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The Impact of Process-oriented Guided Inquiry Learning on Students' Academic Achievement and Capacities for Collaboration and Problem-solving

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Abstract

This study investigates the impact of Process-oriented Guided Inquiry Learning (POGIL) on students' academic performance, collaboration, and problem-solving capacities. This study adopted a two-group experimental design comprising an experimental group that received POGIL pedagogy and a control group that received traditional pedagogy. The 98 seventh-graders from a junior high school in central Taiwan comprised 51 experimental and 47 control group students. The data were collected over one semester using tests to assess academic achievement and scales to measure collaboration and problem-solving. This study used descriptive statistics: distribution frequencies, percentages, mean values, standard deviations, and inferential statistics: ANCOVA to analyze data. The results revealed that the experimental group acquired significantly higher scores on the collaboration and problem-solving scales and academic tests than the control group, indicating that POGIL pedagogy is more effective than traditional pedagogy at improving students' academic achievement and capacities for collaboration and problem-solving. The study confirmed that POGIL pedagogy positively affected student academic achievement, collaboration, and problem-solving capacities.

Keywords: process-oriented guided inquiry learning, academic achievement, collaboration, problem-solving

1. Introduction

The development and application of science and technology impact humans, and this impact is becoming more extensive and far-reaching. Here are some examples: the development of transportation allows humans to travel quickly, sophisticated manufacturing technology provides people with the materials and supplies needed for living, the development of communication technology enables people to acquire knowledge and information quickly from all over the world, and lastly, the popularization of computers, networks, and network communication has enabled the formation of a new system with significant influence, penetrating all aspects of economic, political, cultural, and social life; this has even changed people's communication methods and ways of thinking. In confronting the 21st century's rapidly changing society, how are teachers cultivating students' essential competencies, such as collaboration and problem-solving, to cope with these changes?

In order to address societal changes, many innovative pedagogies have emerged to counter this issue. One such pedagogy is called the Process Oriented Guided Inquiry Learning (POGIL) pedagogy. POGIL is a student-centered and research-oriented teaching method built on cognitive development, cooperative learning, and instructional design. The critical elements of POGIL include students being actively engaged in their learning, teachers functioning as a facilitator, and lessons being taught based on a learning cycle. POGIL focuses on process skills, promotive interactions, and meta-cognition. In POGIL classes, students structure the teams and assign roles to promote positive interdependence. Under a teacher's assistance, students engage in guided inquiry activities; meanwhile, the teacher motivates students to apply process skills, such as cooperation and problem-solving. Students present inquiry results and metacognition at the end of the class (Moog & Spencer, 2008).

Although many student-centered pedagogies can effectively facilitate the achievement of worthwhile learning goals in the classroom, POGIL differs from other approaches in two main ways. One way is clearly and consciously emphasizing developing fundamental and purposeful process skills. The second way is that the teaching materials and activity designs used in the classroom are distinctive. These distinctive materials and designs include (1) an emphasis on the activities of students' self-managed teams and an emphasis on the teachers acting as facilitators rather than sources of information; (2) exploration activities that guide students to construct, deepen, refine, and integrate relevant subjects and guide students to improve their understanding of learning contents; (3) structure and content that encourage the application and development of at least one process skill, rather than depend on the convenience of activity in the classroom or laboratory (POGIL project, 2021).

Hanson (2013) indicated that learning is most effective through 1) building one's understanding based on previous knowledge, experience, skills, attitudes, and beliefs; 2) following the learning cycle of exploration, concept formation, and application; 3) connecting and visualizing concepts with multiple forms of expression; 4) discussing and interacting with others; and 5) reflecting on the learning progress and performance assessment. These characteristics are incorporated into POGIL's instructional design. In the POGIL classroom, students take greater responsibility for their education, learn content that relies on thinking skills rather than memorization, improve academic performance, and establish positive interactions with teachers and peers (Simonson & Shadle, 2013). According to Trevathan et al. (2014), POGIL is suitable for teaching in large classes because it uses highly structured group learning, which makes it easier for students to build content and promotes deep learning. In addition, group members cooperate, share responsibility, rely on each other, complete the learning outcomes of the group, and develop interpersonal skills between peers. Moreover, POGIL teaching suits students of all learning styles, reducing the absence rate (Hale & Mullen, 2009).

Many empirical studies have found that POGIL teaching positively impacts students' academic performance and process skills. Here are some examples: POGIL can increase interactions among students and significantly improve the quality of argumentation skills (Stanford et al., 2016). POGIL can strengthen the interaction between students and teaching materials. For example, students actively explore teaching materials, receive immediate feedback, learn more profoundly, and significantly improve their scientific literacy (Aiman et al., 2020). In addition, POGIL helps students to participate actively in building their understanding so students can better grasp the content of the textbook and improve their academic achievement (Brown, 2010; Hale & Mullen, 2009; Idul & Joevi, 2019; Simonson & Shadle, 2013; Şen et al., 2016; Vacek, 2011; Villagonzalo, 2014). POGIL enhances teacher-student interaction, motivates students to become active learners, and improves student engagement, knowledge retention, and higher-level thinking and application skills (Hale & Mullen, 2009; Irwanto et al., 2018; Liyanage et al., 2021; Rumain et al., 2021; Simonson & Shadle, 2013). Lastly, POGIL improves students' communication, collaboration, problem-solving, critical thinking, logical thinking, information processing, and other process skills (Aiman et al., 2020; Andriani et al., 2019; Idul & Joevi, 2019; Irwanto et al., 2018; Johnson, 2011).

Biological subjects have always been an important field of study in Taiwan's secondary schools. Biology is a branch of science comprising botany, conservation, ecology, evolution, genetics, marine biology, medicine, microbiology, molecular biology, physiology, and zoology (Rogers et al., 2019). The goal of the biological subjects taught at secondary schools in Taiwan is to cultivate the student's interest in and enthusiasm for exploring science, develop their habit of active learning, and enhance their abilities to communicate, work in teams, think independently, and solve problems (Taiwanese Ministry of Education, 2013). However, under exam-led teaching in Taiwan, most biological subject teachers still adopt a traditional teacher-centered pedagogy. The teacher spends most of the class time presenting lectures, and students seldom can conduct peer inquiry together. The instructor lectures, explains concepts, presents analogies, provides answers, and may demonstrate step-by-step procedures for solving various exercises. Although this can be an efficient way to present information, there needs to be a learning environment where students learn effectively and develop crucial thinking skills (Moog & Spencer, 2008). For a long time, the number of Taiwanese junior school students with a learned interest in natural science has decreased, and students' confidence in themselves towards their ability to learn natural science subjects has dropped (Ha et al., 2013).

Many studies have confirmed that proper understanding and learning require functional reorganization by the learners. This reorganization involves combining new knowledge with previous knowledge and beliefs, identifying and resolving contradictions, generalizing, inferring, and problem-solving. Knowledge is personal and constructed in learners' minds (Hanson, 2013). In a POGIL class, a teacher encourages students to reorganize information and knowledge and use the learning cycle to help them develop understanding. The key to the effectiveness of POGIL is guided inquiry activities. The learning cycle guides students to solve problems, requires them to transfer new knowledge to unfamiliar contexts, integrate the new knowledge into their cognition, solve real-world problems in new ways, and cultivate students' process skills from inquiry, including critical thinking, communication, teamwork, and problem-solving. With these strategies, POGIL has proven to be the most effective teaching method for teaching natural science (Lawson et al., 1989).

However, Taiwanese science teachers rarely applied POGIL pedagogy in their classes. There was also no related research. Therefore, this study applied the POGIL teaching method to a seventh-grade biology class in central Taiwan. The goals were to help students construct knowledge, deepen learning, improve academic performance, and cultivate capacities for collaboration and problem-solving. This study applied a two-group experimental design. The experimental group received POGIL pedagogy, and the control group received traditional pedagogy. To determine whether POGIL pedagogy would be more effective than traditional pedagogy in this setting, we measured students' academic achievements and capacities for collaboration and problem-solving.

2. Method

2.1 Participants

This study adopted a pseudo-experimental design. The participants included one instructor and 98 seventh-graders from a junior high school in central Taiwan. The instructor, qualified in information technology education, prepared the POGIL activities and conducted various project studies on teaching and learning approaches. Of the students, 51 (23 boys, 28 girls) were assigned to the experimental group and 47 (22 boys, 25 girls) to the control group. The students' ages ranged from 13 to 14 years old, and their socioeconomic status (SES) in both groups was similar, with the majority of the students coming from low- to middle-SES families.

2.2 Research Design and Hypothesis

This study adopted a pseudo-experimental design, as shown in Table 1.

Table 1. Experimental design

Group	Pre-test	Treatment	Post-test
experimental	O_1	POGIL	O_3
control	O_2		O_4

In this study, the dependent variables were academic performance and capacities for collaboration and problem-solving. The independent variable was the teaching method. Therefore, the significant difference between the experimental and control groups was the pedagogy. We used the following strategies to control interfering variables: (1) The experimental and control groups were from the same school and comprised students of the same grade with similar SES and life experiences. The number and gender distributions were also similar. (2) A homogeneity test conducted before the experiment showed that the two groups of students had similar academic performance and capacities for collaboration and problem-solving. (3) The same instructor taught the experimental and control groups to avoid any influence from the instructor's academic background or personal characteristics. (4) The same teaching units and teaching times were used for the two groups. (5) Pre-tests and post-tests of the two groups were administered in the same week, and the instructor adopted the same testing procedures and guidelines to ensure consistency between the two groups.

The research hypotheses in this study are as follows: 1) The academic performance and capacities for collaboration and problem-solving of the experimental and control groups will be significantly different after treatment. 2) Students' academic performance and capacities for collaboration and problem-solving between the pre-and post-tests of the experimental group will be significantly different after the experimental treatment.

2.3 Experimental Treatments

The experimental units in this study consisted of five topics: the composition of the organism, the nutrition of the organism, the transport role of the organism, the coordination of the organism, and the constancy of the organism. The experimental group received the POGIL pedagogy, which, based on a synthesis of scholars' views (Hanson, 2013; Moog & Spencer, 2008; Simonson & Shadle, 2013), comprised the following steps:

Step one: Structure the teams. POGIL uses learning teams because they are similar to athletic teams. In athletic teams, students work together to achieve common goals. Participants work in teams in the classroom to help each other develop their skills and abilities. The benefits of learning teams cannot be achieved by simply telling students to form a team and have them complete an assignment but by asking them to work together, teach each other, and complete assignments. In this study, each team included one high-achieving student, one underperforming student, and two other students to provide gender and ethnic diversity. Diversity within each team is desirable because the views and talents of the members will vary (Hanson, 2013).

Step two: Assign roles and tasks. During the inquiry process, the roles of each group member (manager, spokesperson, recorder, and strategic analyst) are assigned flexibly, and complementary roles can be assigned to promote each person's interdependence and participation. Team learning promotes an in-depth understanding of the unit's core. Through assigning roles and tasks, students learn to take responsibility and develop process skills, such as problem-solving, communication, teamwork, and time management. Students learn to apply thinking skills and develop positive and interactive relationships with other students and teachers during the learning process.

Step three: Facilitate guided inquiry activities. POGIL uses learning cycle activities to engage students and help them develop comprehension and learning skills by challenging them to reorganize information and knowledge through guided inquiry activities. The learning cycle consists of three phases. The first phase is the "exploration" phase, in which students seek patterns of regularity in the context or data. During this phase, students can use patterns, data, experiments, or exhibits to generate and test hypotheses to interpret or understand the information presented. Teachers act as facilitators, listen to discussions, and intervene only when necessary. The teacher leads students through guided questions to help them understand the correspondence among the data, patterns, or information. The second phase is the "concept invention" or "term introduction" phase, in which students develop concepts from patterns and introduce new terms to refer to previously identified trends or patterns. The third phase is the "application" phase, which applies the concepts acquired by the student in the first two phases to a new situation. This phase requires deductive reasoning skills to generalize the concept's meaning to other situations. Thus, the learning cycle process guides students to develop concepts on independently by allowing them to gain epistemological insights into the nature of scientific inquiry.

Step four: Encourage process skills. In addition to the class content, developing POGIL's process skills, such as critical thinking, communication, teamwork, and problem-solving, is the focus of classroom implementation. At the beginning of the experimental group’s lesson, the instructor took a few minutes to explain the POGIL methodology and emphasized the importance of process skills to the students. The instructor explained how to strengthen and develop these critical and essential skills through the learning cycle, encouraged students to practice critical thinking, interpersonal communication, problem-solving and teamwork, and listed each group's process records as part of the unit's assessment.

Step five: Present the results of the inquiry and use metacognition. In POGIL, teams must discuss team dynamics and address how they work together to achieve their goals and maintain effective working relationships. They need to reflect on what they have learned, identify individual contributions, assess the quality of their results, determine which actions are helpful and which are not, and determine what to continue and change. Each strategist reports verbally to the whole class during the meeting rather than submitting a written report only to the teacher at the end.

The control group was taught using traditional pedagogy with a teacher-centered orientation. The units taught were the same as those in the experimental group. Usually, there are three lessons in a unit. Some units require laboratory operation, and the teacher implements the experimental teaching according to the guidelines in the textbook and requires the students to record and write in the experimental notebook. In this case, the teacher taught the core concepts of the unit by using a lecture. After receiving a lecture, the students carried out example exercises. The instructor assigned homework to the students for practice, which was reviewed in class to determine the students' learning progress. Learning assessments included informal assessments, such as asking students questions at any time in the classroom, and formal assessments, such as implementing paper and pencil tests. No inquiry results were presented, nor were learning experiences shared in the control group.

2.4 Instruments

2.4.1 Collaboration Scale

This scale consists of 11 items in two subscales: introspection (6) and interpersonal (5). Students responded to the items on a five-point Likert scale ranging from 1 "not at all compliant" to 5 "completely compliant". The factor loading of each item of the scale was higher than 0.44, the value of each dimensional characteristic was between 1.03 and 8.40, and the cumulative total variation was 58.00%, indicating good validity of the items within this scale. The overall internal consistency (Cronbach's α = .89) for the scale was good. Cronbach's α for the six subscales ranged from .80 to .82, indicating good internal consistencies among the items.

2.4.2 Problem-solving Scale

This scale consists of 21 items in four subscales: confidence (7), strategies (4), practice (5), and reflection (5). Students responded to the items on a five-point Likert scale ranging from 1 "not at all compliant" to 5 "completely compliant". The scale's overall internal consistency (Cronbach's α = .96) was good. Cronbach's α for the four subscales ranged from .85 to .92, indicating good internal consistencies among the items. In terms of validity, RMSEA=.07<.08, GFI=.81<.90, CFI=.91>.90, TLI=.92>.90, CN=184<200, indicates that the scale's factor structure is good.

2.4.3 Academic Achievement Tests

In order to understand the change in the ability of nature sciences after students receive S-POGILP. This study produced academic achievement tests based on the units of each term examination.

2.5 Data Analysis

This study used the statistical software SPSS for Windows for the data analysis. First, the scores for each item of the scales of collaboration and problem-solving were computed. Second, descriptive statistics were used to analyze the pre- and post-test scores for each group's responses to the scales. Third, a paired sample t-test was performed to determine whether a significant difference existed between the means of the pre-and post-test scores for students in the experimental group. Fourth, using one-factor covariance analysis, the main effects of the experimental treatment were directly analyzed to explore whether significant differences existed between the experimental and control groups in their academic performance and capabilities for collaboration and problem-solving due to the different teaching methods. All statistical tests in this study used .05 as the minimum alpha level.

3. Results

3.1 Comparison of the Differences of Academic Achievement between the Experimental and Control Groups

The results of the independent sample t-test analysis in Table 1 showed that the experimental group final exam score was significantly higher than control group score. These findings indicated that along with teaching time increases, POGIL pedagogy will significantly enhances students' academic achievement.

Table 1. independent sample t-Test of Academic Achievement Tests between the Experimental and Control Groups

	Experimental group		Control group		
Subscale	*M*	*SD*	*M*	*SD*	*t*
1 midterm exam	51.94	25.28	50.98	21.64	0.20
2 midterm exam	55.30	23.84	54.96	19.44	0.08
final exam	66.91	25.32	64.46	23.45	2.68^{***}

$^{***}p < .001$

3.2 Comparison of the Differences of Collaboration and Problem-Solving Between the Experimental and Control Groups

The participants in this study consisted of 51 experimental group students and 47 control group students. A one-factor covariance analysis was used to compare the differences between the experimental and control groups. The independent variable included pedagogy, and the dependent variables were the post-test overall scores for collaboration and problem-solving.

3.2.1 Homogeneity of Variance Test

Table 2 shows the results of Levene's Test of Equal Variances, which showed that the p-value of the scores of collaboration and problem-solving did not reach a significant level (p＞.05). Before treatment, the collaboration and problem-solving capacities of the experimental and control groups were homogeneous.

Table 2. Summary of Levene's Test of Equal Variances

Dependent Variable	*F*	*df* 1	*df* 2	*p*
collaboration	2.23	1	96	.23
problem-solving	3.09	1	96	.13

3.2.2 Homogeneity of Regression Coefficients Test

Table 3 shows the results of the homogeneity of the regression coefficient test, which showed that the *p*-value did not reach a significant level (*p*＞.05). Specifically, the regression slope was the same and did not violate the assumption of the homogeneity of the regression coefficient within the group, so it was appropriate to conduct a covariance analysis.

Table 3. Summary of the Homogeneity of the Regression Coefficients Test

Dependent Variable	Sources	*SS*	*df*	*MS*	*F*	*p*
collaboration	treatment ×pre-test	0.17	1	0.17	0.55	.46
	error	28.35	94	0.30		
	sum	1472.19	98			
problem-solving	treatment ×pre-test	0.17	1	0.17	0.54	.46
	error	29.66	94	0.32		
	sum	1463.71	98			

3.2.3 Analysis of One-Way Covariance

Tables 4 and 5 show the results of the one-way covariance analysis. Table 5 indicates that significant differences existed in the abilities of collaboration ($F = 119.08$, $\eta 2 = 0.56$, $p < .001$) and problem-solving ($F = 107.81$, $\eta 2 = 0.53$, $p < .001$) between the experimental and control groups. Specifically, POGIL pedagogy had a significantly greater impact on students' capacities for collaboration and problem-solving than traditional pedagogy.

Table 4. Average of the Adjustment of the Pedagogy of the Collaboration and Problem-Solving Post-Test

Dependent Variable	Treatment	*M*	*SE*	95% CI	
				LL	UL
collaboration	Experimental	4.37	0.08	4.22	4.52
	control	3.16	0.08	3.00	3.32
problem-solving	experimental	4.34	0.08	4.19	4.50
	control	3.16	0.08	3.00	3.33

Note: CI =Confidence interval; LL =Lower Level; UL =Upper Level

Table 5. Summary Table of the One-Way Covariance Analysis of the Pedagogy of the Collaboration and Problem-Solving Post-Test

Dependent Variable	Sources	*SS*	*df*	*MS*	*F*	η^2
collaboration	treatment	35.75	1	35.745	119.08***	0.56
	error	28.52	95	0.30		
	sum	1472.19	98			
problem-solving	treatment	33.86	1	33.86	107.81***	0.53
	error	29.83	95	0.31		
	sum	1463.71	98			

***$p < .001$

3.3 Comparison of the Differences of Collaboration and Problem-Solving Between the Pre-Test and Post-Test of the Experimental Group

3.3.1 Collaboration Ability

The results of the paired t-test analysis in Table 6 showed that the students' post-test scores in the subscales of introspection (t =25.79, p<.001), interpersonal (t = 25.69, p<.001), and overall (t = 27.39, p<.001) were significantly higher than their pre-test scores. These findings indicated that POGIL pedagogy improved students' collaboration ability.

Table 6. Paired t-Test of Collaboration Scale Scores for the Experimental Group

	Pre-test		Post-test		
Subscale	*M*	*SD*	*M*	*SD*	*t*
introspection	2.54	0.46	4.33	0.35	25.79***
interpersonal	2.64	0.49	4.42	0.32	25.69***
overall	2.58	0.45	4.37	0.31	27.39***

***p < .001

3.3.2 Problem-Solving Ability

The results of the paired t-test analysis in Table 7 showed that the students' post-test scores in the subscales of confidence (t = 27.90, p<.001), strategies (t = 22.82, p<.001), practice (t = 25.99, p<.001), reflection (t = 22.88, p<.001),and overall (t = 31.59, p<.001) were significantly higher than their pre-test scores. These findings indicated that POGIL pedagogy improved students' problem-solving ability.

Table 7. Paired t-Test of Problem-solving Scale Scores for the Experimental Group

	Pre-test		Post-test		
Subscale	*M*	*SD*	*M*	*SD*	*t*
confidence	2.63	0.39	4.35	0.28	27.90***
strategies	2.57	0.53	4.43	0.39	22.82***
practice	2.46	0.48	4.30	0.36	25.99***
reflection	2.46	0.60	4.33	0.27	22.85***
overall	2.57	0.41	4.35	0.26	31.59***

***p < .001

4. Discussion

POGIL is both a philosophy and a strategy for teaching and learning. It is a philosophy because it encompasses specific ideas about the nature of the learning process and the expected outcomes, and it is a strategy because it provides a specific methodology and structure consistent with how people learn and leads to desired outcomes (Hanson, 2013). The theoretical and methodological foundations of POGIL come from experiential learning theory, social constructivism, and meaning learning theory (Moog & Spence, 2008).

Experiential learning theory asserts that experience is the link between theory and practice, and it advocates that the teaching content of schools should be combined with practical experience so that learners can gain knowledge, skills, and values from practice (Dewey, 1938). The constructivist theory claims that learning constructs knowledge through interactions with the environment. Social interaction is the context in which individuals create self-meaning learning (Vygotsky, 1978). The theory of meaningful learning asserts that the construction of knowledge begins with our observation and recognition of events and objects through the concepts we already have. We learn by constructing and adding to a network of concepts (Rhalmi, 2011). The above concepts provide the theoretical and methodological foundations for today's POGIL.

This study examined the impact of POGIL pedagogy on students' academic achievement and capacities for collaboration and problem-solving. The findings showed that POGIL pedagogy significantly impacted students' academic achievement significantly more than traditional pedagogy. This finding is similar to those of several previous studies (Brown, 2010; Hale & Mullen, 2009; Idul & Joevi, 2019; Moog et al., 2006; Simonson & Shadle, 2013; Stanford et al., 2016; Villagonzalo, 2014), which indicated that POGIL could strengthen the interaction between students and teaching materials, build their understanding and knowledge retention, and enhance their higher-level thinking and application skills. A possible reason for these outcomes is that a POGIL learning activity engages students, promotes the restructuring of information and knowledge, and helps students develop their understanding by employing a learning cycle involving three guided inquiry activity phases: exploration, concept invention or formation, and application (Hanson, 2013). In the learning cycle, the first few questions typically build on students' prior knowledge and direct attention to the information provided in the model. The following questions help promote thought to develop relationships and find patterns toward developing a concept in the data. The final questions require divergent thought to find relevance or to look for the boundaries in generalizing students' new knowledge and understanding. Thus, the questions build on each other in complexity and sophistication, leading student groups toward discovering a concept (Moog et al., 2006). Students exposed to higher-order thinking exercises achieve higher results on achievement tests in problem-solving and comprehension. POGIL guides students in reconstructing their mental models into forms consistent with those in the scientific community. As a result, POGIL pedagogy could enhance students' academic performance (Villagonzalo, 2014).

Another finding indicated that POGIL pedagogy significantly impacted students' capacities for collaboration and problem-solving more than traditional pedagogy. This finding is similar to those of several previous studies (Andriani et al., 2019; Idul & Joevi, 2019; Irwanto et al., 2018; Johnson, 2011; Trevathan et al., 2014), which found that POGIL pedagogy enhances teacher-student interaction, helps students collaborate and share responsibilities, develops interpersonal interaction skills between peers, and improves students' collaboration and problem-solving skills. A possible reason for these outcomes is that a POGIL learning activity focuses on inquiry, whose purpose is to explore the situation, phenomenon, question, or problem to arrive at a hypothesis or conclusion that integrates all available information and can, therefore, be convincingly justified. POGIL activities employ questions to guide students' exploration of the models (Hanson, 2013).

Collaboration occurs when team members can effectively and respectfully perform activities, such as answering questions, solving problems, and achieving common goals (Rochmawati et al., 2020). Collaboration allows learners to correct and clarify misunderstandings by teaching each other to generate deep learning and is considered an important learning outcome (Kulikovskikh et al., 2017). A collaborative learner can coordinate the labor division of learning tasks, embrace diverse perspectives, and spark ideas through collaborative interaction to create better quality outcomes, resulting in better decisions made by the collaborating teams (Bialik & Fadel, 2015). In the POGIL classroom, students work together in teams and help each other develop their skills and abilities by participating in complex classroom tasks, gaining more opportunities for research and dialogue with teachers and peers, and achieving the expected group task results. As a result, POGIL pedagogy could enhance students' collaboration ability.

Moreover, in the POGIL classroom, students acquire information, form concepts, and construct understanding by examining a model or executing a task. They respond to questions and integrate this new knowledge with information from other sources (e.g., previous activities, textbooks, and lectures). They then develop skills in applying this understanding by working on exercises and solving problems (Hanson, 2013). Problem-solving describes defining a problem, determining the cause, identifying, prioritizing, and selecting alternatives for a solution, and implementing a solution (Benbow & Zarghami, 2017). In the POGIL classroom, students are challenged most by context-rich problems, essentially short stories presenting problems in disciplinary or real-world contexts. Such problems develop essential process skills, appeal to students' interests, and relate concepts to current real-world issues and other subject areas. As a result, POGIL pedagogy could strengthen students' problem-solving abilities.

Like previous studies conducted in different countries, this study confirmed that POGIL pedagogy was more effective than traditional pedagogy in enhancing students' academic performance and their capacities for collaboration and problem-solving.

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