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Keywords
Active learning, Guided-inquiry learning, Traditional lecturing, Student attitudes

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This paper aims to examine the relative impacts of three different models of learning (collaborative learning, traditional lecturing and process-oriented guided inquiry learning [POGIL]) on student performance and learning perceptions. In a controlled case study, we measured the learning outcomes of 57 undergraduates in a chemistry course taught by the different learning modules, using quizzes and exams as performance measures. In one academic quarter, the collaborative learning method was used exclusively whereas all three models were used subsequently in a second quarter by dividing up lectures into 4 different modules. Student quiz and exam outcomes indicated significant difference between collaborative learning and traditional lecturing ($P = 0.01$) but not within the active learning variants or POGIL versus traditional lecturing ($P > 0.05$), suggesting students performed best on content taught by collaborative learning. When prompted to pick a learning module, 67% of the students chose collaborative learning but not POGIL, indicative of student preference for one active learning variant over the other. However, student engagement and higher-order thinking appeared to be higher under the POGIL module though both skills were also evident during the collaborative learning period. Based on the outcome of the present study, it is recommended that purely inquiry-based lectures should employ short-burst intermittent lecturing to overcome student resistance and negative perceptions.

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Introduction

Contemporary research on classroom instructional modes suggests that teaching models employing active learning strategies result meaningful learning over traditional, passive lectures (McKeachie *et al.,* 1986). Active learning is a student-centered approach based on engaging students in activities and creating classroom environment that permits student ownership of the learning process. This in turn results improved student performance, as measured by traditional tests, as well as creating positive student attitudes towards the learning process (Bonwell and Elson, 1991). Moreover, because active learning strategies incorporate multiple learning styles, such strategies are consistent with educational models based on theories of learning and motivation.

Given the effectiveness of this approach (Michael, 2006), various models have been reported, including cooperative and collaborative learning (Johnson *et al.*, 1998; Cooper, 1995), case-based studies (Herreld, 1994; Rybarczyk *et al*., 2007), and problem-based learning, PBL (Albanese and Mitchell, 1993; Allen, 1996). In the cooperative learning model students work together on problems in a small group setting until all members of the group understand the problem and complete it. Five essential components must be systemically structured into the learning process to make cooperative learning successful (Johnson, Johnson, & Holubec,

1993): positive interdependence, face-to-face promotive interaction, individual accountability, interpersonal and small group skills, and group processing. Much of the research on cooperative group learning suggests that this model leads to improved student performance and increased higher-order thinking skills (Johnson and Johnson, 1989). However many instructors balk at the rather strict criteria required for successful learning.

Problem—based Learning, PBL, which has gained wide acceptance among educators in health professions (Hintz, 2005; Aspy and Quimby, 1993), is a format in which a vague problem scenario, often based on real world issue, introduces students to learning objectives (Greenwald, 2000). Students actively research the problem and present solutions at the level of the traditional lecture-based courses (Anderson, Mitchell, and Osgood, 2005). As a result, PBL contributes to student development in areas of critical thinking, problem solving and the ability to apply their newly learned skills in unfamiliar situations (Hintz, 2005).

The collaborative learning variant is a milder format in which students work in small groups on active learning activities to achieve a common goal. It has the same underpinning principles as the cooperative technique but is more general and has no strict criteria other than the ability to engage students in multiple and diversified activities (Case *et al*, 2007). Other simpler active learning techniques include think-aloud pair problem solving, TAPPS, (Lochhead and Whimbey, 1987) and the "One-Minute" paper (Angelo and Cross, 1988). A more recent active learning variant, funded by the National Science Foundation, is process-oriented guided inquiry learning [POGIL, <http://www.pogil.org>] (Farrell *et al.,* 1999). This variant essentially employs active learning strategies by engaging students on guided-inquiry material. There is no lecturing in the POGIL classroom and instructors are there to facilitate learning, not lecture (Lewis and Lewis, 2005; Spencer, 1999, Farrell *et al.,* 1999).

All of these models are welcome breeze in non-majors chemistry courses in which several obstacles present themselves. For one, most non-majors have negative impressions of the subject and dread taking it. Secondly, because of perceived difficulty in science courses, most non-majors assume they will do poorly in science classes. This is compounded further by pervasive lecturing in most college classrooms that does not engage students in the process of learning (Powell, 2003). The hope then is that active learning would alter negative student perceptions that interfere with the learning process while creating excitement in the classroom (Lujan and DeCarlo, 2006).

We previously experimented POGIL with student cohort accustomed to active learning strategies and collaborative group work. We reasoned that the introduction of POGIL to a group already exposed to collaborative learning would be smoother than if it were introduced to students only familiar with traditional lecturing. Much to our surprise, student resistance was persistent and most students commented that they found POGIL hindrance to their own learning (pilot experiment, data not published). However, as reported by many investigators, when students are exposed to active learning strategies first time, most go through fairly predictable number of stages: denial, followed by shock and panic, then frustration, and finally acceptance (Felder and Brent, 1996; Silverthorn, 2006). But what happens when students who are already familiar with the interactive classroom are challenged with different variants of the active learning format? Would such students have similar reaction as those exposed to active learning first time? This, in addition to a desire to understand how different active learning variants compare to each other and with traditional lecturing, motivated us to assess students' attitudes towards three different classroom instructional modes within the same class and the effect of these different modes on student learning and performance. We hypothesized that:

- Collaborative learning (CL) and POGIL would improve student perceptions and enable deeper learning of the course material.
- Earlier exposure to the milder CL variant would tame student resistance to the more complex POGIL approach.
- Relative to CL, performance measures, such as quiz and exam outcomes, would not be significantly affected under POGIL.
- Student performance under CL and POGIL, as measured by quiz and exam outcomes, would be at least as effective as traditional lectures if not significantly better.

To test these hypotheses, we compared student performances under the three different models of consideration in a chemistry course using standardized assessment instruments and report here our findings.

Methods and Materials

Subjects

Student subjects were enrolled in Chemistry 101, a five-hour-credit course in introductory chemistry series for non-science majors pursuing allied health fields such as nursing and medical assistance. Students enrolled in this study were mostly working adults returning for a second degree and were more familiar with the college environment than the typical college student. During summer 2007, a total of 25 students were enrolled in the course and met two days a week for four hours of instruction, two of which in one day were spent on laboratory activities. The same course was taught in winter 2007 (n = 32) using exclusively collaborative learning. Students in winter session met two days a week for 3 hour of instructions in an eleven-week session. There are 77 student contact hours for the course during the quarter. The same instructor taught both quarters.

Summer 2007 Course Design

Course lectures were divided up into 4 different modules, each lasting two weeks out of the summer eight-week session. Lectures in module 1 employed collaborative learning using modified continuum active learning strategy as shown in Table 1 (Wilke, 2003; Bonwell and Sutherland, 1996). At the end of each session, students were often asked to fill-out “One-Minute Paper”(Angelo and Cross, 1988).

Lectures in module 2 were based on didactic traditional lecturing; there were no active learning exercises or collaborative group activities, and no opportunity to do TAPPS or fill-out the minute paper at the end of the lecture sessions. PowerPoint was used to deliver lectures and all examples were solved on the board. Socratic questions were asked during lecture and volunteer answers solicited, with always the same two or three students answering the questions.

Table 1. Module 1 Lecture Plan (Continuum Active Strategy)

Segment	Duration	Activity
Warm-up question or quiz	~ 5 minutes	Focus student attention on chemistry
Lecture segment	~ 15 minutes	Instructor lectures on class content
Pause Moment Activity (PMA)	~ 15 minutes	Group activity on class content
Second lecture segment	~ 15 minutes	Instructor continues lecturing on content
Pause Moment Activity	~ 15 minutes	Individual active learning exercises (ALE)
Continued PMAs	~ 5 minutes	!▪▪ Students check their responses to the ALEs with group members !▪▪ Or students apply Think Aloud-Pair Problem Solving (TAPPS)
Cycle repeated	Cycle repeated	Cycle repeated

Module 3 lectures were based on process-oriented guided inquiry learning (Farrell *et al.,* 1999), a variation of the active learning format in module 1. Essentially students worked cooperatively in small groups on guided inquiry materials designed based on the POGIL philosophy. We have slightly modified the data presentation portion of the guided inquiry activities in that, whenever possible, data were presented on a large screen using computer simulations. Student groups observed what was happening, discussed among themselves the models shown, and came up with conclusions based on what they observed. For instance, when studying the properties of gas molecules, students watched simulated graphs showing the relationship between temperature and pressure or pressure and volume and manipulations of the various variables involved. This aspect of the activities brought live to the static models generally given in the guided activities and textbook-based models. During POGIL sessions, when misconceptions become too apparent in a group, group managers were asked to consult with other student teams. TAPPS was not utilized but students were asked to fill-out the "One-Minute Paper" at the end of each session.

In module 4, students were given an option to choose from one of the three above modules (modules 1-3) and instruction for those 2 weeks were done under the module students chose.

We note our experimental set-up is different from other published results in which study subjects are divided into different groups, with some group(s) serving as control and the other group(s) as treatment. Here the different teaching-models are tested on the same group of students, thereby controlling for variations across student populations. To control for variations in content coverage, summer 2007 students' performances were compared with those of winter 2007 during which content coverage was exactly the same as that of the summer session.

Winter 2007 Course Design

Instructions in winter quarter 2007 were exclusively by the CL format (module 1) described above. Learning outcomes for the traditional and POGIL model are compared with this course as an additional positive control.

Course Content as Taught under the Learning Modules

The instructional content covered in this study is similar to those covered in traditional lecture-based introductory chemistry courses. No prior chemistry knowledge was required and topics covered included energy and matter, elements and compounds, chemical equations and quantities, acids and bases, common solutions, gases and gas laws, and nuclear radiation. Though emphasized, practical applications of these ideas were discussed using both qualitative and quantitative approaches. Box 1 shows how problems in the class were approached under the different learning modes of instructions discussed in the present study and the instructor-student roles.

Box 1. Comparison of Instructor-Student Roles under the Different Learning Modules

Traditional lecturing:	Barium chloride and sodium sulfate react to form barium sulfate and sodium chloride. If 2.0 grams of barium chloride is used and excess sodium sulfate, how many grams of barium sulfate is produced?
Instructor Role:	Explain to students how to solve the problem and solve it for them (teach by doing philosophy)
Student Role:	Listen passively as instructor explains and does problem (learn by observing philosophy)
Collaborative Learning:	Same example as in traditional lecturing
Instructor Role:	Provide strategies on how to tackle the problem and provide preliminary example (facilitate learning by coaching philosophy)
Student Role:	Work in small groups of 3 to 4 and solve the problem and other active learning exercises collaboratively (learn by doing philosophy)
POGIL Approach:	Consider the model shown below: $P_1V_1 = P_2V_2$ The above mathematical equation describes to us how two of the four properties of gases that we will study in this chapter, pressure and volume, are related to each other. It is called Boyle's Law. Study, with your fellow group members, the computer simulations shown on the large screen and answer the following questions, paying special attention to the data as it is manipulated. ***Key Questions:*** !▪▪ What happens to the pressure as volume drops by about half? What happens if the volume is doubled? !▪▪ How would you describe mathematically this relationship? !▪▪ What could be a practical use of Boyle's law in the real world? !▪▪ How would you explain Boyle's law in nonmathematical terms to a friend? ***Exercises*** (students carry out series of problem solving exercises)
Instructor Role:	Provide strategies to groups on how to tackle the problem and provide support and encouragement (facilitate learning by coaching philosophy)
Student Role:	Work in small groups of 3 to 4 and solve the problem and other active learning exercises collaboratively (learn by doing philosophy)

Assessment of Student Perceptions and Performance

Data were collected from the following sources: a total of 6 weekly quizzes (2 per module) administered at the last session of each week, midterm exams administered at the end of each module, and a comprehensive final exam. The contents of the final exam were subdivided into three sections, each reflecting material taught under the different modules. We used aggregate data (average of individual performances on quizzes, midterm exam, and portion of the final exam taught under each format) to determine the effects of each module on student learning and analyzed differences for statistical significance using GraphPad Prism Software. When averaging quiz scores, we excluded those who did not take both quizzes under the same module. All scores were converted to percent correct responses and the mean percent score is shown for ease of comparison.

Student attitude towards the learning modules were measured using surveys and analyzed by descriptive statistics. The surveys contained nine items pertinent to student perceptions towards the learning modules on a Likert-type scale. We also allowed students to pick a learning module for the last two weeks of instructions, implicitly surveying for student preferences.

Results

Performance as Measured by Quiz and Exam Outcomes

Student performances appeared to be higher for material taught under the active learning modules and worst under traditional lecturing (Table 2). One-way ANOVA analysis on aggregate data showed the three models were significantly different from each other [F (2, 194) = 7.63, P < 0.001]. *Post hoc* tests using Tukey's honestly significant difference (at **!** = 0.01) indicated significant difference between collaborative learning and traditional lecturing, but not within the active learning variants or POGIL versus traditional lecturing, suggesting students performed best on content taught by collaborative learning.

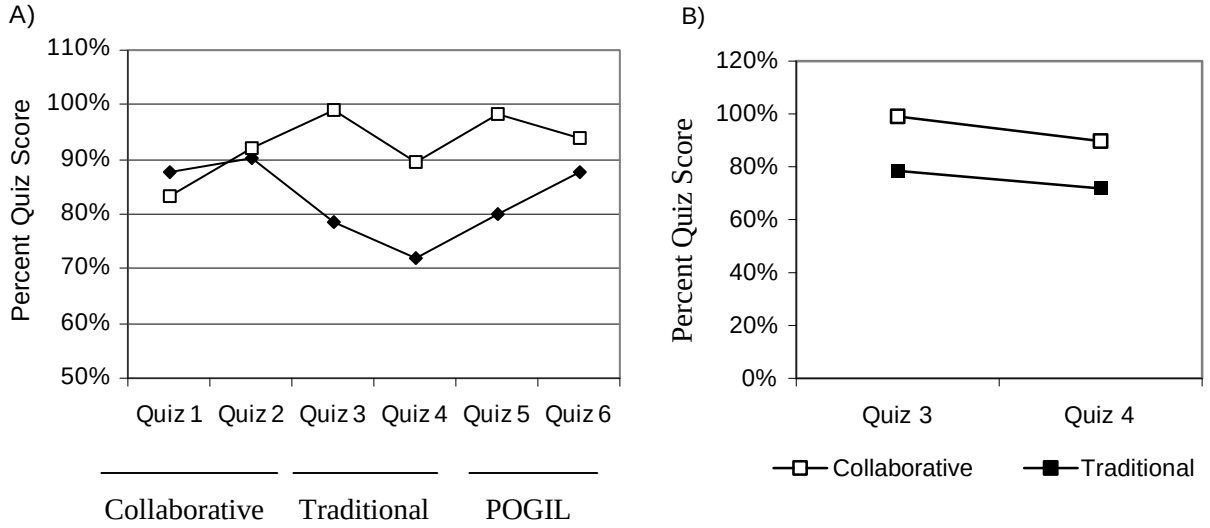
Table 2. Descriptive Statistics of Student's Performance Under each Learning Module

	Mean Percent Score ¨ SD			
Learning Module	Quizzes	Midterm Exam	Final Exam Subsection	Overall Module Score
Collaborative	88.80 ¨ 11.08	90.06 ¨ 13.10	82.18 ¨ 17.82	87.18 ¨ 14.38
Traditional	75.11 ¨ 21.96	75.98 ¨ 15.28	77.59 ¨ 18.33	76.20 ¨ 18.46
POGIL	84.00 ¨ 13.24[a]	84.19 ¨ 12.30	72.46 ¨ 19.66	80.15 ¨ 16.18

n = 21; [a] n = 20

We note that the decrease of student scores in Quiz 4 (Figure 1a, the quiz with the lowest overall mean) whose content was taught by traditional lecturing is partly due to coverage of more challenging material. Although the difference observed was not as pronounced as that seen for the traditional lecturing, a similar pattern of decrease in Quiz 4 score was observed in Winter 2007 when CL was used exclusively (Figure 1a); material coverage for summer and winter sessions was exactly the same and quiz and test formats remained constant, differing only in the specific values or parameter of a given question.

Figure 1. Quiz Outcomes and Its Effect on Student Performance



To control for the effect of content coverage, we ran an independent samples t-test analysis of all summer 2007 quiz outcomes versus those of winter 2007. Analysis (Table 3) showed that there was no significant difference when CL was used in both summer and winter sessions of 2007 (quiz 1, $P = 0.43$; quiz 2, $P = 0.47$) and a mixed outcome when learning was done collaboratively during winter session but by POGIL during the summer session (quiz 5, $P < 0.001$; quiz 6, $P = 0.36$). However, a comparison of the same material covered by traditional lecturing in summer 2007 but by CL during winter 2007 showed significant difference [quiz 3, $P < 0.001$; quiz 4, $P < 0.005$]. Based on these findings, it is apparent that the pronounced decline of student scores in the summer under the traditional lecturing mode is mainly the outcome of the instructional module used. We therefore conclude that CL results significant improvement over traditional lecturing (Figure 1b).

Table 3. Comparison of Summer and Winter 2007 Student Quiz Outcomes

	Learning Module	Summer 2007	Winter 2007				
Quiz #	Summer 2007 vs. Winter 2007[a]	Mean " SD	Mean " SD	% Difference (WI – SU)	T-test	*P*-Value	Sig.?
1	Collaborative vs. Collaborative	87.6 " 14.6	83.4 " 22.2	- 4.2	0.79 (*N* = 53)	0.432	No
2	Collaborative vs. Collaborative	90.0 " 11.0	92.2 " 10.9	2.2	0.73 (*N* = 53)	0.467	No
3	Traditional vs. Collaborative	78.4 " 28.9	99.1 " 5.3	20.7	3.98 (*N* = 52)	0.0002	Yes
4	Traditional vs. Collaborative	71.8 " 23.7	89.7 " 16.9	17.9	3.18 (*N* = 50)	0.0025	Yes
5	POGIL vs. Collaborative	80.3 " 17.2	98.3 " 9.2	18.0	4.71 (*N* = 48)	< 0.0001	Yes
6	POGIL vs. Collaborative	88.3 " 14.5	93.8 " 24.6	5.5	0.93 (*N* = 49)	0.358	No

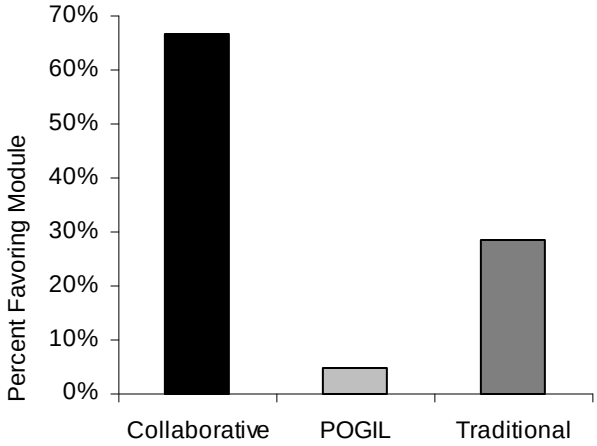
[a]*All winter 2007 instructions were exclusively by collaborative learning.*

Student Perceptions Towards the Learning Modules

We assessed students' perceptions towards the learning modules in two ways. In the first instance we used a novel strategy: we prompted students to pick a learning module for remaining instructional days after they were exposed to all three models. This was done anonymously. We reasoned that students would pick the learning module they felt most positive about. Our criterion for honoring their choice was that there has to be a clear-cut majority, although we have not informed students about this decisive factor. We suspected that students would choose traditional lecturing, the format most familiar to them prior to this course. Contrary to our expectation, and as is shown in Figure 2, most (67%) asked for collaborative learning.

In the second instance, we used attitude surveys on a Likert-type scale. On the 25-item survey, there were three items asking which of the modules students "liked," three items assessing under what format students "assumed" to have learned most, and three items asking which method they will recommend. Table 4 shows student response on these items. Again, these surveys were anonymous. On the statement, "I liked collaborative learning more than traditional or POGIL approach," only 12% disagreed or strongly disagreed. In contrast, 53% disagreed with "I like POGIL" statement and 35% with "I like traditional lecturing." This suggests students liked CL more than traditional lecturing and POGIL.

Figure 2. Students' Preference for Learning Module



Contrary to their performance as shown in Table 1, students assumed to have learned least under POGIL and most under CL. In fact, student performance under POGIL was no less effective than the traditional module and descriptively higher. The response to traditional lecturing was the most polarizing, with 41% disagreeing that they have learned most under this format and 59% assuming they learned most under this format. Thus one must interpret this data with a grain of salt. Interestingly student performances were worst under traditional lecturing relative to CL. We therefore suspect student responses to this item are most likely reflective of their prior preferences.

Table 4. Student Attitude Survey (% Responding)

Item #	Statement	1	2	3	4	5	[1 + 2]
1	I liked collaborative learning more than traditional lecturing and POGIL	0	12	41	18	29	12
2	I liked POGIL more than collaborative learning and traditional lecturing	24	29	29	12	6	53
3	I liked traditional lecturing more than POGIL and collaborative learning	29	6	18	24	24	35
8	I learned most during the collaborative learning format	6	24	29	24	18	29
9	I learned most during the straight lecturing period	24	18	0	29	29	41
11	I learned most by doing the POGIL activities	29	29	24	18	0	59
23	I would recommend collaborative learning more than any other format	0	29	29	18	24	29
24	I would recommend straight lecturing more than the other formats	18	18	12	41	12	35
25	I would recommend POGIL module	29	29	18	18	6	59

Level: 1 – strongly disagree; 2 – disagree; 3 – somewhat; 4 – agree; 5 – strongly agree.

Discussion

Our analyses of the relative impacts of traditional lecturing, collaborative learning, and POGIL on student performance showed that students did significantly better on material taught by CL while their performance did not suffer under the POGIL approach. Our collective quiz and exam data seems to indicate performance was worst during traditional lecturing, though not significantly poor in each case we studied. It therefore appears that CL leads to improved student learning whereas POGIL format does not statistically seem to benefit quiz and exam outcomes. Students' performance improved as they adapted the active learning variants while it decreased during the traditional lecturing sessions (Figure 1a). This suggests that students perform better under content taught by active learning strategies but that students need time to adapt to such strategies. Since both CL and POGIL employ active learning, we speculate (see below) that student perceptions of the modules affected their performance and thus the better outcome observed for the CL module.

One of the proposed hypotheses in the present study was that the introduction of POGIL to a group already exposed to CL, a milder active learning format, would be smoother than if it were introduced to students only familiar with traditional lecturing. We previously pilot-tested this hypothesis on student cohort accustomed to collaborative group work (data not published). In the present study, initial exposure to CL did not tame student reactions to the lecture-free POGIL approach. In fact student frustrations were highest during this module when POGIL activities involved more challenging acid-base concepts then the more manageable gas concepts. This suggests that familiarity with one form of active learning format does not translate to acceptance of another form and student reactions would be similar to that of first-time exposure.

When asked to comment on the usage of group activities and active learning exercises, student perceptions of the learning modules were most positive towards CL, perhaps explaining why students did better under this format. This finding lends credence to previous studies that reported students who find a learning format enjoyable are more likely to improve than those who have negative impressions (Armstrong *et al.,* 2007; Marks, 2000; Robbins, *et al.,* 2006). This point is further supported by a strategy in which we prompted students to pick a learning module after exposure to all three models. Two-thirds of those surveyed chose CL (Figure 2). Given the short duration of each learning module, it is remarkable that majority of students asked for CL and not traditional lecturing. It is no surprise that a small minority asked for POGIL since this approach was least familiar to the students and would require longer exposure before students accepted it. In a three-quarter POGIL biochemistry series, Minderhout and Loertscher (2007) reported that over half of their students asked for lectures at the end of first quarter while less than 20% did so by the end of the third quarter. Both unsolicited and survey student comments also attest to the positive student perceptions of the collaborative module as expressed in the following student quotations:

Unsolicited written comments:

> "The best was when you lectured then [we] did the groups after explaining what were doing like in the first week of class."
>
> "Chemistry was my last pre-req class and I put it off to the end because I thought I would be horrible at it and that I would hate it. Neither of these turned out to be true, and I believe that was due to great instruction (and of course my hard work)."

Representative anonymous survey comments:

> "I learned this way the best."
>
> "It made me actually work with what I had just learned instead of listening and not really paying that good of attention. They really helped me."

One possibility of why students perceived they learned best under CL might be due to the fact that students thought they were getting the benefits of both traditional lecturing and active learning. This, however, was contrary to our classroom observations: though performance measures were not significantly better under POGIL relative to traditional lecturing, student engagement with material was optimal under this format. Student perception, however, is a hurdle one must overcome under the POGIL approach. We therefore suggest that, for student cohorts similar to those in the present study, the first phase of POGIL activities involve mini-lectures that permit setting the stage for students by giving short lectures before students proceed to carry out POGIL activities. Perhaps this can be done in the form of computer-simulated models that engage students visually or even static text-based models that can be explored through mini-lectures by guided-inquiry questioning. Future work will examine the effectiveness of this proposed method.

The student body in the present study consisted of working adults, in both summer and winter sessions, who are familiar with group work in their work setting. This perhaps led to student bias in favor of the collaborative model over the traditional lecture-based format. However, this fails to explain why the POGIL approach, which also employs cooperative group work, did not lead to significant improvement over traditional lecturing. We therefore do not believe student bias as an explanatory reason for the observed student performance under the

collaborative module. Here, it is important to note again that our study corroborates earlier findings that POGIL and other lecture-free pedagogies are no less effective than traditional lectures in terms of exam outcomes (Bradley *et al.,* 2002; Farrell *et al.,* 1999). While these models might not result improved test scores, their benefits are manifested in other ways. Farrell *et al.,* (1999), Minderhout and Loertscher (2007), and others, for instance, reported that fewer students taught by the POGIL approach got Ds, Fs, or withdrew while more received C and higher grades and/or showed higher-order thinking skills when compared to their counterparts in traditional classrooms.

Classroom Observations

Our quantitative data suggests that student learning is enhanced under the active learning modules but not the traditional lecturing. We think there are several factors that contributed to this finding. On the three modules studied, students were actively pursuing understanding of the material in the collaborative learning module while constructing their own understanding under the POGIL format. The small group setting under the active learning variants permitted 1) peer-to peer instructions and one-on-one student-student, student-instructor dialogue, 2) students spending more time with problem-solving and critical thinking issues, 3) positive feelings about the learning process more so than the traditional format, and 4) a general feelings of “effective learning environment” by both the instructor and students. Under the traditional lecturing format, students had no opportunity to crosscheck their understanding of the material with their peers or an opportunity to pursue problem solving either on their own or with peers but rather listened to the lectures delivered by the instructor. Under the active learning variants, the classes were “lively” and noisy, with hands going up whenever a group wanted the instructor’s attention. This collaborative effort among the students coupled with a sense of owning the learning process contributed to the enhanced performance under the active learning variants.

Theoretical Framework for Understanding Student Resistance to POGIL Lectures

Of the two active learning variants examined in the present study, the POGIL approach resulted adamant student protests and frustrations with the technique. Since this was first time our student were exposed to POGIL, we were expecting initial resistance and attempted to tame such resistance preemptively by fist exposing students to a milder active learning format. However, student resistance to POGIL lectures was both persistent and focal.

We believe there are several theoretical explanations that account for the observed student resistance to this innovative instructional module. First, students are accustomed to traditional lecturing in their formal education in classrooms that are teacher-centered and in which the expectation is the transfer of knowledge from the teacher to the student. Thus since their role in such classrooms is passive, students resist new and innovative modes of instructions that require self-directed learning and the shifting responsibility for learning from the teacher to the students (Keeney-Kennicutt, Gunersel & Simpson, 2008). In fact, many of the students in Chem 101 resisted the POGIL approach on the basis that it forced them to study on their own and commented that they “would have hired a tutor to study and enroll an online course if they taught the instructor was not going to lecture.” Secondly, we believe that our attempt to tame student resistance to the more complex POGIL format by first exposing them to the milder collaborative learning format actually contributed to increased student resistance to POGIL. We propose that students strongly identified with the collaborative learning format, associating with it positive values that contributed to their own learning and thus resulting

student attitudinal change. One of the things students strongly valued about the collaborative learning was the fact that short-burst lectures preceded group work and active learning exercises. However, in the POGIL format, there were no lectures on course content and students were directed to work on the guided inquiry questions while the instructor facilitated the learning process. Thus the absence of lectures doomed this technique ineffective in the eyes of the students in spite of what assessment instruments indicated. The benefits associated with the milder collaborative learning were not associated with the POGIL approach, and hence this format suffered from negative student perceptions.

Implications of Present Study

This study has implications for the introduction of new and innovative instructional modes in the classrooms. It suggests that student resistance to active learning variants can be overcome if students perceive the new format helps them learn in a ways that traditional lectures fail to do so. However, instructors need to be explicit in this regard and guide students through the benefits of the new methods. In this context, it was found that short-burst lecturing followed by active learning exercises and group work resulted student attitudinal change and the acceptance of innovative new format. Students associated positive value in engaging such activities and thus were more than willing to accept the new format. However, the use of milder active learning format does not lessen student resistance to more complex and stricter formats. When we first exposed students to the milder collaborative learning format with the hope of this strategy taming student resistance to the use of the more complex POGIL, it was found that student resistance was actually stronger. This implies that instructors should expect student resistance to complex active learning variants to be similar to that of novices introduced to milder active learning formats and be ready to handle it accordingly. Most importantly, our study showed that students are willing to change roles from passive listeners to active learners by taking responsibility for their own learning when the right environment and classroom dynamics are created for them.

Study Limitations

The student cohort under the present study may be unique and not representative of “average” students. All of the students in the present study were in the allied health field and most were pre-nursing majors. Most of these students held bachelors and masters degrees in non-science fields and were returning for a second degree. More importantly, most of them have avoided taking chemistry until the last minute and were self-motivated to meet final requirements for their intended major. While this might explain the higher performance we observed with this student cohort across board, it does not explain why they perform better under the active leaning variants and not the traditional format. Moreover, though student cohorts are intrinsically different, the finding that students prefer one learning format to others is probably transferable.

The greatest threat to the validity of the current study stems from its small sample size, though this was adequate given the size of the observed effect (collaborative vs. traditional, *d* effect = 0.7). With a larger sample size, however, it is possible that the difference between the POGIL approach and traditional lecturing, which did not show statistically significant improvement in terms of quiz and exam outcomes, would rise to the level of statistical significance. That said, as explained elsewhere, students enrolled in the present study favored

CL than both POGIL and traditional lecturing. We do not know if this desire for CL is unique to this student cohort or indicative of universal student desire when exposed to different variants of active learning pedagogies.

Finally, it is worth mentioning that in this study, as is true of all other classroom research, there is inherent limitation in determining statistical significance among different treatments, as there could be many other hidden variables in play. As such, as alluded in above, the mere lack of statistical significance does NOT mean lack of an effect but simply indicates that treatment did not meet standardized level of statistical significance.

Conclusion

We found that collaborative learning benefited students in introductory chemistry more than traditional lecturing while inquiry-based approach was no less effective. The POGIL approach employed structured cooperative group work yet student perceptions were negative towards this module. In contrast, students favored collaborative learning model that employed continuum active pedagogy, suggesting students prefer one active learning variant to the other. Moreover, earlier exposure to the milder collaborative learning did not tame student resistance to the more complex POGIL. We therefore think positive student perceptions made collaborative module more successful than the others. Interestingly though, student engagement on content, higher-order thinking, and process skills were optimal during the POGIL format. Further research in this area is warranted in light of certain limitations in the present study. Future work will also focus on understanding student subpopulations that exhibit enhanced learning under one model versus the others and understanding the characteristics of those students. We do think such study will provide insight to what factors lead to student preference for one model of learning over the others.

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