' prior exposure to the concepts taught in this class varied widely, regardless of whether the student was enrolled in the sciences or humanities. For this course, POGIL accounted for greater than 50% of the in-class activities.

In both courses, I used material that was designed in the United States for native English speakers in secondary school or first-year college undergraduates. The activity used in ALESS was shared with me by one of the organizers of the July 2017 POGIL workshop. The materials used in the CLIL class were taken from the previously mentioned *POGIL Activities for High School Biology* (Trout, 2012b) and *POGIL Activities for AP Biology* (Trout, 2012a).

Although the material was designed for native speakers of English, in both instances students readily engaged with the material. For example, in the ALESS class activity, students' self-assessment of the activity's English indicated that 66% did not find the level of English to be a significant barrier to completing the activity. On the other hand, 33% did indicate that the English was a significant challenge. As evidenced by specific student comments, difficult terms could be understood by referring to the models and students with higher English-speaking proficiency could provide guidance to those with lower speaking proficiency.

Overall, students were very diligent about maintaining the discussions in English as much as possible. They also did not hesitate to ask questions when they struggled to produce answers. I suspect that the careful scaffolding of POGIL-designed questions is essential to promoting discussion in English. In the earlier portions of a POGIL activity, particularly during the exploration phase (Figure 1), questions focus on small chunks of information, thereby lowering the cognitive load. This may allow students to focus more on English output. By the time students reach more complicated questions, they have already discussed in English the information and vocabulary necessary to reach an answer using more complex scientific English. This is certainly an area that warrants further research.

As mentioned above, POGIL emphasizes the use of three- or four-member teams and each person is assigned a specific role. This key component is critical to the development of process skills (Figure 1). From my observation, students tended to take their roles seriously, however in some instances a gentle reminder of their responsibilities was necessary. After POGIL-taught lessons, students were asked to reflect on their performance in their role. They were asked to state which role they took and encouraged to discuss what they felt they did well and what needed improvement. This information was used as a guide to monitor that students were experiencing a variety of roles as well as to check that students were addressing their self-identified weaknesses. Overall, students demonstrated a strong willingness for self-improvement and based on students' assessment of their learning gains, more than 80% responded that work within the teams helped them to improve both scientific knowledge and English proficiency.

In addition to the student roles described earlier, I have also used the role of reader in my classes. As the name suggests, the *reader* is responsible for reading each question to the team. This promotes speaking and also helps to keep the team together in discussion because no member can begin a question before it has been read. Furthermore, the *reader* was implemented as a rotating position. This means that each question must be read by a different member of the team. This helped to ensure that team members were always engaged in speaking English.

Generally, answers to questions in a POGIL activity do not require complete sentences. However, some questions explicitly instruct the students to provide the answer using grammatically correct, complete sentences. In an ELL setting I felt that students' English language development would benefit from writing all answers in complete sentences. This proved to be a challenge for students initially. However, after providing them a strategy for rearranging a question sentence into a statement sentence, teams were able to progress more smoothly (Figure 3). This strategy appeared to be particularly effective in the exploration and concept or term invention phases. However, questions in the application phase are more challenging and this rearrangement strategy does not readily work. Nonetheless, through team effort, students were able to write detailed answers in complete, mostly grammatically correct sentences. Moreover, they accomplished this using the vocabulary acquired during the activity. While students did express frustration over the requirement to write answers in complete sentences, many also stated that it was an important skill to practice.

Strategy for writing complete sentences in your answers

Rearrange a question sentence into a statement sentence:

Example 1:
Question: A glycosidic bond connects which two types of monomers?
Statement (answer): A glycosidic bond connects two monosaccharides.

Example 2:
Question: Which two atoms are connected by a dipeptide bond?
Statement (answer): A carbon and a nitrogen atom are connected by a dipeptide bond.

Figure 3. Image of a PowerPoint slide that was presented to students to provide them a strategy for writing in complete sentences. These questions are connected to the Biological Molecules lesson found in POGIL Actvities for High School Biology (Trout, 2012b, pp. 45-51).

The requirement to write all answers in complete sentences lead to two problems. One problem was a large burden on the part of the *recorder*. Although the team is responsible for reaching a consensus for the answers, the *recorder* does the writing. To address this issue the *recorder* became a rotating position thereby spreading the workload more evenly. Furthermore, the *recorder* was encouraged to read the answer back to the team. The second problem is that the requirement to write all answers in complete sentences requires more time. The activities used in the CLIL course were originally designed to be completed in approximately 50-minute sessions by students who are presumed to be native English speakers. However, in a class composed entirely of ELL students and with the complete sentence requirement, activities required nearly 100 minutes to complete. In some instances, activities were split over two class sessions. Addressing this issue may require selective use of the complete sentence requirement or redesigning activities to be used specifically by ELLs.

To speak fluently and accurately about science, a student must acquire a significant amount of specialized vocabulary and phrases. This is true regardless of whether the learner is conversing in her native language or a second language. Well-designed activities following the POGIL framework allow students to build the necessary vocabulary and phrases while engaging in active discussion with their teammates and the course instructor. Furthermore, language development occurs simultaneously with content acquisition. I have begun using POGIL as a method to promote English language development in science-focused English classes and have experienced an increased level of student-student and student-teacher engagement compared with lessons that do not use a POGIL approach. However, these interactions should be investigated more thoroughly by video recording. Furthermore, results of in-class quizzes and analysis of student reflections indicate that students are also acquiring a sufficient understanding of the scientific content. For example, students were never explicitly told the similarities between DNA replication and RNA transcription. However, when asked to describe the similarities in an impromptu written assessment, over 75% provided correct responses using proper terms and phrases.

There is still much work to be done to optimize this method for an ELL class. For example, developing a strategy to draw students' attention to language embedded within an activity and how to use that embedded language to develop their own language skills. Therefore, I propose that further research should be conducted to investigate the use of POGIL as a framework for teaching science and English in Japanese higher education.

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