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# *Adapting Guided Inquiry Learning Worksheets for Emergency Remote Learning*

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*Abstract.* Process-Oriented Guided Inquiry Learning (POGIL) are a series of learning activities building on student prior knowledge guiding them to construct their own understanding of new concepts in collaborative roles. During the switch to emergency remote learning, POGIL worksheets can be adapted for low bandwidth, low-computing environments, to accommodate the largest swathe of learners in higher education. This article discusses an approach to adapting POGIL worksheets for introduction to computer science for students who may not have the necessary digital tools (i.e., programming software, bandwidth for streaming video, etc.). While the context for this article is computer science, POGIL has a deep history in chemistry education and other natural sciences, suggesting an approach that may be adapted for situations where hands-on laboratory experiments may not be possible.

The POGIL worksheets in this article scaffold the discovery of new concepts while providing sample computer program output, guiding students to make predictions about the connection between program input and program output. Answers are provided to these questions after completion so that students may check their understanding or look to the answers as worked examples. These POGIL worksheets were used the past two years in an in-person classroom situation with minimal computing resources, replacing 3/5 of a classroom lecture doing POGILs collaboratively. In the midst of emergency remote learning, these worksheets were adapted to complement asynchronous lecture videos, but also serve as lecture replacement as needed.

*Keywords.* Computer science education, Collaborative learning, inquiry learning, teaching practice, emergency remote teaching.

## Introduction

During an emergency transition to remote learning the instructor's role continues to be to support learning for all despite the expanded differences in students' contexts during a global disaster. Nurturing a learning community where students continue to grow their sense of belonging holds important implications for engagement and retention (Wilson *et al.*, 2015), particularly for underrepresented groups in STEM (Rainey *et al.*, 2018) and converting traditional classrooms directly to video lectures comes at the risk of fading existing social connections developed in the first half of the semester, as well as potential reductions in students' cognitive engagement. This article provides a practical account of adapting active learning collaborative worksheets from an in-person computer science college classroom to the context of emergency remote teaching.

## Process-Oriented Guided Inquiry Learning (POGIL)

POGIL is an active learning pedagogical approach that incorporates guided discovery of new concepts with groupwork in a classroom setting (Moog, 2014). The POGIL approach is based on constructivism, inquiry, cooperative learning, and a focus on development of process skills as guiding principles and is not particularly prescriptive, but there are some core characteristics that a POGIL class must implement (Moog, 2014):

1. "*Students are expected to work collaboratively, generally in groups of three or four.*
2. *The activities that the students use are POGIL activities, specifically designed for POGIL implementation.*
3. *The students work on the activity during class time with a facilitator present.*
4. *The dominant mode of instruction is not lecture or instructor-centered; the instructor serves predominantly as a facilitator of student learning.*"

Additionally, there are some common features of POGIL classroom implementations that provide a good starting point (Moog, 2014):

- "*Students have assigned roles within their groups.*
- *The activity is designed to be the first introduction to the topic or specific content.*
- *The students are not expected to have worked on any part of the activity prior to class meeting time.*
- *Groups are expected to complete all of the Critical Thinking during class. There may be additional exercises or problems expected to be completed outside of class.* "

"Process-Oriented" in POGIL describes the collaborative nature of the activities and the roles in which students work. Students often work in teams of 3 or 4, with designated roles that usually rotate throughout the semester, typically: manager, recorder, presenter, reflector. This focus on process aims to grow the following skills in students: critical thinking and analytical reasoning, complex problem solving and analysis, as well as written and oral communication.

The term "Guided Inquiry" in POGIL implies two key ideas: the activity is scaffolded so that students are guided to develop the key concepts, and the activity is not an open-ended research question. This guided inquiry is largely grounded in a "Learning Cycle" consisting of the following phases (Moog, 2014):

1. *Exploration*: the learner gathers data and processes it, looking for patterns from which generalizations can be reached. Outside of a laboratory setting, the data is often given to students in the activity.
2. *Concept invention and term introduction*: the learners develop the targeted concept, ideally, where the associated vocabulary is introduced.
3. *Application*: the learners use the newly developed concept in new situations, with the goal of strengthening the concept, showing how it can be used, and/or evaluate its generalizability.

POGIL has a long established history of effectiveness in chemistry learning in higher education (Farrell et al., 1999), which expanded in the past several decades to success in other science, technology, engineering, and math (STEM) disciplines (Vanags et al., 2013; Walker et al., 2017). It is hypothesized that POGIL is an effective active learning teaching strategy as it connects to many of the dimensions of the ICAP Cognitive Engagement Framework which finds that the achievement of students is related to the level of cognitive engagement with the learning materials (Chi and Wylie, 2014):

- *Passive*: the learner receives information from the instructional materials without doing anything additional related to learning.
- *Active*: The learner performs some form of motor action or physical manipulation with the instructional materials.
- *Constructive*: when learners generate or produce additional externalized outputs beyond what was provided by the learning materials
- *Interactive*: when learners participate in dialogues meeting two criteria: (a) both partners' contributions must be constructive, and (b) a sufficient degree of turn taking must occur.

In POGIL, team members are constructively interacting by providing justifications and explaining their reasoning to their groupmates (Moog, 2014). POGIL activities support students in constructing understanding of the key concepts by working interactively with their group.

Growing research literature and meta-analyses generally support active learning pedagogies as more effective at achieving learning outcomes in STEM under typical learning conditions as compared to lecturing (Theobald *et al.*, 2020). However, both active learning and traditional lecturing are difficult to define as there is a wide variety of active learning approaches as well as a wide range of ways to define lecturing. Despite this measurement issue there is a significant amount of literature that states that at best, active learning leads to significant increases in student performance on exams and concept inventories, and at worst, active learning is no different from traditional lecturing in learning gains (Freeman *et al.*, 2014). The potential beneficial effects of active learning are particularly pronounced for students from under-represented groups within STEM (Theobald *et al.,* 2020). Active learning methods in online classes have also lead to improved learning outcomes as compared to watching video lectures (Koedinger *et al.*, 2015).

When introducing students to active learning methods (or POGIL), the instructor should explain the research evidence for why active learning methods are used in the classroom. Research on student attitudes and learning shows that while students may learn more with active methods, they perceive learning less (Deslauriers *et al.*, 2019). This has important implications for student motivation and engagement as well as student course evaluations.

### *POGIL for Computer Science*

POGIL approaches have expanded to computer science (CS), in large part due to the freely available activities shared on the CS POGIL website (CS-POGIL, 2019) as well as the effort of a dedicated team of computer science faculty from various institutions researching and sharing the ins and outs of implementing POGIL in the CS classroom (Yadav *et al.*, 2019; Hu and Shepherd, 2013). Results suggest that POGIL increases the pass rate of underrepresented groups in CS, as was the case for female undergraduates in Hu and Shepherd (2013).

## Experiential Report of POGIL Adapted for Introduction to Computer Science for Emergency Remote Teaching

POGIL and Active Learning pedagogies provide numerous benefits for student learning that is relevant for both in-person and remote coursework, and so POGIL activities are increasingly being incorporated into the author's courses at all levels of computer science at the undergraduate level. Prior to March 14, 2020, courses at the author's institution, a residential liberal arts college with approximately 2,000 undergraduate students and fewer than 100 graduate students in rural Massachusetts, were conducted as they typically progress. An email received March 11, 2020 announced that the college would be moving to emergency remote teaching when classes on March 13 concluded. Students without special permission to remain on campus left the college by March 17. The sixth week of courses were canceled thereby beginning spring break prematurely, with emergency remote courses commencing on April 6. On March 24 it was announced that all courses at the college would be taken as Pass/Fail courses. The transition from traditional settings to emergency remote teaching is described below.

### *Traditional Course Context for CS1 in Python*

During a typical semester at the author's institution, Introduction to Computer Science, or CS1 as it is more broadly known, is offered as a course with multiple "lecture" sessions taught by different instructors, with shared lab sessions, as well as exams, homeworks, and lab assignments shared across the multiple lecture sections. Over three semester iterations of CS1, one of these lecture sections evolved to use worksheets adapted from available POGIL activities in the python programming language for CS1 (Olivieri, 2013; CS-POGIL, 2019) during most class sessions. A typical class would include 10-minutes at the beginning of the class to go over course logistics and any student questions, and then 30 minutes in which students broke out into groups of 2 or 3 to work on that day's POGIL worksheet, followed by approximately 10 minutes at the end of class in which groups would share their answers and questions with the entire class.

It should be noted that this approach is not a "pure" POGIL implementation, as roles were not assigned to students and groups often consisted of pairs. Instead, the emphasis for these activities are mostly on the "Guided Inquiry Learning" portion of the POGIL mantra. However, when introducing POGIL activities to the class early in the semester, the instructor introduces these activities as POGILs, explains the acronym, provides an overview of the evidence that supports use of POGILs in computer science and STEM more broadly, as well as a discussion of the benefits of active learning, including how student perceptions of how much they learned often do not align with the reality, as in (Deslauriers *et al.*, 2019). Anecdotally, students really enjoy being shown the graphs comparing the active versus passive learning conditions and the differences in perceived versus measured learning.

In this last iteration of incorporating POGIL activities into the lecture section, the class included 31 students and as is typical for this course, students did not have access to computers during the lecture sessions. Many computer science POGIL activities assume students can test the program code they write, and so existing POGIL activities were adapted to allow for students to use the learning materials without access to a computer. An example of a typical approach for this is shown in Figure 1. Python programmers may note that this particular example uses the python interactive shell, but other activities also include output from program code when run as a script.

2. Examine the sample code from interactive python, below.

```
0  >>> def countEvens(n):
1  ...     i = 0
2  ...     while i <= n:
3  ...          yield i
4  ...          i += 2
5  >>> g = countEvens(3)
6  >>> next(g)
7  0
8  >>> next(g)
9  2
```

a. How does the function `countEvens(n)` differ from the previous `countEvens(n)`? ________________________________________

b. Write a line of code to print the next value yielded by `g`. ________________________________________

c. If we replace line 5 with `g = countEvens(10)`, what will the first five calls of `next(g)` generate? _____ _____ _____ _____ _____

d. Write a new function, `reverseGen(..)`, that takes a list and yields values from the

*Figure 1. A POGIL activity showing a new concept in lines 0-6, and what output would be from the computer on lines 6-9.*

In addition to the original adapted 18 POGIL worksheets for CS1 in python (Olivieri, 2013; CS-POGIL, 2019), an additional 23 POGIL worksheets were developed to cover the remaining learning objectives of the institution's CS1 course. These additional concepts include everything from tuples to generators, recursion, and a variety of the concepts of user-defined types. Most of these new activities have only been used in the classroom once or twice, and so are still under development. The added benefit of these POGIL worksheets is that they continue to cover course content past the course's textbook coverage (Downey, 2012), providing students with additional materials to which they can refer even when the course moves beyond its text.

As an illustrative example, we will step through the POGIL activity for the data structure "dictionary" at a high-level which is publicly accessible via Howley (2020). In python, a dictionary is a collection of mappings of one object to another. This is related to the "list" data structure, a list of objects that are mapped to a numerical index (i.e., the first object is `'hello'`, the second object is the number 5, the third object is another list, etc.). These POGIL activities begin with stated learning objectives related to content and process (i.e., what should the student be able to *do* after completing the activity), as well as assumed prior knowledge, of which lists are a very important one for the dictionary concept. The Critical Thinking Questions step students through the various phases of the Learning Cycle:

- *Explore*: Question 1 introduces a data structure to represent a list of dog names and the names of their faculty owners: `dog2owner = [['pickle','iris'],['rex','saul'],['tex','doug']]`
  Students are somewhat familiar with these dog/owner combinations as they are running examples throughout the course, often accompanied by photographs. POGIL questions then step students through the process of writing python code to access Pickle's owner's name, or the name of a dog given the owner's name. This activity explores the organization of the data with the intention of showing how this particular data structure may not be ideal for the data itself.
- *Concept Invention & Term Introduction*: A second question introduces example code that uses a dictionary data structure containing the same data and shows some output:
  `0 >>> dt = {'pickle':'iris','rex':'saul','tex':'doug'}`

```
1 >>> dt['rex']
2 'saul'
```

POGIL questions then ask the learners to predict what the output may be, given a different input and to explain in plain language what the different outputs and inputs represent. When describing what the data structure "dt" does, students are essentially describing the concept of a python dictionary without being told explicitly what it is. Some specific terms are introduced after the students explain those pieces. For example, on line 1, students may explain that 'rex' represents the dog's name and is referenced between square brackets like a list index on line 1, but when dt is defined in line 0, 'rex' appears before a colon. The worksheet may then describe that 'pickle', 'rex', and 'tex' are what is known as "keys" of the dictionary, and they are somewhat similar to numerical list indices (as students may already have noted in their responses).

- *Application*: An application question for this concept asks students to write a line of python code using dt to print the names of their instructor and their instructor's dog.

Following questions reinforce but also introduce different aspects of the concept using the explore-invent-apply Learning Cycle. These questions are defined under a "Critical Thinking" section which is then followed by an "Application Questions" section that provides practice activities intended to be completed by students after class. For the faster-paced groups, these Application Questions provide activities they can pursue during leftover time.

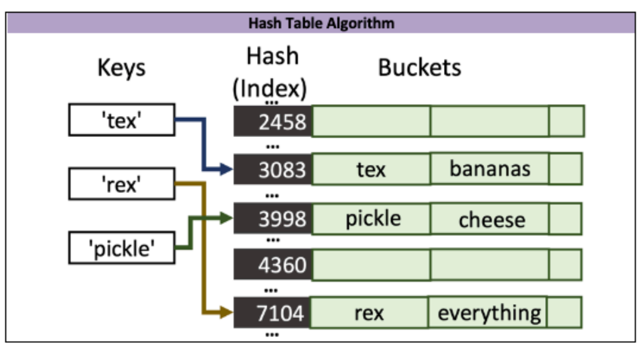
For certain topics, a "Concept Model" with relevant declarative knowledge precedes the typical Critical Thinking questions in order to provide information that can be better explored given the newcomers' perspective. Recursion and Hashing were two of such topics, an excerpt of the concept model section from Hashing is shown in Figure 2.

**Concept Model:**

> **FYI:** A python Dictionary is an implementation of a ***Hash Table algorithm.*** Hash Tables are an array of items which calculate an index from the item's key and use this index to place the data into the array. A ***Hash Function*** is the function that calculates this index (i.e., a ***Hash***) from the item's key.

The following diagram of a Hash Table represents the following python dictionary (a mapping of dog names as keys to their favorite food as values):

```
dogFood = {    'tex':'bananas',    'rex':'everything',
               'pickle':'cheese'    }
```




1. Where are the Hash Table keys located in this diagram?

______________________________________________

______________________________________________

2. If we wanted to look for the value mapped to **'tex'** what Hash/index would we look for?

*Figure 2. A Concept Model preceding Critical Thinking questions for a Hashing POGIL.*

Using these POGIL activities in the classroom in the most recent iteration of the CS1 course, the instructor noted incredibly broad student participation in answering and asking questions during class, as compared to previous iterations. A potential hypothesis for this anecdotal evidence is that increased cognitive engagement with learning materials leads to enough understanding to generate questions in ways that passive absorption may not afford. Discussing questions beforehand with peers may also reduce evaluation anxiety and perceived costs of seeking help, leading to more help-seeking (Howley and Rosé, 2018). Furthermore, when students work on a learning exercise and then discuss with their peers, this may result in increased confidence in the correctness of their responses, and thus result in increased willingness to share answers.

### *Adaptations for Emergency Remote Teaching CS1 in Python*

When emergency remote teaching began after a three-week hiatus, the college administration emphasized asynchronous learning approaches as much of the student body is distributed across global time zones. Further logistical changes with the CS1 course resulted in combining the two lecture sections and asynchronous lecture videos being the main form of content delivery with no required synchronous learning incorporated into the course. However, POGIL activities were included as optional learning activities accompanying lectures and were posted to the course's learning management system (LMS). Sample answers to the POGIL activities were also shared in the LMS, along with instructions on POGILing remotely (hand-out available as an Appendix to this article), when the worksheets were shared prior to lecture videos, as a means of replacing the "sharing out" portion of the class that would ordinarily help resolve student confusion about the activities, concepts, and responses.

Anecdotally, students familiar with learning via POGIL continued to some extent with the activities. The instructor heard from several of the 31 students in the original lecture section that they continued to work-through POGIL activities with their partners from prior to the pivot to emergency online learning. Students mentioned that POGILing with a partner was one way to generate a little more social interaction in their otherwise social-distanced lives. And so, despite the de-emphasizing of the POGIL worksheets, there was continued student interest in learning through active means and working with partners. Beyond this logistical change and the addition of providing sample answers, no other changes were necessary for the POGIL activities, as they were already constructed assuming students would not have significant access to a computer.

While this version of the CS1 python POGIL worksheets assume restricted access to a computer, it does require some ability to acquire the materials either online, or possibly as a print copy. There is considerable benefit in interacting with the python interpreter to check possible responses, as it provides immediate feedback and allows for many different possible solutions that cannot be exhaustively covered by an answer sheet. However, static POGIL worksheets can provide additional opportunities for students to generate predictions about what small changes in code will do and more deeply engage with the learning materials when computer access is limited.

Interacting constructively with a partner or a group is the ideal context for POGIL, but in the case of emergency remote learning, this is not always possible. Instructions that accompanied the remote POGIL worksheets suggested connecting with a peer for established collaboration times via phone, popular messaging app, or email. In the cases where this is not possible, engaging with the Learning Cycle in an individual setting would still result in constructive-level cognitive engagement which could lead to improved learning over passively absorbing asynchronous videos (Koedinger, 2015; Chi and Wylie, 2014).

## Conclusion

In hindsight, these POGIL activities would have made ideal activities for low-stakes synchronous recitation sections in which students move into virtual breakout rooms and work on the worksheets together coming back as a small class to share out answers and questions at the end. Students with limited access to streaming video conferencing could still earn complete/incomplete participation credit by submitting their POGIL work individually.

POGIL worksheets provide minimally digitally-reliant constructive learning opportunities for situations of emergency remote teaching that work effectively in traditional settings as well. Remote POGIL also encourages social interaction and collaborative learning that have additional benefits for student learning, and possibly for student morale. Feelings of belonging to a learning community have positive implications for behavioral and emotional engagement in STEM classrooms (Wilson *et al.*, 2015) as well as positive implications for retaining members of underrepresented groups in STEM (Rainey *et al.*, 2018), with which POGIL's constructive dialogues may assist in cases of forced isolation as in the emergency remote teaching of 2020.

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