# Using POGILs and Blended Learning to Challenge Preconceptions of Student Ability in Introductory Chemistry

**By Phillip Boda and Gary Weiser**

*Success for students majoring in STEM (science, technology, engineering, and mathematics) within undergraduate chemistry courses is crucial for retention in science degree programs, especially for students perceived as lacking content knowledge and skills. This study leveraged blended learning structures in a remedial chemistry course combined with a Process-Oriented Guided Inquiry Learning (POGIL) curriculum as a potential intervention. The authors collected two data measures from this course and its nonremedial counterpart during the same semester: (a) pre-/postcourse Assessment of Basic Chemistry Concepts and (b) final grades. The authors also collected final grades of all students who populated the nonremedial course during the following semester and analyzed the data via descriptive statistics, t-tests, and analysis of covariance methods. The data support that students who were in the remedial class exhibited increases in conceptual understandings. This conceptual growth was comparable to the growth of students admitted directly into the nonremedial course. These "remedial" students went on to be 134% more likely to get a satisfactory matriculation grade (>80%) in this same subsequent nonremedial class compared with those directly admitted. Implications for this study emphasize the importance of remedial science course pedagogy and curriculum influencing student success and retention.*

Attrition rates among STEM (science, technology, engineering, and mathematics) majors remain high compared with their non-STEM peers (Chen, 2013). Considering this reality, researchers have begun to investigate mitigating factors to STEM attrition. Wang (2013) showed that, in addition to high school STEM performance, early college supports have significant impacts on students' desire and ability to continue along STEM degree pathways. Similarly, Wilson and her colleagues implemented a model for high-retention programs that introduced novel educational experiences in students' coursework to emphasize more holistic elements of learning beyond the traditional content dissemination model (Wilson et al., 2012). Implementing this model at her university, Wilson improved retention specifically among past underperformers who were most likely to drop out of their STEM major (Wilson et al., 2012). With these findings in mind, our study sought to design, implement, and study a novel, remedial postsecondary chemistry course—aptly named CHEM100: Preparation for Chemistry—that could prepare students for the traditional first course in the chemistry-major pathway, CHEM101.

This research study began at a large, urban public university in the northeastern United States, where more than 50% of the students in the introductory chemistry course (CHEM101) failed to receive a grade high enough to continue along their STEM-degree trajectory. One of the authors of this research study was hired to develop a course that met two main goals defined by the department: (a) introduce students to the content they would need to maintain an 80% or higher final grade (a retention requirement of the university's STEM-major programs) and (b) foster collegiate learning skills that students would find useful even if they chose not to pursue a science degree.

To achieve these goals, the authors drew from a growing body of research on Process Oriented Guided Inquiry Learning (POGIL) as a learning environment for the course as well as from trends in blended learning environments, both of which have shown potential to increase student interest, increase participation in scientific ways of knowing, and increase content acquisition. The authors believed that supporting these aspects of science learning provides novel ways not only to increase the passing rate of students that matriculate into CHEM101, but also to increase their retention in the overall chemistry-major pathway.

## Purpose

Among undergraduate education researchers, both POGILs (Meeks, 2015) and blended learning environments (Baum, 2013) have been proposed interventions designed to improve teaching practice and classwork flexibility, respectively. However, research involving the simultaneous use of both to create a remedial and flexible STEM course has been sparse. This project drew from literature on both strategies to quantify the impact of combining these changes in the learning environment within this CHEM100 remedial course compared with a concurrently implemented course for perceived higher ability students that adopted a traditional lecture-based learning environment (CHEM101). The new course had fundamental changes designed to alter the curricular, pedagogical, and assessment elements from the traditional undergraduate structure (textbook, lecture, and practice problems/exams, respectively) into a more inquiry-based structure (analysis of data, learning cycle/argumentation, and inquiries/quizzes/exams, respectively). This novel course also provided the flexibility afforded by a blended learning environment. In light of the nature of the subsequent course that students would matriculate to after CHEM100 (i.e., CHEM101), the structure of summative exams was similar to that of the traditional courses the students would face when in their later science courses.

Given these goals, the following questions guided our study:

1. What growth in basic chemistry concepts do CHEM100 students exhibit within a course using POGILs in a blended learning context?
   a. Is this degree of conceptual growth comparable to that of the next matriculation course in their degree program, CHEM101?
2. How do students who have taken CHEM100 compare with those students who were not required to take the remedial in terms of matriculated retention in CHEM101?

## Background literature

### *POGIL*

Active learning and purposefully structured courses have been shown to increase performance on standardized exams across STEM degrees (Freeman et al., 2014). Additionally, active learning environments that involve weekly (or daily) assignments combined with formative feedback have led to a decrease in the achievement gap between “unprepared” or low-ability students and their high-ability counterparts (Haak, HilleRisLambers, Pitre, & Freeman, 2011), even in large-lecture settings (Pennebaker, Gosling, & Ferrell, 2013). Within the CHEM100 remedial course, this research adopted a curriculum that was well suited to an active learning environment structure (in this case, a POGIL curriculum).

POGILs have been used both in large lecture-style courses (Bailey, Minderhout, & Loertscher, 2012) and have shown success for diverse populations (Brown, 2010). This curriculum leverages active learning beyond traditional undergraduate science instruction to foster scientific epistemologies, increased conceptual understandings, and positive attitudes in students (see Moog & Spencer, 2008), for a complete explication of these embedded elements). Even in piloting rounds of implementation, POGILs foster examination scores on a par with, or higher than, their traditional counterparts (Chase, Pakhira, & Stains, 2013). However, although POGILs have been used to promote motivation in diverse populations of undergraduate students and success in gatekeeper STEM courses (Fakayode, Yakubu, Adeyeye, Pollard, & Mohammed, 2014), a study of their impact on degree-program retention has yet to be researched sufficiently.

### *Blended learning*

Garrison and Kanuka (2004), as well as others (Halverson, Graham, Spring, Drysdale, & Henrie, 2014; Stockwell, Stockwell, Cennamo, & Jiang, 2015), have described blended learning as a restructuring of coursework where “text-based asynchronous Internet technology” is blended with “face-to-face learning” to foster a “thoughtful integration of classroom face-to-face learning experiences with online learning experiences” (Garrison & Kanuka, 2004, p. 96). These experiences are well suited to science and engineering classrooms, particularly when there is a lack of resources or no substantial way to represent a phenomenon in question, which then necessitates students to work virtually to make sense of the phenomenon in collaboration with physical observation and discussion (De Jong, Linn, & Zacharia, 2013).

Although blended learning elements are not a silver bullet for improving college science teaching (Bernard, Borokhovski, Schmid, Tamim, & Abrami, 2014), they can be a way to change the learning environment for students in unique need of alternative classroom contexts. In his research on explicit learning of "learning strategies" (i.e., learning how to learn), Tuckman (2002) found that when comparing a traditional in-class experience without technological experiences to a blended learning design, the blended learning structure contributed to higher GPAs. Moreover, a latter study by Tuckman and Kennedy (2011) found that students who were ranked among the lowest ability level coming into their undergraduate degree and took part in a blended learning class maintained a higher term GPA, were more likely to be retained during their tenure, and had 50% higher graduate rates than their counterparts.

## Research design

Using the literature on POGILs and blended learning, one of the authors of this study took on both roles of researcher and practitioner in that he was hired to both teach the course and provide evidence of its success toward the goals of the department. This dual-role helped form a direct link between learning elements emphasized by the theories used for the project and the actual teaching practice implemented in the CHEM100 classroom.

Although it is beyond the scope of this article to describe POGILs sufficiently as learning elements (see Moog & Spencer, 2008) for an introductory explanation), we summarize POGIL learning as involving the following characteristics:

1. Presents a research-based succession of concepts derived from how students best learn the ideas and what supports can foster such learning.
2. Integrates fundamental principles or themes that cut across concepts with moments to reflect on how concepts and principles interrelate.
3. Contains a guiding question for each concept presented.
4. Provides data and representations as forms of evidence from which students are able to draw claims about the guiding question.
5. Increases in complexity both within and between activities to foster more in-depth critical inquiry into how concepts in science interplay in consort with one another.

As an example of these elements, the authors provide a link to the first POGIL lesson from the textbook used (in an adapted form) in the CHEM 100 course (Moog & Farrell, 2014; https://pogil.org/uploads/attachments/cj5b7jvk603t9klx44pf0g836-chemactivity-1-original.pdf).

Corroborating the findings described in the literature review was a U.S. Department of Education meta-analysis, which highlighted that the largest difference in student learning by course structures was between blended learning environments and face-to-face learning, more so even than compared with completely online versus face-to-face learning (U.S. Department of Education, 2010). In discipline-specific research from an introductory chemistry course, students in a blended course structure did just as well, if not better, on some topics as their traditional face-to-face counterparts (Baepler, Walker, & Driessen, 2014). The authors, therefore, sought to include online, blended learning elements in teaching the materials from the POGIL curriculum.

These online inclusions involved replacing one day of a usually twice-a-week course with an online response system with two embedded learning elements directly connected to the POGIL curriculum and the nature of blended learning environments:

1. A weekly post for students to complete of "3 things you learned, 2 things you are wondering, and 1 big question" (i.e., a 3-2-1 structure), wherein they engaged with a group-think mentality (such as the one emphasized in POGIL structures) but did so in a low-risk environment (i.e., online), therefore allowing for students that may not have engaged with the POGIL discussion in person out of fear of being wrong or looking less smart than their counterparts to more thoroughly participate in the POGIL curriculum.
2. Weekly exploration concepts via embedded text, simulation video, real-world applications, and how-to problem-solving tutorials followed by an online concept quiz—this learning element aligning specifically to blended learning structures in that it represents a chance for students to interact with the content in ways not feasibly

> possible in a short time period during traditional undergraduate classrooms where content is provided by lecture and taken down as notes by students to be read later in coordination with practice problems and recitation sections.

Within the in-person course session each week, students worked collaboratively in groups of three or four to generate claims based on evidence from the data provided in the POGIL curriculum. These claims were then written down on dry erase boards in a claim-evidence-reasoning structure, and then each group showcased their dry erase board to the entire class. During this activity, the instructor would routinely ask students to examine their classmates' claims, the evidence they provided to justify their claims, and their reasoning that their evidence appropriately supported their claims.

To build consensus over the weekly concept, students then defined similarities across two or more boards and refuted any differences in a whole-class discussion among student groups, emphasizing the close examination of evidence to support claims from the data provided. Final claims about what the data support across all claims were included in a growing list of "grand claims" that students could apply freely in subsequent POGILs. This structure departs from the traditional remedial course in that the important pedagogical moves for the professor were not to disseminate vocabulary and refine conceptual misunderstandings, but rather to facilitate the analysis of data to produce claims and develop consensus between students.

**FIGURE 1**

**Sample question from Assessment of Basic Concepts in Chemistry (ABCC).**

12. A 1.0-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and solid iodine together weight 27.0 grams.


The tube is then heated until all the iodine evaporates, filling the tube with iodine gas. After heating, the total weight will be:

A. less than 26.0 grams.
B. 26.0 grams.
C. 27.0 grams.
D. 28.0 grams.
E. more than 28.0 grams.

13. What is the reason for your answer to question 12?

A. A gas weighs less than a solid.
B. Mass is conserved.
C. Iodine gas is less dense than solid iodine.
D. Gases rise.
E. Iodine gas is lighter than air.

## Methodology

This research sought to describe how students who took CHEM100 faired in terms of content retention when they matriculated into the next course in the sequence of their degree (CHEM101) compared with their counterparts who enrolled into CHEM101 without taking the preparatory CHEM100 class. By studying *both* courses concurrently (CHEM100 and CHEM101) using the same measure (performance on a chemistry concept inventory; Assessment of Basic Chemistry Concepts [ABCC]) of conceptual understanding and reasoning, this study sought to quantify the effect of the novel learning environment (CHEM100) compared with that of the traditional instructional approach of lecture and homework (CHEM101). More specifically, it sought to challenge the notion that CHEM100 students (who were deemed unprepared for CHEM101 by the university) were inherently less able than the CHEM101 population of high-ability students.

## Data collection

Data was collected through a time series, pre-/postcourse design using the ABCC (Royce, 2012). The ABCC was implemented within both the CHEM100 and CHEM101 courses in the fall of 2015, on the first (pre) and last (post) days of class. This measure focuses on both conceptual knowledge and reasoning behind the choices for each question about general chemistry concepts, and thus it provides a glimpse into both student content knowledge application and the justification of their answers. Figure 1 shows a sample of one such question and its subsequent reasoning choice.

### *Demographic data*

Out of 37 students taking CHEM100 in the fall semester of 2015, 26 students agreed to participate in the pre-post ABCC assessment. Out of 63 students taking CHEM101 that same semester, another 26 agreed to participate. Student demographics in each course were similar to that of the college demographics as a whole: ~70% students of color, 30% White students; ~60% female, 40% male. Although attrition was higher than acceptable percentages widely used in education research (>20%), final grades of attrite students were not significantly different from the final grades of participating students, $\chi^2(1, N = 100) = 2.2$, $p > .10$, which suggests that choice to participate was not due to a factor that affected classroom success.

## Data results and analysis

### *Research Question 1*

The normal distribution parametric assumption was met for all five data sets (pre/post CHEM100 fall 2015; pre/post CHEM101 fall 2015; and final grades CHEM101 spring 2016) using the Shapiro–Wilk test to assure reliability in inferential statistics tests used (Razali & Wah, 2011). We used an unpaired *t*-test to compare the pre- and postcourse ABCC scores between the two fall 2015 courses (CHEM 100 and CHEM101) and found that students in the more advanced course had a higher average ABCC score at the end of the fall 2015 semester than their remedial peers, $t(50) = 2.06$, $p = .04$. This should not come as a surprise; students who were required to take the remedial CHEM 100 course started the fall 2015 semester with a lower precourse average performance on the ABCC, $t(50) = 3.56$, $p << .01$, than their nonremedial peers.

Given the advantage nonremedial students had entering the semester, it is not fair to compare the two groups one-to-one. As researchers, we need to account for the precourse characteristics of students that differed between the remedial and nonremedial class. This can be accomplished via an analysis of covariance (ANCOVA), in which a relevant precourse covariate that may be affecting postcourse outcomes (in this case, the precourse ABCC scores of students) is accounted for by adjusting the postcourse outcome values of one group by linear transformation. We checked that the necessary assumptions were met (plotting linearity, finding slope homogeneity $p$ value of greater than .3, and confirming covariate independence with $p$ value less than .01), allowing us to use precourse ABCC values as a covariate that was affecting postcourse measures of student performance (Montgomery, 2008).

Table 1 displays the pre-/post-ABCC means and standard deviations for both the comparison groups of CHEM100 and CHEM101 for fall 2015. Table 1 also reports the adjusted postcourse ABCC means that were not significant after accounting for the pre-ABCC scores as covariate within the ANCOVA analyses. Table 2 provides greater details of the ANCOVA analysis.

Via paired *t*-tests, the data indicate

**TABLE 1**

**Means and standard deviations on ABCC, pre-/postcourse for CHEM 100 and CHEM 101 with adjusted postcourse ABCC means from ANCOVA analysis.**

| | | Precourse ABCC | | Postcourse ABCC | | Adj. postcourse ABCC |
|---|---|---|---|---|---|---|
| **Course** | *n* | *M* | *SD* | *M* | *SD* | *M* |
| CHEM 100 | 26 | 29.0** | 9.87 | 34.8* | 11.2 | 36.1[a] |
| CHEM 101 | 26 | 38.6** | 9.40 | 40.9* | 10.0 | 39.6[a] |

*Note:* ABCC = Assessment of Basic Chemistry Concepts. ANCOVA = analysis of covariance.
[a]no statistically significant difference.
$^*p < .05$. $^{**}p << .01$.

**TABLE 2**

**One-way ANCOVA of postcourse ABCC scores of both courses (CHEM 100 and CHEM 101) after controlling for precourse ABCC scores.**

| Source | *df* | *SS* | *MS* | *F* | *p* |
|---|---|---|---|---|---|
| Adjusted means | 1 | 124.25 | 124.25 | 1.11 | .297 |
| Adjusted error | 49 | 5498.7 | 112.22 | | |
| Adjusted total | 50 | 5623.0 | | | |

*Note:* ABCC = Assessment of Basic Chemistry Concepts. ANCOVA = analysis of covariance.

that there was a significant and positive gain in basic chemistry conceptual understanding for students who took CHEM100 in fall 2015, $t(50) = 2.07$, $p = .05$, Cohen's $d = .42$; however, no statistically significant gain was found among students taking CHEM101 that same fall semester, $t(50) = .296$, $p > .05$.

In the ANCOVA analysis to determine if there was a statistically significant difference between the postcourse ABCC scores of students from CHEM100 or CHEM101 after controlling for observed precourse differences, no significant difference was measured, $F(1, 49) = 1.11$, $p >> .05$. Although a basic analysis might suggest that the postcourse ABCC scores for the high-ability CHEM101 students were significantly better than the low-ability CHEM100 students, using ANCOVA to control for initial conceptual understandings of basic chemistry concepts completely accounts for the difference in growth. Underscored by the high gains (via paired *t*-test) observed in ABCC scores among CHEM100 students but not CHEM101 students, the results from the ANCOVA highlight the power of a novel pedagogy, curriculum, and learning environment (such as the one implemented here in CHEM100) to help perceived unprepared, low-ability students grow in their basic chemistry conceptual understandings to levels on a par with their perceived prepared, high-ability counterparts.

### *Research Question 2*

Final analysis of retention was calculated based on the percentages of students that met the departmental requirement for retention in the degree within the CHEM100 students' matriculation course (>80% for their final grade in CHEM101 spring 2016). The authors conducted further analysis by comparing the percentage of students that took CHEM100 who met that retention requirement with those that matriculated directly into CHEM101 without having taken CHEM100 because of their perceived high ability.

After students that took CHEM100 in the fall of 2015 matriculated into CHEM101 in the spring of 2016, final grades for all students (including both remedial students from CHEM100 and introductory, nonremedial students) enrolled in CHEM101 during the spring 2016 semester were collected (see Table 3 below for a summary of this data). CHEM 101 had a standardized, PowerPoint-based curriculum that is implemented each semester—no matter the professor on record teaching it—with the same elements and the same goals, likely contributing to the consistent failing marks (over a 10-year period) that spurred the purpose of our here-described research.

We grouped these students into two populations—low-ability students who took CHEM100 in the prior semester and high-ability students who were allowed to take CHEM101 without remedial instruction. Comparing the percentages of students that received 80% or higher on their final grade in CHEM101 during spring 2016, we find that students that took CHEM100 in fall 2015 were more likely to receive a program retention grade (36%) than students who went directly into CHEM101 on the basis of their perceived high-ability (only 18%). Nominally, these low-ability students were also more likely to pass the course (86%) than their high-ability peers (64%), but we did not find these passing rates to be statistically different from each other.

## Discussion and implications

Although there have been relatively few studies of using POGILs in a

**TABLE 3**

**Means, standard deviations, and percentages of students' final grades in spring 2016 CHEM 101, students that took CHEM 100 are presented separately from those that did not.**

| | | Descriptive statistics | | Percentages | |
|---|---|---|---|---|---|
| **Population** | ***n*** | ***M*** | ***SD*** | **Passing[c]** | **Retained[d]** |
| Low-ability students[a] | 14 of 36 | 75.1 | 11.3 | 86% | 36% |
| High-ability students[b] | 22 of 36 | 68.0 | 11.0 | 64% | 18% |

[a]Low-ability students were those that were required to take CHEM 100 in the fall of 2015.

[b]High-ability students were those that were not required to take CHEM 100 prior to taking CHEM 101.

[c]Passing was awarded if students received 65% or higher on their final grade in CHEM 101.

[d]Retained was awarded if students received 80% or higher on their final grade in CHEM 101.

blended learning environment (cf. Baum, 2013; Meeks, 2015), the research reported here highlights the success of a novel pedagogical and curricular structure for use in undergraduate introductory chemistry. Advising faculty at the university had previously classified would-be CHEM100 participants as low ability on the basis of standardized testing and experience. This study highlights how changing the structure of such an introductory course can ameliorate the perceived lack of conceptual knowledge that places diverse student populations in remedial courses. Instead, the data support that early STEM majors at risk of dropping from their current degree pathway benefit greatly from introductory courses such as CHEM100 that provide novel pedagogical and curricular changes in their learning environments through using POGILs in a blended learning context.

## Research limitations

We readily admit that the small sample size (particularly in light of the number who agreed to take the ABCC pre- and postcourse test) is a major limitation in our findings. However, given that the final grades of the attrite group were not significantly different from the pre-post participants, we argue that this limitation is minimal. Moreover, future projects that seek to study this type of learning environment at the undergraduate science level are needed to ask higher education faculty to be responsive to enacting such a novel pedagogy and curriculum in their courses. We also note that for the average student it is reasonable to expect that receiving additional instruction (in the form of a prior course) will result in their doing better than those who do not receive the additional instruction, but in the remedial context that is not always the case. Studies such as one by Gellene and Bentley (2005) found that remedial chemistry courses have rarely produced improved performance. We therefore believe our findings to reflect growth above what would be expected of a remedial course taught in a more traditional style.

## Conclusions

Our findings align and build on existing literature on active learning environments at the undergraduate level in the sciences (Freeman et al., 2014; Wilson et al., 2012). Learning environments such as these help students with diverse learning backgrounds meet the goals of introductory science courses more broadly through increased motivation (Fakayode et al., 2014) and increased success on exams implemented within traditional lecture-style programs (Bailey et al., 2012; Brown, 2010; Chase et al., 2013). This type of course structure can also be used to challenge perceived unpreparedness that disproportionately place minority students into remedial science courses without considering the success that novel course structures can have for all students in undergraduate science programs (Haak et al., 2011).

Blended learning environments are useful and novel structures for undergraduate science education that have been supported for their success across all disciplines (U.S. Department of Education, 2010), and when combined with an active learning pedagogy such as POGILs, this course structure can increase retention for perceived low-ability students in their matriculation to general undergraduate chemistry courses. This research substantiates the need for an inquiry into the use of such learning environment changes as effective models for significantly growing perceived low-ability students' conceptual understandings and reasoning in introductory chemistry courses at the same rate as their perceived high-ability counterparts, as well as increase their retention in matriculation courses within their degree. ■

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