Peer-Led Guided Inquiry in Calculus at the University of South Florida

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Abstract

This paper describes the development of a Peer-Led Guided Inquiry (PLGI) program for teaching calculus at the University of South Florida. This approach uses the POGIL (Process Oriented Guided Inquiry Learning) teaching strategy and the small group learning model PLTL (Peer-Led Team Learning). The developed materials used a learning cycle based on three phases of inquiry: exploration of a model, concept invention, and application. Fifty minutes weekly of lecture in Engineering and Life Sciences Calculus were replaced by the PLGI curriculum, where students worked in groups with peer leaders as instructors. The main outcomes measured were pass and withdrawal rates for sections using this approach compared to historical and concurrent sections not using PLGI. Our results showed higher pass rates in Life Sciences Calculus (18% gain in comparison to historical sections and 8.2% gain in comparison to concurrent non-PLGI sections). In Engineering Calculus, we also saw higher pass rates for PLGI sections (18.2% gain in comparison to historical rates and 4.0% gain in comparison to concurrent non-PLGI sections). Withdrawal rates also declined for both Life Sciences and Engineering Calculus. Both sexes had greater pass rates and lower withdrawal rates in both types of calculus. PLGI sections showed higher pass rates for African-American students in life sciences (16.5% gain in comparison to historical sections and 8.7% gain in comparison to concurrent non-PLGI sections). The impact of PLGI for African-American students was more dramatic in Engineering Calculus (24.9% gain in comparison to historical sections and a 17.6% gain in comparison to concurrent non-PLGI sections).

Keywords: Peer-led guided inquiry, POGIL, PLTL, Calculus.

Background

The United States is suffering from a shortage of graduates in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Kuenzi, 2008; National Commission on Mathematics and Science Teaching for the 21st Century, 2000). Considerable money and time have poured into efforts to increase student retention in STEM areas; for example a search of National Science Foundation (NSF) Division of Undergraduate Education awards at the time of this writing reveals over 2000 funded projects with this goal. Impact evaluations have been reported in the literature, including several meta-analyses summarizing the effectiveness of diverse innovations (Bangert-Drowns, Hurley, & Wilkinson, 2004; Borman, Hewes, Overman, & Brown, 2003; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Hattie, Biggs, & Purdie, 1996; Lou, Abrami, & d'Apollonia, 2001; Springer, Stanne, & Donovan, 1999).

How might one evaluate these projects? In many cases, researchers have used end-of-intervention exams and surveys (Hein, 2012; Hinde & Kovac, 2001; Lewis & Lewis, 2005; Lewis & Lewis, 2008; Khoumsi & Hadjou, 2005). These typically measure student achievement in content knowledge, attitude towards the program, or specific skills such as problem solving, which are relevant to their intervention goals (Tien, Roth, & Kampmeier, 2002); however, measuring pass/fail rates in a course and persistence to graduation has more practical significance (Peters, 2005). In particular, student persistence to graduation can demonstrate the long-term impact of an intervention. Unfortunately, persistence to graduation is hard to track, because students may transfer schools, take leave, change majors, or withdraw due to financial or other considerations. Consequently, long-term, large population evaluations of interventions based on graduation rates are limited (Gellene & Bentley, 2005). On the other hand, for individual students in most institutions, passing gateway courses is important because they are required for enrollment in advanced courses. For example, students in many STEM disciplines need a grade of C or better in the first semester of a basic calculus I course to register for more advanced courses. Failures in these gateway courses are a major factor in low retention rates; if the gateway courses can better prepare students for more advanced courses, the benefits can be significant, especially when these courses serve many students in large enrollment institutions. Although pass/fail rates are closely connected to final exam scores, pass rates and persistence in the STEM coursework can be better indicators than final exam scores because they also take into account students who withdraw from the course and do not take the final exam.

NSF reported the first-year retention rate at 64.2% in STEM at the national level during 1994 to 2000 (Hayes, 2002). In an NSF-funded study conducted by the Mathematical Association of America, the results from a stratified sample of 521 colleges and universities show a 73% passing rate (C or better) in Calculus I in Fall 2010 (Bressoud, Carlson, Pearson, & Rasmussen, 2012), suggesting that the situation may be improving. Studies focused on the evaluation of educational interventions in mathematics also hint at progress. Final exam performance for reform and traditional groups in calculus courses across eight studies suggest that reforms made a difference in questions involving analysis of graphs, conceptual issues, and problem solving, but not necessarily in procedural questions (Darken, Wynegar, & Kuhn, 2000). Inquiry-based learning has been linked to improvements in subsequent course performance for low-achieving students (Kogan & Laursen, 2014). Gilmer (2007) reported improved achievement and retention results of 88 total participants over 5 years in the Academic Investment in Math and Science (AIMS) program compared with control groups and with average results reported by NSF. However, students were selected for the experimental group on the basis of higher prior achievement. Russomanno et al. (2010) also described an extensive series of interventions, including peer mentoring, in their STEM Talent Expansion Program (STEP), and were able to report strong positive effects for first year and Black students via propensity score re-weighting to account for differences between experimental and comparison groups.

Here we examine the effect on student retention of a particular intervention using guided inquiry activities and undergraduate student "peer leaders" at the University of South Florida in Calculus I classes intended for engineering and life sciences majors. This effort was one part of a large 5 year project initiated by a group of faculty in statistics, mathematics, engineering, biology, and chemistry in 2008, supported by a National Science Foundation STEM Talent Expansion Program (STEP) grant. The goal of the grant was to increase the number of students graduating with an undergraduate degree in STEM. The premises of the project were that calculus may be a major barrier for

Bachelor degree enrollment (Fall 2007) and graduation (academic year 2006-7) in STEM disciplines and total, USF Tampa Campus.

	Number of declared majors	Degrees
Biology	1,254	136
Engineering	2,609	379
Mathematics	143	17
Chemistry, Physics	2,617	307
Total	28,514	5,215

Table 1.

progress toward the STEM degree, and that significant improvement in retention rates in calculus is likely to improve graduation rates. We describe the context and setting of the University of South Florida prior to the beginning of the project activities in 2008, previous efforts in chemistry at improving student retention, and the particular implementation of reforms in Calculus I. We then describe the statistical methods used to analyze student passing and retention rates and discuss our results, which suggest that PLGI can have a significant positive impact on student success.

Peer-led Guided Inquiry at the University of South Florida

University context. The University of South Florida is a large public research university with over 47,000 students at four different campuses. The Tampa campus (referred to as USF in what follows) is the largest, with just over 30,000 students, around 20,000 of whom are undergraduates. The undergraduate student body is quite diverse, and in particular has a large Hispanic student population. About 58% of the students are female, although that percentage is much smaller in some of the STEM disciplines, excluding biology. Many students entering the university are transfer students coming from community colleges.

To illustrate the problem facing USF in terms of graduating STEM majors, consider the n u m b e r s o f enrolled STEM students and numbers of degrees granted at USF (Table 1).

T h e data in Table 1 suggest the possibility that, in STEM disciplines, many students are either failing to graduate or are taking substantially more than four years to do so: if there were constant enrollment and it took 4 years to get a degree, one would expect the ratio of majors to degrees to be 4. However, in all cases, the ratio is much greater than that.

By having low passing rates, some gateway courses – such as the calculus sequence – may contribute

to these low success rates, making progress through a STEM major challenging for many students. Before the beginning of the STEP project activities in 2006, for example, passing rates in calculus I courses for engineering and life sciences majors were very low (46% of 479 students in Engineering Calculus I and 52% of 735 students in Life Sciences Calculus I).

Because USF is a large campus with many different majors, a variety of calculus courses are offered. The university offers calculus courses designed for engineering students (Engineering Calculus I, II, and III), for students in the life sciences (Life Sciences Calculus I and II), and for other majors such as mathematics and education (Calculus I, II, and III). Most of the students registered in these courses are taking the calculus sequence because it is required for their major, with the exception of Life Sciences Calculus II, which can be replaced for students in some majors by a statistics course. The Principal Investigators decided to focus their attention on the calculus courses that were directly connected to STEM applications, and therefore implemented activities in Engineering and Life Sciences Calculus. Here we are concerned only with one aspect of the project activities, namely the "peer-led guided inquiry" in Engineering and Life Sciences Calculus I, and the impact of this activity on retention and pass rates.

USF's prior experience reforming chemistry teaching. The interventions implemented in Calculus I were modeled on previous successful reforms undertaken in general chemistry at USF. At USF, general chemistry was taught in a lecture hall with up to 190 students. A program to implement various active learning strategies was developed in chemistry in 2002. The first component of this reform was the use of guided inquiry materials based on the POGIL (Process Oriented Guided Inquiry Learning, see http://www.pogil.org) teaching strategy. The second was to use a small group learning model adapted from Peer-Led Team Learning (PLTL) (http://www.pltl.org, 2003). In the PLTL model,

students meet weekly in small groups of 6-8 students with undergraduate peer leaders who have completed the course in a prior semester (Swarat, Drane et al. 2004; Tenney and Houck 2004). Because USF has such a large student population, we needed to modify this model by maximizing the number of students an individual peer leader can work with effectively. Our solution was to replace one of three 50-minute lectures per week with smaller groups in these peer-led sessions. The combination of carefully crafted guided inquiry materials and peer-led cooperative learning, which we call Peer-Led Guided Inquiry locally but is more generally known as peer-led POGIL, has enabled us to successfully create opportunities for inquiry, even, if necessary, in the context of a large class size.

During the first semester of implementation in chemistry, we conducted a quasi-experiment to investigate the differences between a class taught with the reform and one that relied entirely on lecture, both taught by the same instructor. Students in the reform section outperformed the comparison section on exams, with the difference approaching one-half of a standard deviation. Within the reform section, students attending a larger number of the peer-led sessions tended to perform better on exams, even when controlling for SAT scores. More details of the analysis and results from this initial implementation can be found in Lewis & Lewis (2005). With these encouraging results in hand, we offered a reform section again the following year, this time without the same-instructor comparison section. After three years of implementation in this fashion, rotating the reform section among instructors, results from multi-level models confirmed that students in treatment sections consistently outperformed their counterparts in the traditional sections (S. E. Lewis & Lewis, 2008). At present, all daytime sections of first semester general chemistry have adopted the reform.

Implementation in Calculus I. To implement a similar reform in calculus, we needed to develop guided inquiry materials for both Engineering and Life Sciences Calculus, recruit and train undergraduate peer leaders, and solve some practical hurdles such as scheduling issues.

The initial calculus guided inquiry materials used in the peer-led sessions were developed by the PIs and one of the graduate students and were based on the POGIL model. Subsequently, a second team (including one of the PIs from this project) produced a compendium of activities for Calculus I, now available in Straumanis, Beneteau, Guadarrama, Guerra, and Lenz (2013).In chemistry, early examples of such activities were developed by Moog and Farrell, (Farrell, Moog, & Spencer, 1999; Moog & Spencer, 2008). In this model, students work in groups of 3 or 4 on activities that employ a three-phase learning cycle. In the first phase, exploration, students examine some mathematical data (such
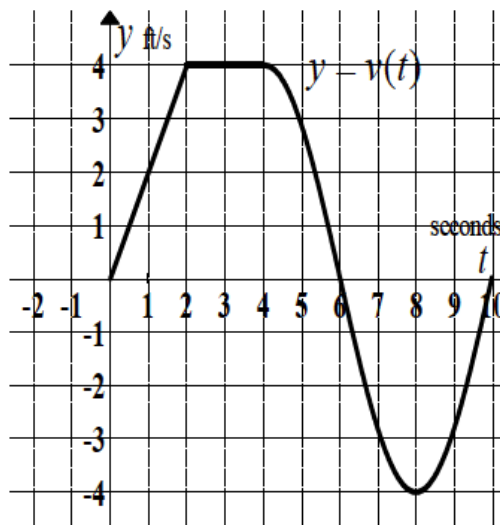
Model 1: A High-Wire Act

$v(t)$ positive →

← $v(t)$ negative

2ft

The graph at right plots the velocity $v(t)$ of a circus performer during a high-wire bicycle act. At $t = 0$ she is 2 feet from the starting platform.

Construct Your Understanding Questions

1. Based on the picture <u>and</u> the graph, over what time interval is the bicycle moving forward? …moving backward?

2. At $t = 0$ s, the bicycle's **position** = <u>distance from the starting platform</u> =_____ ft.

   At $t =$____ s the bicycle is farthest from the starting platform and its velocity = ____ft/s.

3. (Check your work) Are your answers above consistent with the fact that at $t = 6$ s the bicycle is momentarily stationary? If not, check your understanding of Model 1.

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4. Recall that when $v(t)$ is positive, the area between the graph of $y = v(t)$ and the t-axis from a to b is equal to distance traveled between $t = a$ and $t = b$.

   a. On the graph in Model 1 (above), shade the area equal to the distance traveled between $t = 0$ and $t = 2$ s. Use the grid to estimate this value = _____feet.

   b. On the axes below-right, plot the bicycle's **position** at $t = 2$ s. Note that **position** is <u>defined as the distance from the starting platform</u>. (The point at $t = 0$ is given.)

   c. Now add shading to the graph in Model 1 so the *total* shaded area equals the distance traveled between $t = 0$ and $t = 4$ s. This value =____ ft

   d. On the axes at right, plot the bicycle's **position** at $t = 4$ s.

   e. Add shading to Model 1 so the *total* shaded area equals the distance traveled between $t = 0$ and $t = 6$ s. Estimate this value =____ft

   f. On the axes at right, plot the bicycle's **position** at $t = 6$ s

5. The definite integrals $\int_0^2 v(t)\, dt = 4$ and $\int_0^4 v(t)\, dt = 12$ are associated with parts a and c of the previous question. Give the definite integral (and value) that is associated with part e.

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as graphs, pictures, a description of a real-world context) called the "model" and answer a series of questions that prompt the recognition of patterns or trends in the model. These questions are called "directed" questions, which means that they have a single correct answer, and can be answered directly based on examination of the model. For example, the following model, consisting of a picture, a description of a real world situation, and a graph, together with the first three directed questions, address the concept of the relationship between position and velocity (integration and differentiation, called the "Fundamental Theorem of Calculus"):
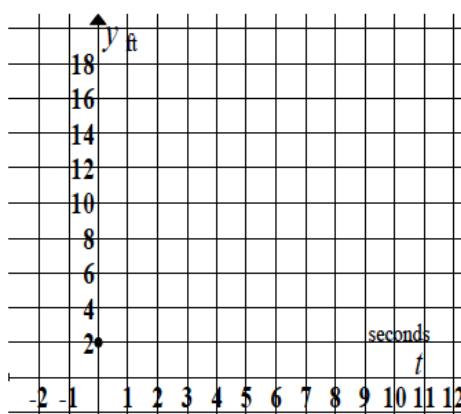
Notice that part of the second question's answer can be found in the description of the model, and the purpose of that question is to make sure the students are examining the model carefully. The patterns in the data which students should notice in the model from answering the directed questions, in this example, the relationship between position and velocity, form the basis for a mathematical concept, and the next phase, concept invention, is accomplished via a series of questions called "convergent" that require some synthesis or analysis of information contained in the model. In this activity, for example, students are reminded that area under a velocity curve represents distance travelled, and then are asked a series of questions that lead them to construct the position curve of the circus performer, based on the graph of her velocity.

These questions culminate in the introduction of the mathematical term used to describe the trend the students have observed. For instance, in this activity, after constructing the position curve of the circus performer, the students are asked a series of questions that gets them to connect differences in position with areas under the velocity curve. The discovery that these are the same leads students to the statement of the Fundamental Theorem of Calculus in this context, in other words, the statement that the definite integral of

the velocity function, over a given interval, gives change in position during that interval. The final phase, application, provides students with opportunities to use their new knowledge to solve a new mathematical problem. In this activity, for instance, students are given a velocity function, are asked to identify the position function from a series of choices, and have to write down and calculate the definite integral that gives the change of position for that new function. Sometimes in this phase, students are asked more open-ended "divergent" questions that might not have unique answers or might require research outside of the activity.

The activities implemented in the calculus classrooms included a pre-assignment based on algebra tools needed for the day's work and some early questions in the activity. At the beginning of each peer-led session, students took a five minute multiple choice quiz based on this pre-assignment and concepts from the previous week's activity. The main goals of the quiz were to ensure that students completed their pre-assignment and arrived on time. At the end of the session, students fill out a brief report, answering a critical thinking question based on the main mathematical idea of the activity as well as a "process" question prompting students to reflect on their own learning. In this activity, for instance, a critical thinking question might be to ask the students to explain the relationship between position and velocity. A process question might be for groups to identify what problem-solving strategies were effective that day, and what areas of improvement the group needs in order to work effectively.

Implementing such guided inquiry activities in the classroom is challenging. In order to have undergraduate peer leaders develop the necessary classroom skills and deepen the mathematical knowledge required to lead a classroom of students in such a guided inquiry activity, one of the PIs and her graduate student developed a weekly training session for the peer leaders. At this session, the PI and her graduate student ran the activity in the way the peer leaders would in the following week, thus modeling the behavior they wanted the peer leaders to exhibit in the classroom.

We decided to replace 50 minutes of lecture time in Engineering Calculus I and a recitation session in Life Sciences Calculus I with a peer-led session. The first peer-led sessions were implemented in Spring 2009, in Engineering Calculus I, followed by implementation in Engineering and Life Sciences Calculus I in Fall 2009.

Methods

The main outcome measures for this study are pass rates (grade of C or better) and withdrawal rates. For analysis, pass was coded as 1 for a minimum course grade of a "C", and 0 for a grade worse than a "C", because "C" or better is required for the engineering and life sciences de-

grees. Withdrawal was coded as 1 for a course grade of "W" and 0 for any other grades. A student receives a "W" at USF without academic penalty if he/she drops a course before a specified date roughly two-thirds of the way through the term.

The unit of analysis is the specific course section. We report percentages of the total number of students in each study condition (historical, concurrent no intervention, concurrent PLGI intervention, as defined in the following paragraph) to enable determination of how many students were affected by the intervention and the overall retention rate in each group. There is no randomization of instructors or students. The instructors volunteered to participate in the PLGI curriculum, and students chose sections based on their own time schedules.

The first PLGI sections were offered in Spring 2009. Here we consider data related to peer-led sections from Spring 2009 through Spring 2012. We also used institutional records starting from Spring 2003, to provide historical comparisons; we regarded students not in peer-led sections from Spring 2009 to Spring 2012 as "concurrent non-PLGI sections" while records from Spring 2003 to Fall 2008 were used for historical comparisons. Because this

is an observational study, we wanted to include historical data as an additional source of comparison. On the other hand, using only historical comparisons might not be sufficient to take into account general trends in grading or other changes in circumstance at the university.

We examined a number of possible confounding factors, including SAT math score, sex, and race/ethnicity, to check for possible bias associated with these factors before designing our analysis into the intervention effect. We report SAT math scores for each group (Figure 1), and we used Cohen's d ($d < 0.2$: no or trivial difference, $d > 0.2$: small, $d > 0.5$: medium, and $d > 0.8$ large difference) to quantify the magnitude of score differences (Cohen, 1977). We performed exploratory data analysis to examine the pass rates in the three comparison groups and their potential relationship with sex, and race/ethnicity. We used logistic regression to examine the effect of instructional group, sex, race/ethnicity, and their interactions, on pass rates. SAS (Version 9.2) was used for the analysis. A p-value at or below 0.05 is considered to be statistically significant.

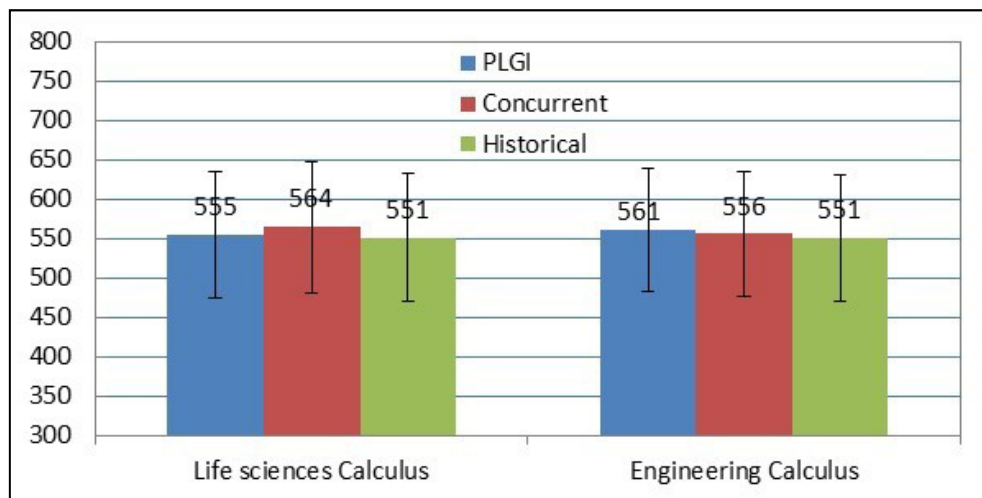To find a satisfactory model, we first fit a model with all possible predictors and their interactions included (the

Figure 1. SAT math score for the three comparison groups; error bars represent one standard deviation.
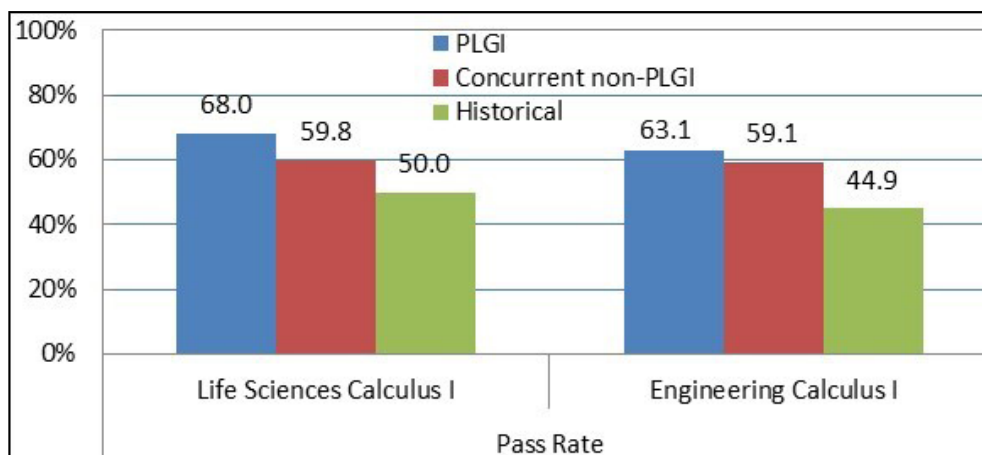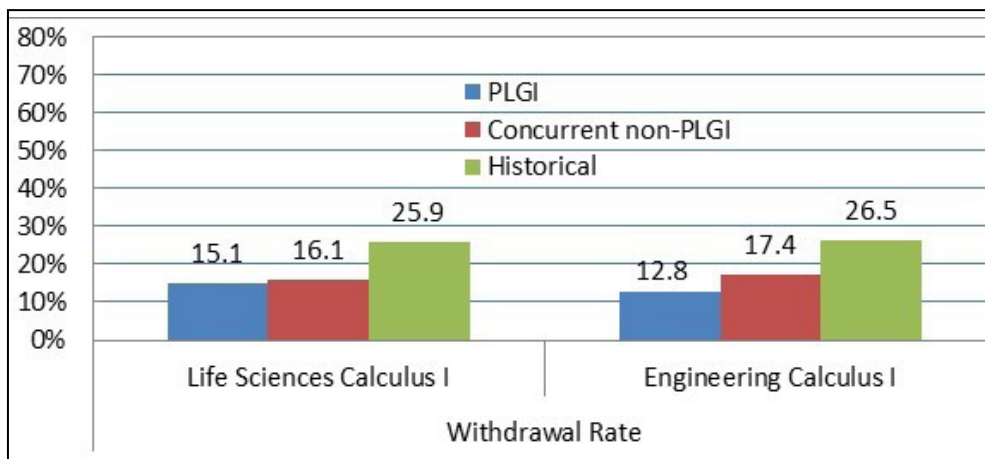

Figure 2. Pass rate by group and courses
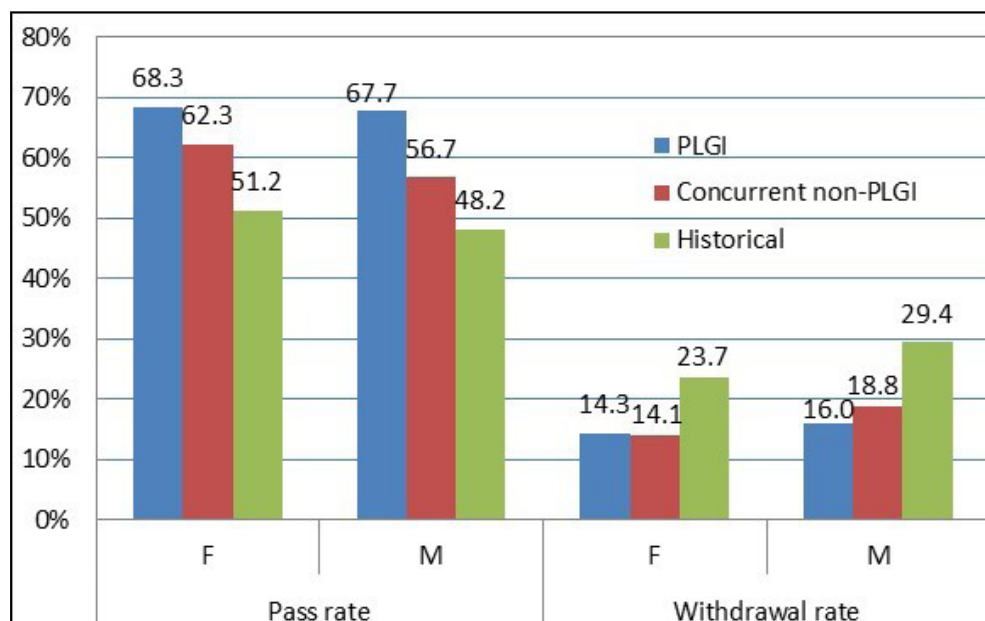
Figure 3. Withdrawal rate by group and courses.

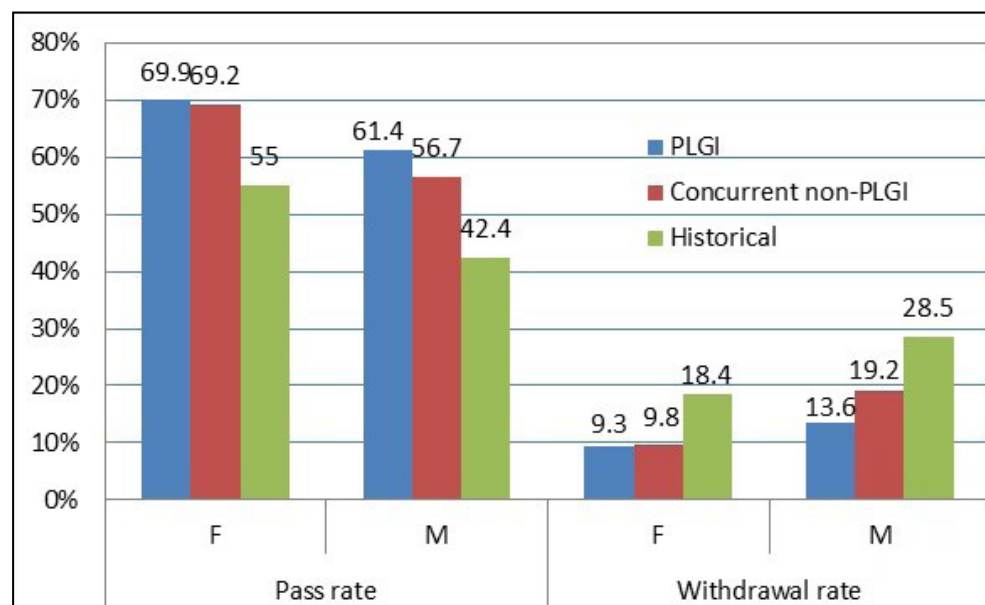**Figure 4. Pass/withdrawal rates by sex for Life Sciences Calculus I.**

Figure 5. Pass/withdrawal rates by sex for Engineering Sciences Calculus I.

saturated model). We then deleted interaction terms and used likelihood ratio tests to evaluate the fit of the reduced models, retaining the most parsimonious model that provides an accurate fit.

Peer leading is only offered during the Fall and Spring semesters. We only examined daytime sections because there were too few students in night sections where PLGI was implemented. During this period, there were a total of 54 PLGI sections (1512 students) in Life Sciences Calculus and 19 non-PLGI sections (595 students). The historical group had 2550 students in 84 day sections. In Engineering Calculus there were 21 PLGI sections (1097 students) and 13 non-PLGI sections (690 students). The historical group has 2985 students in 56 day sections.

A secondary analysis examines survey data collected from students enrolled in PLGI sections in Fall 2010. Here a seven-question survey was administered to students at the close of the semester. Students were asked a series of yes/no questions regarding their perception of the PLGI curriculum. A qualitative analysis describes the results of the open-ended questions. As this survey was conducted only once, the sample size is smaller than for other analyses.

Results

An examination of the SAT mathematics scores in the students found no meaningful differences between the groups or between courses (see Figure 1).

Figure 2 provides the pass and withdrawal rates for students in Life Sciences Calculus I, for all three comparison groups, and for students in Engineering Calculus I. PLGI sections in Life Sciences Calculus showed an improvement in pass rates: 68.0% passing, as compared with 50.0% for students in the historical group and 59.8% in the concurrent non-PLGI group. In Engineering Calculus, the pass rate for sections using PLGI rose from 44.9% for students in the historical group and 59.1% for students in the concurrent non-PLGI group to 63.1%.

Withdrawal rates (Figure 3) decreased in Life Sciences Calculus from 25.9% (historical) and 16.1% (non-PLGI) to 15.1% (PLGI). In Engineering calculus, there was a decrease from 26.5% (historical) and 17.4% (concurrent non-PLGI) to 12.8% (PLGI.)

Thus, students in the PLGI groups in both Life Sciences and Engineering Calculus I had higher pass rates, and lower withdrawal rates, as compared with the historical groups before the implementation and the concurrent non-PLGI groups.

Figures 4 and 5 provide the pass and withdrawal rates by sex for students in Life Sciences Calculus I and in Engineering Calculus I, for all three comparison groups. Pass rates were higher and withdrawal rates were either lower or comparable for both sexes and for both courses under PLGI than under either comparison group.

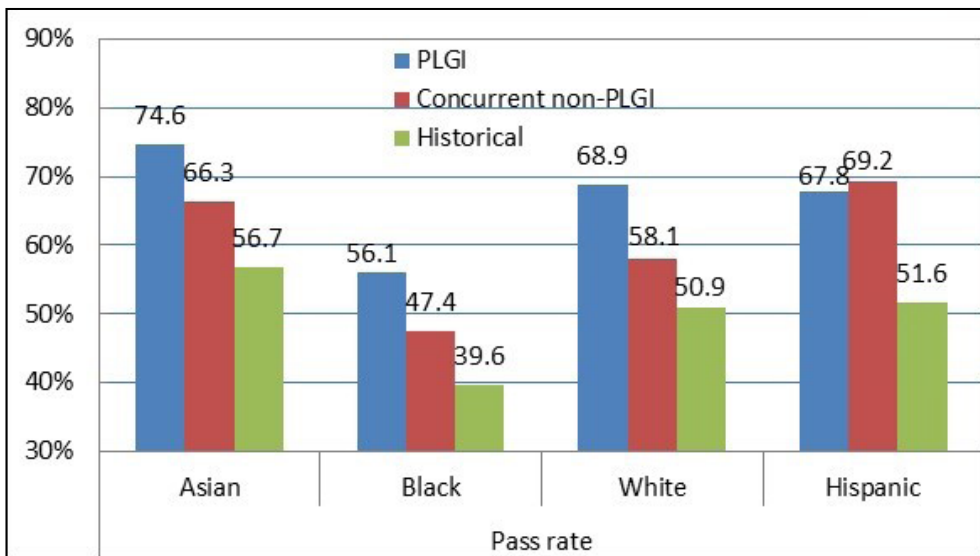Figures 6 and 7 provide the pass rates by Race/Ethnicity for students in Life Sciences Calculus I and in En-

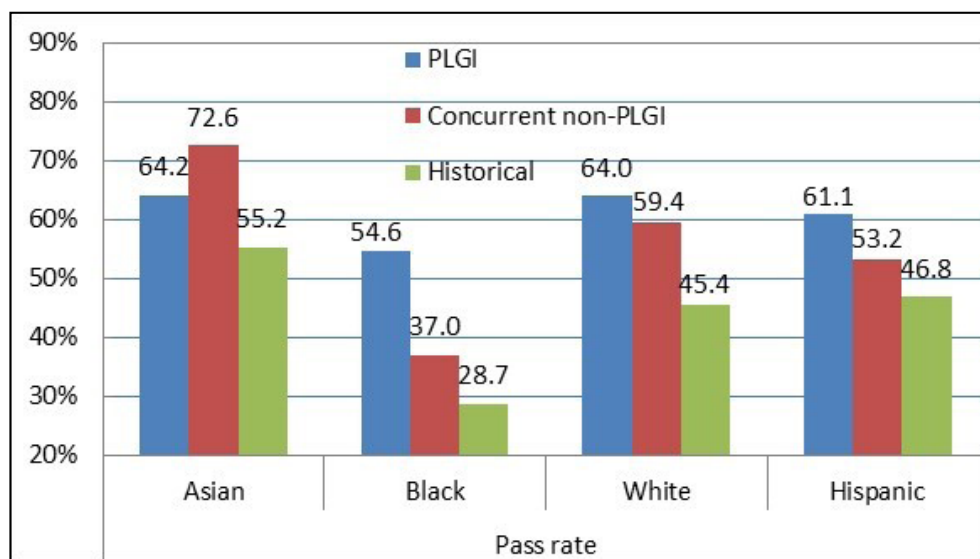**Figure 6. Pass rates by Race/Ethnicity for Life Sciences Calculus I.**

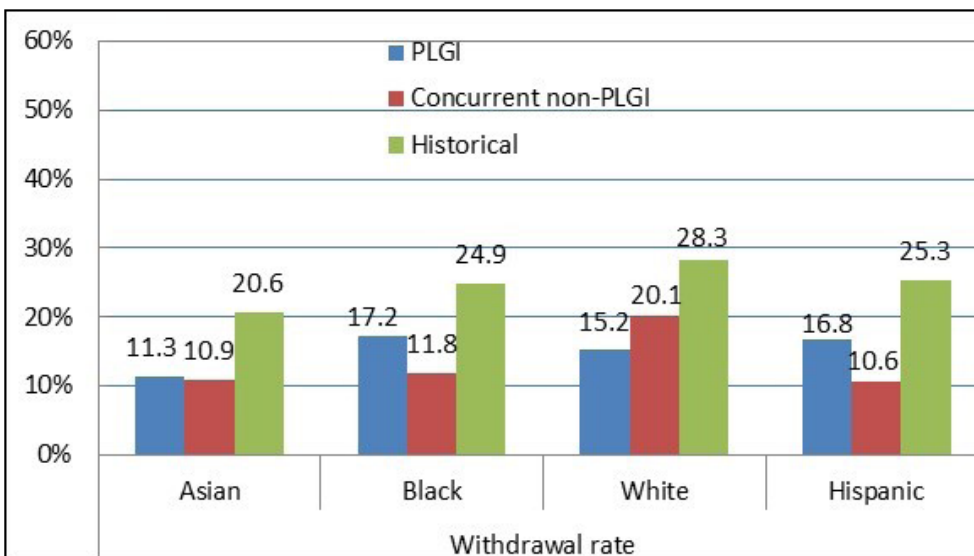**Figure 7. Pass rates by Race/Ethnicity for Engineering Calculus I.**

Figure 8. Withdrawal rates by Race/Ethnicity for Life Sciences Calculus I.

gineering Calculus I for Asian, Black or African American, White and Hispanic or Latino students. Here the pattern is more complex. PLGI and concurrent non-PLGI pass rates are better for students of all ethnicities than historical pass rates. In Engineering Calculus I, all groups except for Hispanic had higher passing rates for PLGI than for the concurrent non-PLGI group, and in Life Sciences Calculus I, all groups except for Asian students had higher pass rates in PLGI compared to the concurrent non-PLGI group.

Figures 8 and 9 provide the withdrawal rates by Race/Ethnicity for students in Life Sciences Calculus I and in Engineering Calculus I for Asian, Black or African American, White and Hispanic or Latino students. Overall, PLGI and Concurrent non-PLGI withdrawal rates are lower for students of all ethnicities than historical withdrawal rates. In Life Sciences Calculus I, all groups except white students had higher withdrawal rates in PLGI compared with the concurrent control group; in Engineering Calculus I, all groups except Asians had higher withdrawal rates for PLGI than for the concurrent non-PLGI group.

Logistic regression for Life Sciences Calculus I

The model selection procedure found that no interaction terms were significant predictors of outcomes. Accordingly, the final model only uses the main effects of group, sex, and race/ethnicity.

Estimates for the main effects for passing are given in Table 2. These results may be easiest to understand by examining the odds ratios. For example, the odds of someone in the concurrent non-PLGI group passing is 0.71 times the odds of someone in the PLGI group passing, if sex and race/ethnicity are held constant. The confidence intervals around the odds ratios show that the results are unambiguous, except for the Hispanic/White comparison. The p-values have the same pattern.

Logistic regression for Engineering Calculus I

The results for Engineering Calculus I are qualitatively similar to those for Life Sciences Calculus I and are summarized in Table 3. The strengths of some of these comparisons differ between the classes. After controlling for sex and race/ethnicity, the effect of PLGI as compared with the concurrent non-PLGI group is weaker with a p-value of 0.08. The effect of PLGI compared with the historical group remains highly significant (p < 0.001).

Student survey

Results from surveys administered in Fall 2010 to students in PLGI sections are given in Table 4. There were 199 Life Science Calculus respondents and 120 Engineering Calculus respondents.

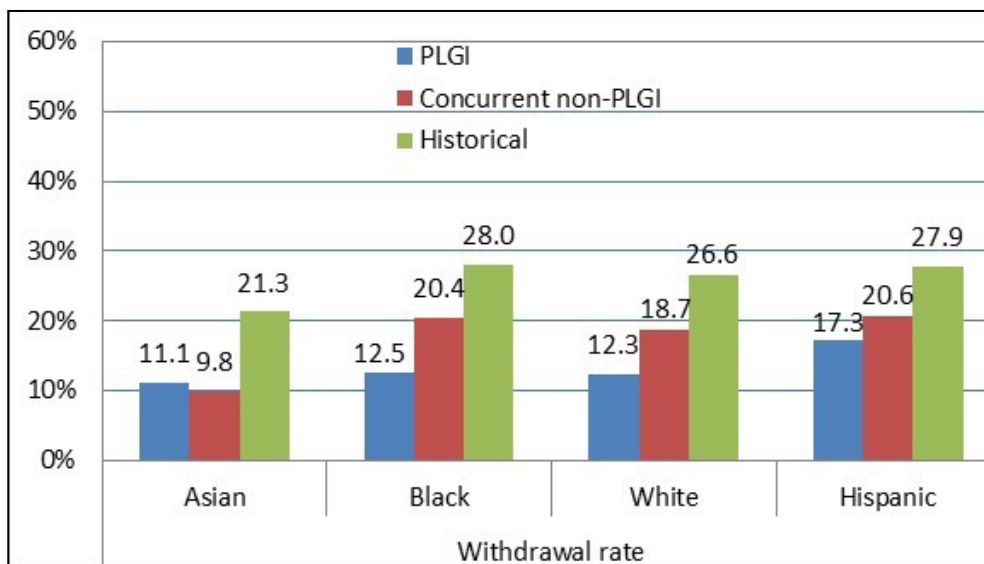Table 4. Survey questions and results for students enrolled in peer leading*"Yes" corresponds to answering "with."

Figure 9. Withdrawal rates by Race/Ethnicity for Engineering Calculus I.

Parameter	Estimate (SE)	χ^2	$Pr > \chi^2$	Odds Ratio (95% CI)
Intercept	0.81 (-0.07)	141.39	<0.0001	
Concurrent vs PLGI	-0.34 (-0.1)	11.55	0.001	0.71 (0.58, 0.87)
Historical vs PLGI	-0.74 (-0.07)	117.05	<0.0001	0.48 (0.42, 0.55)
Male vs Female	-0.14 (-0.06)	5.09	0.02	0.87 (0.77, 0.98)
Hispanic vs White	0.07 (-0.08)	0.76	0.38	1.08 (0.91, 1.27)
Asian vs White	0.28 (-0.09)	10.06	0.00	1.32 (1.11, 1.57)
Black vs White	-0.48 (-0.09)	27.24	<0.0001	0.62 (0.51, 0.74)

Table 2. Parameter estimate results from the regression for Life Sciences Calculus I.

Parameter	DF	Estimate	Error	χ^2	$Pr > \chi^2$	Odds Ratio (95% CI)
Intercept	1	1.00	0.09	116.70	<0.001	
Concurrent vs PLGI	1	-0.18	0.10	3.05	0.08	0.84 (0.69, 1.02)
Historical vs PLGI	1	-0.75	0.07	105.74	<0.001	0.47 (0.41, 0.54)
Male vs Female	1	-0.51	0.08	44.40	<0.001	0.60 (0.52, 0.7)
Hispanic vs White	1	-0.08	0.08	0.95	0.33	0.93 (0.79, 1.08)
Asian vs White	1	0.31	0.12	6.98	0.01	1.36 (1.08, 1.71)
Black vs White	1	-0.73	0.11	41.26	<0.001	0.48 (0.39, 0.6)

Table 3. Parameter estimate results from the reduced model for Engineering Calculus I.

Discussion

The results presented here are based on an intervention affecting a very large number of students (2609 students in Life Sciences and Engineering Calculus I). These results suggest that our implementation of PLGI had a substantial positive impact on pass and retention rates in both classes. The increase in pass rates is on the order of 4 to 8%, and the decrease in withdrawal rates is on the order of 1 to 5%, depending on the type of calculus class taken. The evidence of the impact of the PLGI intervention is especially strong because our research design includes historical and concurrent comparisons as well as an examination of SAT math scores. We conclude that PLGI may be a useful intervention for improving outcomes in calculus instruction. It might be worthwhile to evaluate the effect of PLGI in other kinds of mathematics and science instruction at a variety of institutions.

The model selection procedure does not show any evidence of an interaction effect involving sex or race/ethnicity. We suspect, however, that a study designed specifically to study this issue might reveal such interactions. For example, in Figure 7, a higher percentage of Asian students passed Engineering Calculus I in the concurrent non-PLGI group than those in the PLGI group, while 17% more black students in the PLGI group passed versus those in the concurrent non-PLGI group.

The results from the student surveys (Table 4) suggest that students may not always recognize the positive effects of interventions of this type. Indeed, there is evidence from other studies that many students are resistant to inquiry-based learning interventions (Brickman, Gormally, Armstrong, & Hallar, 2009). Despite the push back from students, support was garnered from faculty and administration in developing first day activities to encourage student buy-in and in integrating peer leading with the instructors' curriculum. Continuing to work on buy-in from students and integration of curriculum seems key to the future success of the peer leader program.

The present study does have some limitations. Instructors were not randomly assigned to PLGI or concurrent non-PLGI sections. In addition, at the time of the peer leading intervention, the department also initiated additional tutoring opportunities targeting calculus I students, which might contribute to the improvement in pass and retention rates over historical controls. Moreover, USF began raising its admission standards in 2009. We are thus not able to conclude that PLGI was the only factor that led to improved outcomes as compared with historical sections. On the other hand, since students in PLGI sections showed substantial improvement (in multiple measures) even as compared with concurrent non-PLGI sections, the data strongly suggest a positive effect of PLGI.

There were several challenges that the study team faced in implementing the PLGI intervention, such as student resistance to an inquiry-based curriculum, faculty

Questions	% Yes	% Yes
	Life Sciences Calculus	Engineering Calculus
1. Did you feel like you benefited from the peer leading sessions?	58.3	46.7
2. Would you rather have had a lecture hour instead of the peer leading session?	46.2	57.9
3. If you took another calculus course, would you take it with* or without* the sessions?	46.7	34.7
4. Would you attend the peer leading sessions if they were only supplemental/voluntary?	49.3	40.5
5. Did working in groups help you learn calculus?	57.3	55.4
6. Did the lab worksheets help you learn calculus?	48.2	43.0
7. Would you recommend your peer leaders be asked to continue next semester?	90.3	55.4
*"Yes" corresponds to answering "with."		

Table 4. Survey questions and results for students enrolled in peer leading

resistance to losing an hour of lecture to the undergraduate peer leaders, difficulty coordinating a large number of sections of calculus, and the time needed to develop curriculum and train peer leaders and graduate students. It was thus crucial to have administrative support both at the department and college levels.

Although the study team is planning to examine the effect of the PLGI intervention on student retention in follow-up STEM courses, there are many questions that would be valuable to examine further. These include the differences of the effect of this type of curriculum on minority groups, and the effect of instructor selection or other biases. This study did not address student learning of particular mathematical concepts. It might be useful to examine the difference between the implementation of this guided-inquiry curriculum when undergraduate peer leaders are used in the classroom versus having the activities implemented by faculty. Finally, we speculate that the experience of peer leading might have substantial effects on those students' mastery of the relevant mathematics, and it might be valuable to examine this hypothesis.

The experience of working with highly talented undergraduate peer leaders was extremely rewarding for the faculty members involved in the project. The development of the curriculum materials used in the classroom as well as the training materials used once a week in the peer leader training was done in cooperation with faculty, graduate students, and undergraduate peer leaders, and thus, provided a kind of "vertical integration" that was exciting for all the participants in the project.

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References

Bangert-Drowns, R. L., Hurley, M. M., & Wilkinson, B. (2004). The Effects of School-Based Writing-to-Learn Interventions on Academic Achievement: A Meta-Analysis. *Review of Educational Research, 74*(1), 29-58.

Borman, G. D., Hewes, G. M., Overman, L. T., & Brown, S. (2003). Comprehensive School Reform and Achievement: A Meta-Analysis. *Review of Educational Research, 73*(2), 125-230.

Bressoud, D. M., Carlson, M. P., Pearson, J. M., & Rasmussen, C. (2012). *Preliminary Results of the Study of Characteristics of Successful Program in College Calculus.* Paper presented at the 12th International Congress on Mathematics Education, Seoul, Korea.

Brickman, P., Gormally, C., Armstrong, N., & Hallar, B. (2009). Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. *International Journal for the Scholarship of Teaching & Learning, 3*(2).

Darken, B., Wynegar, R., & Kuhn, S. (2000). Evaluating Calculus Reform: A Review and a Longitudinal Study. In A. S. E. Dubinsky, and J. Kaput (Ed.), *Research in Collegiate Mathematics Education IV*: American Mathematical Society and Mathematical Association of America.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: a meta-analysis. *Learning and Instruction, 13*(5), 533-568.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A Guided-Inquiry General Chemistry Course. *Journal of Chemical Education, 76*(4), 570. doi: 10.1021/ed076p570

Gellene, G. I., & Bentley, A. B. (2005). A Six-Year Study of the Effects of a Remedial Course in the Chemistry Curriculum. *Journal of Chemical Education, 82*(1), 125. doi: 10.1021/ed082p125

Hattie, J., Biggs, J., & Purdie, N. (1996). Effects of Learning Skills Interventions on Student Learning: A Meta-Analysis. *Review of Educational Research, 66*(2), 99-136.

Hayes, R. Q. (2002). 2001-02 STEM retention report: The retention and graduation rates of 1994-2000 freshman cohorts entering science, technology, engineering and mathematics majors in 200 colleges and universities. Norman OK: Consortium for Student Retention Data Exchange.

Hein, S. M. (2012). Positive Impacts Using POGIL in Organic Chemistry. *Journal of Chemical Education*. doi: 10.1021/ed100217v

Hinde, R. J., & Kovac, J. (2001). Student Active Learning Methods in Physical Chemistry. *Journal of Chemical Education, 78*(1), 93. doi: 10.1021/ed078p93

Khoumsi, A., & Hadjou, B. (2005). Learning Probabilities in Computer Engineering by Using a Competency - and Problem-Based Approach. *Journal of STEM Education, 6*(3 & 4), 5-13.

Kogan, M., & Laursen, S. L. (2014). Assessing long-term effects of inquiry-based learning: A case study from college mathematics. *Innovative higher education, 39*(3), 183-199.

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action (Congressional Research Service Reports, Order Code RL33434)*. Washington, DC: Congressional Research Service.

Lewis, S. E., & Lewis, J. E. (2005). Departing from lectures: an evaluation of a peer-led guided inquiry alternative. *Journal of Chemical Education, 82*(1), 135-139.

Lewis, S. E., & Lewis, J. E. (2008). Seeking effectiveness and equity in a large college chemistry course: an HLM investigation of Peer-Led Guided Inquiry. *Journal of Research in Science Teaching, 45*(7), 794-811. doi: 10.1002/tea.20254

Lou, Y., Abrami, P. C., & d'Apollonia, S. (2001). Small Group and Individual Learning with Technology: A Meta-Analysis. *Review of Educational Research, 71*(3), 449-521.

Moog, R. S., & Spencer, J. N. (2008). *Process oriented guided inquiry learning (POGIL):* Oxford University Press, USA.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). Before it's too late: A report to the nation from the national commission on mathematics and science teaching for the 21st century. from http://www.ptec.org/items/detail.cfm?ID=4059

Peters, A. W. (2005). Teaching Biochemistry at a Minority-Serving Institution: An Evaluation of the Role of Collaborative Learning as a Tool for Science Mastery. *Journal of Chemical Education, 82*(4), 571. doi: 10.1021/ed082p571

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis. *Review of Educational Research, 69*(1), 21-51.

Straumanis, A., Beneteau, C., Guadarrama, Z., Guerra, J., & Lenz, L. (2013). *Calculus I – A Guided Inquiry*: Wiley.

Tien, L. T., Roth, V., & Kampmeier, J. A. (2002). Implementation of a peer-led team learning instructional approach in an undergraduate organic chemistry course. *Journal of Research in Science Teaching, 39*(7), 606-632. doi: 10.1002/tea.10038

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