EngageCSEdu Teaching Paper

Process Oriented Guided Inquiry Learning (POGIL) in Computer Science

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In this paper, we describe Process Oriented Guided Inquiry Learning (POGIL), an evidence-based instructional strategy that incorporates multiple practices that are particularly useful for students from underrepresented populations. In a POGIL classroom, students work in teams on activities that are specifically designed to guide them to discover and understand core concepts (the *guided inquiry*). At the same time, teams develop process skills such as communication, teamwork, critical thinking, and problem solving (the *process oriented*). The teacher is an active facilitator who observes and coaches teams, helps to resolve problems, and leads classroom discussion.

First, we describe the underlying motivation, key elements, and related research. Second, we briefly describe the elements of a typical POGIL activity to show how student teams, activity design, and active facilitation by a teacher interact to create a powerful learning experience. As an example, we use a POGIL activity on project scheduling that helps students to understand key concepts in the context of baking cookies. Finally, we briefly describe other POGIL activities in the EngageCSEdu collection and summarize available resources to help teachers learn about and implement POGIL in their classrooms.

1. INTRODUCTION

Research shows that motivation and learning are enhanced when students: work in teams; combine and connect content, process, and representations; create or construct understanding; receive prompt, regular feedback; and reflect on their work (for summaries, see e.g. Committee on Developments, 2000; Zull, 2002). Similarly, the ICAP (Interactive, Constructive, Active, Passive) model describes how learning outcomes increase as learning environments progress from *passive*, to *active*, to *constructive*, to *interactive*, so that students interact with each other to construct understanding (Chi, Wylie, 2014). Many of these practices are particularly effective for students from underrepresented populations (e.g. Boykin, Noguera, 2011; Chávez, 2008; Chávez, 2011; Finley, McNair, 2013; Kuh, Schneider, 2008). For example, Boykin and Noguera (2011) conclude that active engagement in academic tasks is the key to learning, that student engagement and positive attention from instructors reinforce each other, and that there are clear benefits from collaborative learning, when students develop a malleable view of intelligence, self-efficacy, and self-regulated learning.

This paper describes Process Oriented Guided Inquiry Learning (POGIL), an evidence-based instructional strategy that incorporates many of these practices. The following subsections introduce POGIL principles, elements, and research results. Section 2 describes a POGIL activity on project scheduling, to show how activity design, student teamwork, and active facilitation by a teacher interact to create a powerful learning experience. Section 3 describes POGIL activities in the EngageCSEdu collection, and resources to help teachers learn about and implement POGIL in their classrooms.

1.1 Process Oriented Guided Inquiry Learning (POGIL)

In a POGIL classroom, student teams work on activities that are specifically designed to guide them to discover and begin to understand core concepts (the *guided inquiry*). At the same time, teams develop process skills, such as communication, teamwork, critical thinking, and problem solving (the *process oriented*) (Moog, Creegan, Hanson, et al, 2006; Moog, Spencer, 2008). Thus, POGIL is explicitly constructivist and collaborative. The teacher's role shifts from disseminator of information ("sage on the stage") to facilitator of learning ("guide on the side"), who continually assesses how and when to offer additional guidance as the teams work (Hanson, 2006).

POGIL was originally developed in college general chemistry (e.g. Farrell, Moog, Spencer, 1999; Moog, Creegan, et al 2006; Moog, Farrell, 2008), and is now used across STEM disciplines, including computer science (Kussmaul, 2012; Hu, Shepherd, 2013; Hu, Shepherd, 2014), engineering (Douglas, Chiu, 2009; Rutten 2012), mathematics (Lenz, 2014), and in a variety of settings including minority-serving institutions and community colleges (e.g. Higgins, 2013).

Typically, using POGIL in a class increases pass rates (grade of A, B, or C) (e.g. Farrell, Moog, Spencer, 1999; Straumanis, Simons, 2008). In a software project course, POGIL activities on team communication helped students to understand the importance of communication in real software projects (Kumar, Wallace, 2014). In a survey, CS teachers who used POGIL strongly agreed that students in a POGIL classroom learn more, are more engaged and active, and develop better communication skills (Hu, Kussmaul, Knaeble, Mayfield, Yadav, 2016).

2. SAMPLE ACTIVITY – PROJECT SCHEDULING

This section describes specific elements of a POGIL activity and classroom, using a sample activity on project scheduling.

2.1 Classroom Environment

Some teachers use POGIL almost daily; others use it every week or two to develop key concepts. Using POGIL only a few times in a course may be challenging since it takes time for students (and teachers) to get comfortable with a different approach to learning.

POGIL is used successfully in settings ranging from small seminars to large lecture halls. Ideally, each student team sits at a table where members can see any shared materials. Without tables, teams can move their chairs together, but a shared writing surface is helpful; some POGIL teachers give each team a small whiteboard to write or draw answers.

Many teachers give each student a paper copy of the activity. Others have teams share a copy to encourage collaboration. If computers are available, some teachers provide activities as electronic documents (e.g. a Google Doc for collaborative editing), although it can be difficult for several students to view a laptop screen. Particularly in larger classes, a clicker system can be useful to quickly gather responses from teams or individuals.

2.2 Teams & Roles

POGIL uses teams of 3-5 students who work together to discuss and agree on answers to the questions in the POGIL activity; such collaboration usually improves understanding for all team members (Johnson, Johnson, 1999; Stump, et al, 2011; Hammar Chiriac, 2014). Teachers often find that smaller teams work more efficiently, but larger teams develop stronger process skills. Teams of three often work better in a lecture hall with fixed seating. Teams of four can discuss as a group and split into pairs for programming. Teams of four or five may work well if some students take charge of laboratory equipment.

Effective teams can have a large impact on student outcomes (Hammar Chiriac, 2014). Some teachers allow students to form their own teams, but most POGIL teachers assign teams, and try to consider and balance several factors:

- Don't isolate students, particularly from underrepresented groups. Thus, avoid teams with only one woman, one minority, one international student, etc.
- Group students by level of experience and ability, and avoid teams with a wide range. A common guideline is "high and middle, middle and low, not high and low". A team that answers some questions quickly might spend more time on open-ended or optional questions, which are common in POGIL activities.
- Find a balance between teams with similar members, which tend to have fewer problems, and teams with diverse members, which tend to learn more about effective teamwork. As students gain experience and confidence, they could work in more diverse teams.

To encourage all students to fully participate, teams stay together for weeks or months, but each member has a different role each day. Some teachers post teams and roles in the classroom; others expect teams to rotate roles on their own. The roles highlight the different tasks in a team and encourage all team members to participate and develop the full range of process skills.

For example, the *manager* makes sure everyone focuses, participates, and understands the activity, while the *recorder* writes down answers or a summary for the team, and the *speaker* presents results to the rest of the class. During the activity, the teacher reinforces these roles in a variety of ways (see examples below).

In a POGIL classroom, the teacher is an active facilitator who observes team dynamics and works to help all teams work more effectively. A teacher who notices a problem in a team might first wait to see if the team can resolve the problem, then offer advice and assistance, and only rearrange teams as a last resort.

2.3 Learning Objectives

Student-centered learning with POGIL usually takes more time than a teacher-centered lecture on the same topics, so it is essential to specify learning objectives that are student centered, active, specific, and measurable. Thus, objectives do not use words like "know" or "understand" and focus on tasks students could perform on a test or homework assignment. POGIL is also designed to help students develop process skills (e.g. communication, teamwork, critical thinking, problem solving), and so POGIL activities often specify process objectives too, although these are usually less specific.

The objectives for the scheduling activity (Figure 1) include both content and process.

After completing this activity, learners should be able to:

- Explain *Work Breakdown Structures (WBS)* and how they are used; create and interpret a WBS using paper or software tools.
- Explain *Gantt Charts* and how they are used; create and interpret a Gantt Chart using paper or software tools.
- Explain *Critical Path Analysis (CPA)* and how it is used; perform and interpret a CPA using paper or software tools.

This activity should help learners develop teamwork and management skills.

Figure 1: Learning Objectives for Scheduling Activity

2.4 Getting Started

To provide a transition and encourage prompt attendance, teachers might start class with a short quiz on prior content, a few comments on the activity, a warmup exercise, or even a mini-lecture.

For example, in the scheduling activity, the teacher might first describe the importance of scheduling in software development and other work, and tells students that the activity uses a cookie recipe as an example of work with steps that are connected – some steps must occur other steps. (The teacher might even provide cookies to stimulate student interest.)

Note that some students might consider cooking to be a gender-specific activity, so the teacher could observe that everyone needs to cook, and be alert for and quickly respond to any stereotype responses within teams.

The scheduling activity is organized into 6 parts labeled A through F. Part A is a warmup where students estimate (individually) and discuss (as a team) how much time is needed to make a batch of cookies. The teacher then asks each team to share an insight, which often highlight challenges in estimation and scheduling. For example, teams might observe that it can be helpful to share several estimates, or that people with more experience tend to have better estimates.

2.5 Models, Questions, & Learning Cycles

To guide higher-level thinking and learning, a POGIL activity contains *models* (e.g. diagrams, graphs, tables, code snippets) and a sequence of *questions* about the models. The models and questions are carefully designed to guide students through an E-I-A *learning cycle* (Abraham, 2005; Karplus, Thier, 1967) to *explore* the models, *invent* key concepts, and finally *apply* their new understanding (Hanson, 2005). Typically, the first questions direct student attention to help them explore important elements of the model that would be obvious to an expert, but not to all students. Later questions guide students to invent understanding of a new concept, and then to apply that understanding. Questions are also categorized as *directed* (easily answered from the model or prior knowledge), *convergent* (most teams will give the same answer, or one of a few answers), or *divergent* (teams are likely to give quite different answers). The models and learning cycles distinguish POGIL activities from worksheets that students complete alone or in small groups.

In the project scheduling activity, the first model is a cookie recipe (see Figure 2). In Part B of the activity, each team is given a set of cards, each with one step in the recipe (see Figure 3). First, the activity tells each team to sort the cards into groups (e.g. steps that involve dry ingredients). Sorting is not difficult, but this initial exploration ensures that students have read the cards. Second, teams compare the cards and recipe to identify gaps or differences. This analysis takes more effort and ensures that students have carefully read the recipe. Third, they write an outline of groups and steps on a worksheet (see Figure 4, first two columns), and learn that this outline is a *Work Breakdown Structure*.

Cookie Recipe

Assume that all needed equipment & ingredients are available.
(Variations of this recipe have circulated online for over 20 years.)
Cream the "wet" ingredients (in an electric mixer, if possible):

- 2 cups (1 lb.) butter or margarine
- 2 cups white sugar, 2 cups brown sugar
- 2 tsp. vanilla

Mix in one by one:

- 4 eggs

…

Figure 2: Model for Scheduling Activity – A Cookie Recipe

cream wet ingredients (wet)	chill dough (wet)	blend oatmeal (dry)	wash dishes (cleanup)

Figure 3: Four Sample Cards with Recipe Steps

Part C of the activity tells each team to split up the cards and have each team member estimate the time for some of the steps. The team then discusses whether the sum of the times represents the total time for one cook, and whether the total could be divided by the number of cooks. In part D, teams put the step cards into a chronological order, respecting dependencies between steps. They then copy this schedule onto the worksheet, so that each row shows the start and stop time for a step, and learn that this is a *Gantt Chart* (see Figure 4, all columns).

#	Group / Step	time	00	05	10	15	20	25	…
A	*Group: Wet Ingredients*		*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	
1	*add dry to wet*	*5*				*xx*			
2	*chill dough*	*15*							
3	*cream wet ingredients*	*5*	*xx*						
4	*mix in eggs*	*5*		*xx*					
B	*Group: Dry Ingredients*				*xx*	*xx*	*xx*	*xx*	
1	*mix dry ingredients*				*xx*				
…									

Figure 4: Partially Completed Worksheet for Scheduling Activity

In parts E and F, the team considers what happens where there are several cooks (who can work in parallel) or constraints (e.g. a food processor that can only be used for one step at a time), and develop the concepts of a *Responsibility Chart* and the *Critical Path Method*.

Note that in most cases, students develop and understand concepts before they learn the common terms for those concepts. In contrast, if students are first given terms and definitions, they may not develop a full understanding.

2.6 Teacher Facilitation

As teams work through the activity, it may look like the teacher is just walking around and "not really teaching," but effective classroom facilitation is challenging and multi-faceted.

The teacher *oversees the class*, cueing teams to work quickly but effectively. For example:

- "Managers, your teams have 4 minutes to finish section B."
- "Speakers, be ready to present your team's answer to question 3."
- "Reflectors, describe one area of strength for your team, and one area for improvement."

The teacher *monitors and assists* individual teams' *progress* and *process*. For example:

- "Manager, I notice that one of your team members isn't participating in discussion."
- "Reflector, how could the manager help the team move more quickly?"
- "Team, remember than everyone should discuss and agree on each answer before you go on to the next question."

In some cases, the teacher might take further steps, and talk individually with a student who dominates or avoids discussion, or even reassign teams.

The teacher *leads discussions* where teams "report out" to share and verify their conclusions and consider other perspectives. The teacher might ask each team's Speaker to present their answer to a question, write or draw it on the board, or fill in a web form. The teacher might have teams rotate materials, swap members, or meet to compare answers and resolve disagreements.

The teacher *evaluates the activity*, and notes areas of strength and areas for improvement. The teacher usually has their own copy of the activity (sometimes with answers and notes on facilitation) and mark difficult or confusing questions, unexpected answers, ideas for clarifications and improvements, etc.

2.7 Follow Up

The teacher has several options to follow up on the activity. The teacher could grade the team and their completed activity, for effort and perhaps for correctness. The teacher could give a short quiz on key concepts. Students could complete homework that applies and builds on the concepts. The team recorder could revise and submit a more polished copy of the completed activity, or the reflector could submit a brief report on the team's areas of strength and areas for improvement.

For the scheduling activity, the teacher could have students create a WBS and Gantt Chart for a different scenario (e.g. the set of course requirements for an academic major), or have students create a schedule with a software tool (e.g. Open Workbench or Microsoft Project).

3. RESOURCES AND LEARNING MORE

For teachers, POGIL requires significant effort to adopt new classroom techniques and to develop or adapt materials. The POGIL Project (http://pogil.org) is a 501(c)3 organization that trains teachers; reviews, endorses, and distributes high-quality POGIL materials; and provides consultation and other support. The POGIL Project provides a professional development curriculum of over twenty 90-minute workshop sessions and a pool of trained workshop facilitators. The workshops use POGIL to help teachers understand how it works, learn about principles, and consider ways to use POGIL in their own classes. Half- and full-day workshops introduce basic concepts and practices to help teachers decide whether to implement POGIL. Multi-day workshops, including regional summer workshops across the US, provide further training on classroom facilitation, activity design, and related topics. To date, over 250 POGIL workshops have reached over 6500 teachers.

The CS-POGIL Project is a NSF TUES project to develop POGIL activities for CS and foster a community of POGIL practitioners in CS, and the IntroCS-POGIL Project is an NSF IUSE project to expand the use of POGIL in introductory CS courses. These projects have a website (http://cspogil.org) with an index of POGIL activities for CS and related areas. We estimate that over 200 activities have been written, mostly for CS1 and CS2, but ranging from AP CS Principles and other courses for non-CS majors, through advanced electives such as artificial intelligence and theory of computation.

The EngageCSEdu collection contains a variety of POGIL activities, including:

- *Searching in Hi-Lo – CS1 First Day Activity on Algorithm Design & Analysis* is designed for students with no CS background. They explore a simple number guessing game to learn that CS involves the design and analysis of solutions to problems.
  https://www.engage-csedu.org/find-resources/searching-hi-lo-cs1-first-day-algorithm-design-analysis
- Two activities on HTML. *HTML 1: Markup* focuses on markup in general, and common HTML tags. *HTML 2: Documents & Links* focuses on document structure, links, and other more advanced tags.
  https://www.engage-csedu.org/find-resources/pogil-activity-html-1-markup
  https://www.engage-csedu.org/find-resources/pogil-activity-html-2-documents-and-links

- Activities for a Java CS1 course, including *Java Operators* (% and /) and *Recursion* (using factorials and summations).
  https://www.engage-csedu.org/find-resources/pogil-activity-java-operators-and
  https://www.engage-csedu.org/find-resources/pogil-activity-recursion
- A set of activities to help students learn about Java syntax and style by studying a working implementation of a game, including: *Shut the Box*, *Tic-Tac-Toe*, *Anagrams*, *Towers of Hanoi*, and *Beetle*.
  https://www.engage-csedu.org/find-resources/shut-box
  https://www.engage-csedu.org/find-resources/tic-tac-toe
  https://www.engage-csedu.org/find-resources/anagrams-0
  https://www.engage-csedu.org/find-resources/towers-hanoi
  https://www.engage-csedu.org/find-resources/beetle
- Three activities on *Unit Testing in Java with JUnit*, that explore testing, the JUnit framework, and effective test strategies.
  https://www.engage-csedu.org/find-resources/pogil-activities-3-unit-testing-java-junit

4. CONCLUSIONS

This paper has provided an overview of POGIL. It described an activity on project scheduling to show how the activity design, student teams, and teacher facilitation. It provided information about resources to help teachers understand POGIL and consider how to use it.

As summarized at the start of the paper, learning outcomes improve when students: interact in teams; construct or create their own understanding; combine and connect content, process, and representations; receive prompt feedback; and reflect on their work. These practices help all students but are particularly effective for students from underrepresented populations. All of these practices are central to a POGIL classroom.

Interested teachers should review the POGIL activities in the EngageCSEdu collection and on the CS-POGIL website, and should participate in a POGIL workshop to experience POGIL as a student and understand more about how to facilitate their own classroom.

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