JOURNAL OF CHEMICAL EDUCATION
Article
pubs.acs.org/jchemeduc

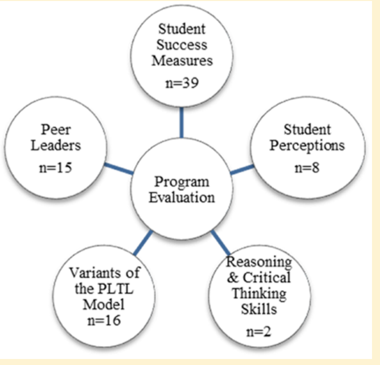
Small Groups, Significant Impact: A Review of Peer-Led Team Learning Research with Implications for STEM Education Researchers and Faculty

Sarah Beth Wilson[†] and Pratibha Varma-Nelson[*,‡,§]

[†]Department of Chemistry and Biochemistry, Rose-Hulman Institute of Technology, Terre Haute, Indiana 47803, United States
[‡]Department of Chemistry and Chemical Biology, Indiana University-Purdue University Indianapolis, Indianapolis, Indiana 46202, United States
[§]STEM Education Innovation and Research Institute (SEIRI), Indiana University-Purdue University Indianapolis, Indianapolis, Indiana 46202, United States

Supporting Information

ABSTRACT: Peer-led team learning (PLTL) research has expanded from its roots in program evaluation of student success measures in Workshop Chemistry to a spectrum of research questions and qualitative, quantitative, and mixed methods study approaches. In order to develop recommendations for PLTL research and propose best practices for faculty who will integrate PLTL in their classrooms, the theoretical frameworks, study designs, results, and limitations of sixty-seven peer-reviewed studies, spanning a variety of STEM disciplines and institution types, were examined. Five program evaluation themes emerged from this synthesis of the literature: student success measures; student perceptions; reasoning and critical thinking skills; research on peer leaders; and variants of the PLTL model. For each of the themes, areas for future study and implications for practice are suggested to STEM discipline-based education researchers and faculty.



KEYWORDS: *First-Year Undergraduate/General, Second-Year Undergraduate, Philosophy, Collaborative/Cooperative Learning, Distance Learning, Constructivism*

INTRODUCTION

In the recommended peer-led team learning (PLTL) model, groups of approximately eight students are guided by a trained peer leader to collaboratively solve problems for 90−120 min each week.[1] The peer leaders are usually recent completers of the course who have demonstrated interest in helping others learn, have exemplary communication skills, and adeptness in the subject matter. Compensation for peer leaders has ranged from modest salaries or college credit to promises of meaningful recommendation letters, depending on the culture of the implementing institution.[2] Additionally, PLTL workshops being an integral part of the course have usually been interpreted as being a requirement of the course and a complement to the lecture. Although not intended to be implemented as a remedial program,[3] several studies have reported PLTL's unique effectiveness for females, underrepresented minorities (URM), and under-prepared students.[4−9]

HISTORY

Beginning in 1991, small, peer-led groups were formed for collaborative problem-solving within a large-enrollment general chemistry course at the City College of New York.[1,2,10,11] Given the initial promising results, the National Science Foundation (NSF) funded the development of these peer-led workshops in general chemistry (Table 1). Then, a Workshop Chemistry Curriculum Planning Grant was awarded to Gosser and Weiner. One year later, Gosser, Radel, and Weiner were granted a $1.6 M continuing grant by NSF-DUE as part of the Systemic Change Initiative to partner with ten senior and community colleges at the City University of New York as well as the Universities of Pittsburgh and Pennsylvania to continue the development of Workshop Chemistry curriculum for chemistry courses. Development of the pedagogy was extended to include a first-semester organic chemistry course at the University of Rochester as well as sophomore organic (both semesters) and general, organic, and biochemistry (GOB) courses at St. Xavier University.[2] Shortly thereafter, Workshop Chemistry was renamed as Peer-Led Team Learning (PLTL).

Early PLTL publications reported improvements in students' course grades and enthusiasm for learning,[1,10] which led to interest in disseminating the pedagogy more widely. In 1999, the National Science Foundation funded the PLTL project to disseminate the methodology across Science, Technology,

Received: October 29, 2015
Revised: July 1, 2016
Published: August 10, 2016

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 1. Summary of Peer-Led Team Learning Grants from the National Science Foundation-Division of Undergraduate Education[a]

Dates	Project #	Title	Objective
8/1991 − 7/1994	9150842	Development of Peer Problem Solving in General Chemistry	Development of Workshop Chemistry model
1/1994 − 6/1995	9450627	A Workshop Chemistry Curriculum	Redesign of the undergraduate chemistry curriculum at City College of NY and partner community colleges to incorporate Workshop Chemistry
5/1995 − 4/2001	9455920	A Workshop Chemistry Curriculum	Expand and refine the Workshop model for a broad range of chemistry courses and perform evaluation for a consortium of institutions
9/1997 − 1/2005	9972457	Peer-Led Team Learning: National Dissemination by the Workshop Project	National dissemination of PLTL model to 5 STEM disciplines
9/2000 − 1/2005	0004159	Peer-Led Team Learning: National Dissemination by the Workshop Project	Prepare WPAs for dissemination activities, particularly targeting two-year colleges
2/2003 − 7/2007	0231349	PLTL National Dissemination: Building a National Network	Consolidating the informal PLTL network and engaging this faculty fully in the national dissemination effort
9/2001 − 2/2005	0196527	Strategies to Promote Active Learning in Chemistry Courses: Multi-Initiative Dissemination Workshops	Multi-Initiative Dissemination (MID) project for PLTL, Chem Connections, Molecular Science, and New Traditions
12/2010−11/2015	0941978	Cyber PLTL (cPLTL): Development, Implementation, and Evaluation	Development, implementation, and evaluation of cPLTL

[a]The National Science Foundation Division of Undergraduate Education (NSF-DUE) provides grants in order to promote excellence in undergraduate science, technology, engineering, and mathematics.

Engineering, and Mathematics (STEM) disciplines nationally, which included a variety of national dissemination strategies and created the Workshop Project Associate small grants initiative. The PLTL project team was also awarded supplementary funding for dissemination to two-year colleges. Similarly, a grant was funded in 2003 in order to provide inspiration, instruction, support, and mini-grants to strengthen the PLTL national network across science, technology, engineering, and mathematics (STEM) courses[2] as well as economics.[14] Additionally, PLTL dissemination was funded through the Multi-Initiative Dissemination (MID) Project.

While most of the implementations of PLTL were as a complement to the lecture, the PLTL pedagogy was also integrated into the Center for Authentic Science Practice in Education (CASPiE) project, an initiative to develop laboratory modules to provide undergraduates with authentic research experiences, including guidance from peers as they pursue research-based projects.[15] At last estimate, PLTL has been implemented at more than 150 institutions in the United States, from two-year community colleges to large research universities.[2] Additionally, faculty in Australia, China, India, and Turkey have consulted with Dr. Varma-Nelson to implement PLTL (P. Varma-Nelson, personal communication, January 28, 2016). Thus, the original funding from NSF facilitated the formation of an autocatalytic community of STEM faculty that have contributed to the large and continuously growing body of PLTL literature, including: a guidebook[16] and a suite of manuals[17−21] which were written to provide examples of workshop problems for a variety of chemistry courses; recommendations for training peer leaders; and responses to frequently asked questions.

The early developers of the PLTL model evaluated the program using a mixed methods design which included course grade comparisons, surveys, interviews, and focus groups of faculty and students. Six "critical components" emerged (ref 17, p 4):

- Faculty involvement. The faculty members teaching the course are closely involved with the workshops and the training of workshop leaders.
- Integral to the course. The workshops are an essential feature of the course.
- Leader selection and training. The workshop leaders are carefully selected, well-trained, and closely supervised, with attention to knowledge of the discipline and teaching/learning techniques for small groups.
- Appropriate materials. The workshop materials are challenging, intended to encourage active learning and to work well in collaborative learning groups.
- Appropriate organizational arrangements. The particulars, including the size of the group, space, time, noise level, etc., are structured to promote group activity and learning.
- Administrative support. Workshops are supported by the department and the institution as indicated by funding, recognition, and rewards.

■ THEORETICAL FRAMEWORKS

PLTL is informed by at least two theoretical frameworks: social constructivism and equity. Constructivism is a theoretical framework which asserts that people actively develop concepts and models in order to make sense of their surroundings and experiences, rather than discover existing knowledge,[22−24] thus, "knowledge is constructed in the mind of the learner."[25] This knowledge construction process is aided through social interactions.[26] In particular, both the discussion of different processes of solving problems as well as the debate about interpretation of data are socio-collaborative tasks in which participants construct meaning during their group interactions[26] as "they practice constructing, negotiating, evaluating, and defending their understanding."[27] Moreover, the fundamental rationale for utilizing peer leaders as facilitators of group work is to establish the dynamic of slightly more advanced learners scaffolding the education of novices. The realm of conceptual understanding that students can attain with support from a more knowledgeable other, such as a peer leader, is known as the zone of proximal development (ZPD).[24] Nevertheless, peer leaders also serve as role models, not just facilitators, during PLTL workshops. Social learning theory suggests that individuals observe the conduct and outcomes of

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

role models, then expect similar results if they emulate the role model's behaviors,[28,29] such as career planning and practicing discipline-specific skills.[30] The ideal role model is one who is slightly older and more advanced in that field for the role model's achievements to seem most relevant and attainable for the student.[30,31] For PLTL students, peer leaders serve as intellectual and social role models[32] who have succeeded in their institutional culture as well as the particular course.[33] Furthermore, several studies have suggested that same-gender mentors, such as peer leaders, are particularly impactful for female students in STEM disciplines.[34,35] Likewise, URM role models create a more welcoming academic culture in which other students see academic success and leadership roles as attainable.[36,37] Lastly, the workshop materials must include creative, nonalgorithmic problems which are structured to be challenging for the students within the students' ZPD.[38]

The other theoretical foundation by which PLTL researchers are commonly guided is equity, which Lynch[39] parsed into three constructs: equity of outputs; equity of inputs; and equity as fairness. Equity of outputs refers to a situation in which the demographics or background of successful students is analogous to the demographics or background of the overall student population.[39,40] PLTL's differential effectiveness for females and underrepresented minorities can be classified as an equity of output initiative since the intervention has been demonstrated as a means to begin closing the achievement gap.[41] Equity of inputs is the situation in which all students are granted equal opportunity to educational resources.[39,41] Female and minority peer leaders can be classified as equity of inputs because several studies have reported that peer leaders attribute gains in content learning,[42,43] and critical thinking skills.[6] Therefore, students of different demographic backgrounds should be given the opportunity to benefit from PLTL leadership roles. Thus, PLTL can be classified as an equity of input initiative[39] because peer leaders of various ethnicities and genders are employed as role models.[41] Lastly, equity as fairness refers to the balancing act between meeting the needs of some students and determining the appropriate costs to other students by making "trade-offs in staffing patterns, class, size, and expenditure of funds".[39] This balancing act was acknowledged in the "critical components" as administrative support and is addressed each time an institution decides to implement PLTL.

■ PURPOSE

The purpose of this review is to synthesize the research designs and findings (See Supporting Information: Tabular Summary of Peer-Led Team Learning Research Literature) in the context of various settings and disciplines in order to propose areas for further PLTL research and best practices for faculty who will integrate PLTL in their classrooms. This work is an extension of Gafney and Varma-Nelson's[41] review of the evaluation, dissemination, and institutionalization of PLTL as many more institutions have now implemented PLTL. Moreover, PLTL research has blossomed over the last several years; this body of literature spans several discipline-based education research (DBER) fields. Therefore, cross-disciplinary recommendations for discipline-based education researchers and STEM faculty are proposed.

■ SAMPLING

Peer-reviewed work published from the time of the 2008 James Flack Award Address[2] through December 2015 is featured in this review. While there is a monograph[11] published since 2008, an examination of the Web site of the publisher did not indicate a rigorous peer-review as part of the publication process. This review is broader and includes peer-reviewed studies since 2008. The search protocol included: (1) accessing the databases Scopus, Science Direct, Institute of Electrical and Electronics Engineers (IEEE) Xplore, PsycArticles, PsycINFO 1887-current (EBSCO), Journal Storage (JSTOR), Papers on Engineering Education Repository (PEER), Educational Resources Information Center (ERIC) Proquest, and ERIC (EBSCO); (2) searching individual discipline-based education research (DBER) journals; and (3) performing citation searches in Google Scholar of articles obtained through the other search mechanisms. Qualitative, quantitative, and mixed methods studies were all included in this review, as long as the articles reported methodology, analysis techniques, and findings. Executive summaries (a.k.a. white papers) and articles that were anecdotal in nature are excluded from this analysis.

Overall, 67 studies (36 quantitative; 12 qualitative; and 19 mixed methods) from a variety of STEM education journals were identified for inclusion in this review, including: *Journal of Chemical Education*; *Journal of Research in Science Teaching*; *Chemistry Education Research and Practice*; *Journal of College Science Teaching*; *The Chemical Educator*; *International Journal of Instructional Research*; *International Journal of Science Education*; *International Journal of Teaching and Learning*; *International Journal of Science and Mathematics Education*; *International Journal of Learning, Teaching, and Education Research*; *Australian Journal of Education in Chemistry*; and others. Some of the PLTL studies contributed to more than one theme, so the sum of the *n*'s indicated in the abstract figure is greater than the total number of studies. Typically, conference proceedings in areas of chemistry are not reviewed and, therefore, are not included in a literature review. However, outside of chemistry, this situation can be different. Conference proceedings from the Special Interest Group on Computer Science Education (SIGCSE) conferences were included in this review because those manuscripts undergo a rigorous, blind peer-review process.[12] Likewise, conference proceedings from the American Society for Engineering Education (ASEE) Frontiers in Education are included in this review because the research proceedings are reviewed using a comprehensive rubric prior to publication.[13]

■ OUTLINE OF THE REVIEW

The PLTL literature can be categorized into five themes: student success measures; student perceptions; reasoning and critical thinking skills; research on peer leaders; and variants of the traditional PLTL model. Implications of these findings are enumerated for STEM education researchers and faculty.

■ STUDENT SUCCESS MEASURES AS A MEANS OF PROGRAM EVALUATION

PLTL student success measures were evaluated in a variety of undergraduate disciplines, including: general chemistry;[3,7,44−53] organic chemistry;[54−57] allied health, which is also called GOB;[58] introductory biology;[4,59] anatomy and physiology;[60] bioinformatics;[61] mathematics;[62−66] computer science;[8,67−71] engineering;[72−75] psychology;[76] and physics.[51] Although

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 2. Factors which Studies Presented as Indicators of Student Success

Study Authors with Reference Numbers	Mean Course Grade	Pass Rate (% ABC)	DFW Rate	First-Semester ACS Exam Scores	Semester Exam Grades	Retention	Discipline[a]
Akinyele[58]			*				G.O.B.
Alger and Bahi[44]				*			Chem.
Alo et al.[69]		*		N/A			C.S.
Amstutz, Wimbush, and Snyder[82]	*			N/A			Anim. Sci.
Báez-Galib et al.[104]		*					Chem.
Biggers et al.[67]		*		N/A			C.S.
Chan and Bauer[45]				*	*		Chem.
Curran et al.[94]				N/A	*		Math
Drane et al.[4]	*					*	Bio., Chem., Phys.
Drane, Micari, and Light[89]	*					*	Bio., Chem., Math, Phys., Eng.
Finn and Campisi[60]				N/A	*		Bio.
Flores et al.[65]		*		N/A			Phys., Chem., Math
Foroudastan[73]				N/A		*	Eng.
Hockings, DeAngelis, and Frey[46]	*					*	Chem.
Hooker[86]		*		N/A		*	Math
Horwitz and Rodger[8]	*	*		N/A		*	C.S.
Lewis[7]		*		*		*	Chem.
Lewis[52]						*	Chem.
Loui et al.[88]				N/A	*	*	Eng.
Lyle and Robinson[57]	*				*		Chem.
Mauser et al.[48]	*		*	*			Chem.
Merkel and Brania[66]		*		N/A		*	Math
Mitchell, Ippolito and Lewis[49]	*	*		*		*	Chem.
Mottley and Roth[74]	*			N/A			Eng.
Pazos et al.[75]				N/A		*	Eng.
Peteroy-Kelly[59]	*			N/A	*		Bio.
Rein and Brookes[54]	*						Chem.
Reisel et al.[62]	*			N/A			Math
Reisel et al.[64]	*			N/A			Math
Reisel et al.[63]	*			N/A			Math
Roach and Villa[70]				N/A		*	C.S.
Shields et al.[53]	*						Chem.
Smith et al.[50]	*		*	*			Chem.
Snyder, Carter, and Wiles[81]	*	*		N/A	*		Bio.
Stewart, Amar, and Bruce[3]		*	*			*	Chem.
Tenney and Houck[80]	*	*					Bio., Chem.
Tien, Roth, and Kampmeier[55]	*	*					Chem.
Wamser[56]		*		*			Chem.
White, Rowland, and Pesis-Katz[14]	*			N/A			Nurs.

[a]Discipline abbreviations: Anim. Sci. = Animal Science; Bio. = Biology; Chem. = Chemistry; C.S. = Computer Science; Eng = Engineering; G.O.B. = General, Organic, and Biochemistry; Nurs. = Nursing; and Phys. = Physics.

implementation of PLTL has been reported in a high school setting,[77] no peer-reviewed articles were available at the time of this review article. Lastly, there is one PLTL program assessment study evaluating a graduate-level nursing course.[14]

A meta-analysis of the student success as a measure of program evaluation studies was not performed for this review article because effect size measures were not reported in 69% of the student success studies. Specifically, Hedges' g[78] was not reported for any evaluation parameter in any of the studies and Cohen's d was only reported for 31% of the studies. Hedges' g is an alternative effect size calculation (difference in means divided by the standard deviation) which is similar to Cohen's d for enabling comparison across studies, but Hedges' g calculation includes a correction factor for small population sizes.[79]

Course Grades

The most common factor reported as a measure of student success, course grades, were reported by fifty-three percent of the program evaluation research studies (Table 2). PLTL students' course grades were statistically higher than non-PLTL students' course grades in 13 of these studies.[3,7,8,46,49,53,57,59,80−83] In 12 of these studies, participation in the weekly PLTL workshops was mandatory for students in the program, peer leaders were trained weekly by the professor and/or a learning specialist, and the professors were involved in workshop material development, although in the Hockings, DeAngelis, and Frey,[84] Mitchell, Ippolito, and Lewis,[49] and Shields et al.[53] studies, attendance was mandatory once the students elected to participate in the program. Although PLTL

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

participation was voluntary in the Stewart, Amar, and Bruce study,[3] they controlled for high school rank, SAT scores, and GPA while assessing the correlation between attendance and course grade in addition to maintaining all other standard implementation practices. The workshop durations in these 13 studies ranged from 50 min[7,49] to 2 h.[3,8,50,53,57,84] Even though in the literature it has been suggested that workshop durations be between 90 and 120 min in order to provide adequate time for students to discuss the concepts behind the workshop problems deeply,[41] Gafney reported his findings:[85] *We observed a strong correlation between the length of the Workshop session and the nature of the Workshop activities. As the length of the Workshop increases, time spent on question-and-answer work decreases and the time spent on group activity increases. This correlation needs to be tested over a larger number of sites. However, the preliminary data suggest that short Workshops should severely limit the number of Workshop problems in order to preserve time for interactive discussion and debate.*

Therefore, having too many questions assigned for a 50 min workshop would lead to peer leaders feeling pressured to merely make sure students had answers to problems.[85] Consequently, if the workshops have a shorter duration, as in the Lewis[7] and Mitchell, Ippolito, and Lewis[49] studies, it is recommended that the problem sets be small enough for the students to discuss concepts in depth. Since Lewis and Mitchell, Ippolito, and Lewis studies reported significant improvement in student learning after implementing 50 min workshops, it would be valuable to see both the problems they utilized and the activities facilitated in order to engage students to get the increased mean course grades in the shortened duration. While in the PLTL literature it is recommended that the appropriate workshop duration was 90−120 min,[16] there appears to be more room for flexibility.

Both Drane et al.[4] and Chan and Bauer[45] studies reported no significant difference in course grades for PLTL and non-PLTL students, but it should be noted that students' participation in PLTL was optional in both studies. Drane et al.[4] reported no significant difference in course grades for physics PLTL students, but (1) the group size was 10−12 students per peer leader, which is larger than recommended 8−10 students per peer leader, and (2) the workshops were not offered weekly (6 workshops in 10 weeks). Since Mitchell, Ippolito, and Lewis[49] (10−16 students per peer leader), Reisel et al. (6−12 students per peer leader),[62−64] and Tenney and Houck[80] (10−12 students per peer leader) reported significantly higher % ABC rates for PLTL students than non-PLTL students even though the recommended 8−10 students per peer leader ratio was exceeded, it appears that the slightly higher group size in Drane et al.'s[51] physics PLTL was not the root cause of lack of significant differences in PLTL and non-PLTL students' grades. Perhaps if the physics PLTL students had enough consistent involvement in their groups to fully realize the benefits of involvement in a community of learners who reflect on their learning, negotiate meaning, and develop a common toolkit of strategies which Tien, Roth, and Kampmeier[55] reported as benefits to PLTL involvement. Chan and Bauer's study[45] compared the grades of PLTL students with those of non-PLTL students who had opted to participate in an equal number of hours of other educational opportunities, such as self-organized study groups; instructor-led review sessions; drop-in tutorials; or instructor office hours. It is not clear if the lack of significant difference in grades stems from comparing PLTL students' grades to a collective of student grades from those who were involved in a "social knowledge construction"[45] settings, as PLTL would be classified, and students who participated in tutoring. Instead, it would be interesting to compare the PLTL students' performance to the performance of students in each of the other interventions. In conclusion, research indicates that when PLTL is designed to encourage the consistent participation of small student groups involved in a social constructivist task, there is a significant, improvement in student performance, as measured by course grades.

In addition to or in lieu of reporting the comparison of mean course grades for PLTL and non-PLTL students, 18 studies reported % ABC (also known as pass rate) and/or % DFW rate, which enumerates students who withdrew from the course or earned grades of D or F. Mitchell, Ippolito, and Lewis;[49] Wamser;[56] Tien, Roth, and Kampmeier;[55] Tenney and Houck;[80] Akinyele;[58] Biggers;[67] Stewart, Amar, and Bruce;[3] and Horwitz[8] reported significantly higher pass rates for PLTL students. Although the Alo et al. study[69] of implementation of PLTL in various Computing Alliance of Hispanic Serving Institutions (CA-HSI) partners did not include statistical analysis of differences in pass rates for PLTL and historical non-PLTL students, they reported a 60% increase in ABC grades for University of Houston Downtown college algebra PLTL students as compared to historical non-PLTL course grades. Additionally, they reported improvement in the pass rates of both computer science I (18%) and computer science III (29%) at the University of Texas at El Paso (UTEP).[69] There was no improvement in UTEP's PLTL computer science II pass rates during the same time period. Tenney and Houck[80] and Mottley and Roth[74] reported positive correlations between introductory PLTL workshop attendance and course grades. A positive correlation between workshop attendance and course grades had also been reported by Wedegaertner and Garmon in Gafney and Varma-Nelson's book (ref 41, p 19−20). Hooker[86] reported that there was a higher percentage of students with ABC grades, but the difference for the small populations did not reach statistical significance. Finn and Campisi[60] reported statistically significant improvement on a tissues/muscle physiology unit and a partial effect in terminology/cells unit, and no effect in other anatomy and physiology topics, suggesting that PLTL may be more effective for certain question styles, as discussed later.

Since workshop session durations among the Mitchell, Ippolito, and Lewis;[49] Wamser;[56] Tien, Roth, and Kampmeier;[55] Tenney and Houck;[80] Akinyele;[58] Biggers;[67] and Horwitz[8] studies who reported significantly higher pass rates for PLTL students ranged from 50 min to 2 h, their cumulative results again suggest that the duration of workshops may be a flexible parameter of workshop implementation. Lastly, Merkel and Brania[66] reported no significant difference in PLTL and non-PLTL grade distributions, although they suggested that the variability of commitment of peer leaders and shortened duration of workshops may have been factors. These program evaluation studies indicate that there is a positive correlation between consistent workshop attendance and increased proportion of students earning A, B, or C grades when facilitated by reliable peer leaders.

American Chemical Society Exam Scores

Thirty-five percent of the chemistry program assessment studies measured student success on a nationally normed American Chemical Society (ACS) First-Semester Chemistry Exam. Lewis[7] reported that PLTL students earned significantly

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

higher ACS exam score percentages than traditional students, despite comparable SAT scores. Alger and Bahi[44] reported that there was no significant difference in PLTL and non-PLTL students' performance on an ACS exam, but the study included a comparison of two different academic interventions instead of implementing a standard control study design. Wamser[54] reported that PLTL students' ACS exam scores were in the 77th percentile, while the historical non-PLTL students' ACS exam scores were in the 69th percentile. Mitchell, Ippolito, and Lewis[49] reported that PLTL and non-PLTL students in first- and second-semester general chemistry courses earned comparable ACS exam scores. Chan and Bauer[45] also reported no significant difference in PLTL students' ACS exam scores and those of students engaged in a variety of non-PLTL interventions in their randomized, quasi-experimental study.

Chan and Bauer[45] converted the ACS exam scores to Z scores instead of comparing mean ACS exam scores, a key technique if comparing student performance on multiple versions of an exam because it allows the researcher to compare scores from different normal distributions. They found no significant difference between PLTL and non-PLTL students' ACS exam Z scores. This finding, that studies can simultaneously show significant improvement in students' course grades, yet comparable ACS exam scores suggests that there may be a set of skills that are assessed in the calculation of course grades which are not assessed by ACS exams. For example, Smith et al.[50] reported that PLTL general chemistry students discussed problem-solving process only when they had different answers, while cyber Peer-Led Team Learning (cPLTL) general chemistry students were more likely to have a problem-solving focus during the workshops, yet their scores on the ACS exam scores were comparable. Their finding suggests that standardized assessments may not measure important attributes of student development or behavior, such as having a problem-solving mindset. In 2010, Holme et al.[87] reported the development of assessments to measure students' problem-solving, metacognition, and cognitive development, but utilization of these new instruments has not yet been reported in PLTL literature.

Retention in the Course

The least commonly reported measurement of program success in the literature was retention, defined as completing the course with a grade of A, B, C, or D.[3,7,8,51,66,84,86] The creation of small communities of learning in order to increase student retention is often cited as a reason for institutions to implement PLTL.[2] Five of these seven studies reported a statistically significant difference in the retention rate of PLTL students,[3,7,8,46,51] while two studies reported no significant difference in retention rate.[66,86] A difference between the Merkel and Brania[66] study and the studies which report significant differences in retention rate is the duration of the workshop sessions. The calculus I PLTL workshops investigated by Merkel and Brania[66] ranged in duration from 50 to 75 min, while the recommended duration of a PLTL workshop session is 90−120 min in order to provide adequate time "for productive cooperative work and the development of problem-solving skills."[41] Therefore, although several other studies reported significant improvement in student performance when workshop durations were shorter,[5,7,47,49] modifications of this parameter should be monitored. While not statistically significant, Hooker[86] reported a notably higher retention rate of PLTL students than non-PLTL students. Furthermore, the PLTL students provided feedback in the end-of-semester survey that PLTL created interdependent communities of learning for the students in which they felt a sense of belonging (ref 59, p 224). However, measuring student success as completion of a course classifies student who earned a D as being in the same category as those who "successfully" completed a course with an A, B, or C. Therefore, increases in pass rate or % ABC should be considered stronger evidence for PLTL improving student performance than mere course completion.

Retention in a Series of Courses

The alternative definition of retention, students persisting in subsequent courses, was reported in seven studies, which reported either the number of students enrolling in the next course of the curriculum sequence[49,88] or the number of students completing a sequence of courses.[52,70,73,75,89] Pazos et al.[75] reported from their regression analysis that, after adjusting for SAT math score, gender, and ethnicity, engineering students who participated in two or more PLTL workshops during the semester were five times more likely to complete the four-course engineering analysis sequence than students who participated in fewer than two workshops. However, participation in two PLTL workshops per semester would not afford students the consistent involvement in PLTL that would be expected to impact their development of a common toolkit of strategies which Tien, Roth, and Kampmeier[55] had reported as benefits to PLTL involvement. Loui et al.[88] reported a significant relationship between workshop attendance and retention for female PLTL students. Lewis[52] reported a significant impact for general chemistry I PLTL experience and enrollment in general chemistry II and organic chemistry I. Mitchell, Ippolito, and Lewis[49] reported that there was no significant correlation between participation in first-semester general chemistry (GC1) PLTL and enrollment in second-semester general chemistry (GC2). However, the statistically significant increase in pass rate of GC1 PLTL students compared to GC1 non-PLTL students coupled with the pass rate of GC2 PLTL students being 16% higher than GC2 non-PLTL students led to an important difference in the retention of students in the chemistry course sequence at their institution, even though GC1 PLTL and GC1 non-PLTL students were equally likely to enroll in GC2. Lastly, Drane, Micari, and Light[89] reported that workshop participants were significantly more likely to complete their course sequence in three of four disciplines (biology, chemistry, and organic chemistry, but not engineering analysis) than nonparticipants. While longitudinal studies can be more complicated, retention in a series of courses is an area requiring more future studies to assess the impact of PLTL on students' long-term success.

■ REASONING AND CRITICAL THINKING AS A MEANS OF PROGRAM EVALUATION

There are two studies in which PLTL participation was evaluated for its impact on reasoning or critical thinking skills, both of which reported positive relationships with PLTL participation. Peteroy-Kelly[59] suggested that the use of concept mapping was a proxy for conceptual reasoning because concept mapping required greater metacognitive reflection than paragraph writing.[90] Therefore, concept mapping is an indication of enhanced reasoning skills. Furthermore, Peteroy-Kelly[59] reported PLTL students' statistically significant increase in (1) semester exam scores; (2) final exam scores; (3) course grades; and (4) post-test use of concept maps to communicate

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 3. Summary of Student Perceptions Studies

Study Authors with Reference Numbers	Findings
Chan and Bauer[45]	(1) No sig. difference in performance or chemistry self-concept between PLTL and non-PLTL populations; (2) Significant, but modest decrease in chemistry perceptions, but no difference between PLTL and non-PLTL populations
Curran, Carlson, and Celotta[94]	Significantly lower perceived difficulty of statistics course for PLTL students
Finn and Campisi[60]	> 70% of students positively evaluated the learning gains of PLTL
Horwitz and Rodger[8]	Significantly lower perception of instructor covering material too quickly for PLTL students compared to non-PLTL students
Loui, Robbins, Johnson, and Venkatesan[88]	PLTL students reported better understanding of course material
Peteroy-Kelly[59]	(1) 65% of students agreed or strongly agreed that participation in PLTL increased their understanding of biology concepts and the relationships between concepts; (2) 52% of students agreed or strongly agreed that participation in PLTL improved their ability to think logically and sequentially through a biology problem or argument.
Tien, Roth, and Kampmeier[55]	PLTL students were significantly more likely to credit workshop involvement with increased learning than non-PLTL students perception of recitation
White, Rowland, and Paesis-Katz[14]	Students thought PLTL workshops were "pivotal" to (1) Increased content understanding; (2) Increased problem-solving and critical thinking skills; and (3) Decreased course anxiety

relationships between nonscience words. Quitadamo, Brahler, and Crouch[6] utilized the California Critical Thinking Skills Test (CCTST)[91] to assess critical thinking gains. They reported a significant critical thinking gains affiliated with PLTL involvement as well as particularly positive performance and retention gains for females. However, the researchers did not report that they affirmed the reliability and validity of the instrument in their setting prior to using the instrument in their study, as Bauer had done in his chemistry self-concept inventory study.[92] There was only one study of each type, so further research is needed to affirm the reproducibility of findings across settings and disciplines.

■ STUDENT PERCEPTIONS AS A MEANS OF PROGRAM EVALUATION

Three different approaches have been used to assess students' perceptions about the impact of their involvement in PLTL: Student-Assessment of Learning Gains (SALG) survey;[93] content-related self-concept or attitude instruments; and focus group feedback.

Student Self-Assessment of Learning Gains

Since the inception of PLTL, the most common means to measure the students' perceptions of the impact of PLTL involvement has been the SALG survey, developed by Seymour,[93] or modified versions thereof (Table 3). Finn and Campisi[60] reported that over 70 percent of their PLTL students rated their learning gains in PLTL positively. Similarly, Tien, Roth, and Kampmeier[53] reported that PLTL students were significantly more likely to credit PLTL workshop involvement with increased learning than non-PLTL students' perceived learning gains from recitation. Engineering PLTL students in Loui et al's study[88] reported gains in their content understanding, while 65% of the introductory biology students in Peteroy-Kelly's[59] study reported that PLTL participation helped them understand the main concepts (or relationships between concepts) of the course. Computer science PLTL students in the Emerging Scholars Program reported a significantly lower perception than their non-PLTL counterparts that their instructor covered course material too quickly,[8] while over 70% of PLTL students in Curran et al's study[94] reported significantly lower perceived difficulty of their statistics course than the non-PLTL statistics students. These studies suggest that the workshop experiences helped the PLTL students feel that they could learn the course content more effectively at the given pace of instruction.

Some controversy exists in the literature about the reliability of self-reported data. For example, Cook and Campbell[95] related that subjects (a) tend to report what they believe the researcher expects to see, or (b) report what reflects positively on their own abilities, knowledge, beliefs, or opinions. Therefore, participant feedback about their perceived learning gains should be granted less weight than more direct methods to assess differences in self-concept, anxiety levels, reasoning or critical thinking skills, or content understanding.

Attitude and Self-Concept Instruments

Chan and Bauer's[45] study reported no significant difference between PLTL and non-PLTL students' scores on the Attitude to Subject of Chemistry (ASCI),[96] which measures five aspects of student's chemistry-related perceptions, including: interest and utility; anxiety; fear; emotional satisfaction; and intellectual accessibility. Likewise, these researchers reported no significant difference between PLTL and non-PLTL students' scores on the Chemistry Self-Concept Inventory (CSCI),[92] an instrument which measures the degree to which each student views himself or herself as capable in the field of chemistry, science, or academic settings. The researchers interpreted their findings as evidence that students who "take full advantage" of professor-led review sessions, self-assembled group, tutoring sessions, or PLTL are equally benefitted with respect to chemistry attitude or self-concept.[45]

Focus Group Feedback

White, Rowland, and Paesis-Katz[14] performed PLTL program analysis of their graduate-level nursing course as a qualitative study in which student perceptions were gathered through focus group feedback. The researchers reported that students perceived the PLTL workshops as crucial to their content understanding, problem-solving, and critical thinking skills, as well as diminished course anxiety. These findings are aligned with the focus group feedback gathered during the initial evaluation of PLTL.[16,41]

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 4. Summary of Research on Peer Leaders Studies

Study Authors with Reference Numbers	Findings
Amaral and Vala[9]	(1) Mentors earned higher grades in first-semester general chemistry than their counterparts, even if deemed underprepared for the course in the pretest; (2) Mentors took more subsequent chemistry courses and continued to perform higher than nonmentors
Brown, Sawyer, and, Frey[99−101]	(1) Students led by a facilitative leader "acknowledged, built upon, and elaborated on each other's ideas" with equal involvement; (2) In contrast, students with an instructional leader tended to work individually when not listening to the peer leader, be answer-focused, and unequally participate; (3) Student discourse was related to problem structure
Flores et al.[70]	Peer leader graduation rate was 97%, compared to 49% 6-year graduation rate for overall undergraduate population
Gafney and Varma-Nelson[43]	(1) At least 92% of respondents positively rated their peer leading experience for: (a) Appreciation of small-group learning and different learning styles; (b) Gained confidence in presenting and working as a team; (c) Greater appreciation of what it takes to be a teacher; (2) 18% still undergraduates; 43% employed in a science field; 23% in medical or graduate school; 7% teaching; 4% employed in a nonscience field; 3% no response/unemployed
Hug, Thiry, and Tedford[68]	(1) 89 peer leaders over 5 semesters from 6 Computing Alliance for Hispanic Serving Institutions; (2)Peer leaders self-reported significant increases in decision-making skills, facilitation skills, and content knowledge
Johnson, Robbins, and Loui[72]	Peer leader journal entries reflected a transition from content expert focus to seeking effective facilitation techniques as the semester progressed
Murray[76]	PLTL students' perform significantly higher on a statistics and research methods instrument than non-PLTL students
Pazos, Micari, and Light[97]	They developed 10-question scaled protocol to evaluate peer-led group dynamics on two dimensions: Group interaction style and problem-solving approach
Brown, Sawyer, and, Frey[99−101]	(1) Students led by a facilitative leader "acknowledged, built upon, and elaborated on each other's ideas" with equal involvement; (2) In contrast, students with an instructional leader tended to work individually when not listening to the peer leader, be answer-focused, and unequally participate; (3) Student discourse was related to problem structure
Schray et al.[117]	(1) No significant difference in students' course grades, regardless of peer leader type; (2) Surveys suggest that standard peer leaders are more likely to "teach" than in-class peer leaders, but better manage disruptive behavior
Snyder and Wiles[81]	Peer leaders reported perceived gains in (a) Learning from multiple viewpoints; (b) Experiencing new and different approaches to learning
Stewart, Amar, and Bruce[3]	(1) Peer leaders reported increased leadership skills, confidence, and content knowledge; (2) one-third of the peer leaders expressed growing interest in teaching
Tenney and Houck[80]	Notable increase in proportion of chemistry majors' declaring intentions to teach
Tenney and Houck[42]	Peer leaders reflected they benefitted by (a) Better learning content; (b) Collegial relationship with college instructor; (c) Enhanced teaching skills and love of teaching; (d) Improved people skills

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

■ RESEARCH ON PEER LEADERS

Thus far, peer leader research has consisted of two varieties (Table 4): characterization of peer leader behavior and assessing the impact of the PLTL experience on the peer leaders themselves. For example, the Light group at Northwestern University developed an observation protocol to characterize peer leader behavior from their observations of their Gateway Science Program's STEM workshops,[97] which are analogous to PLTL workshops.[98] Using exploratory factor analysis, the researchers determined two factors from their observation survey: group interaction style and problem-solving focus. The two factors, mapped as a two-by-two matrix to generate four types of interaction/problem-solving styles, enabled the research team to hone their observation protocol instrument to ten scalar questions. Likewise, the Light group conducted a pre- and post-semester phenomenographic study[98] to characterize peer leader beliefs and actions as either teacher-centered or learner-centered. The researchers found that nearly half of the peer leaders in their sample who began with teacher-centered style transitioned to a more facilitative, or learner-centered, style as the semester progressed, which coincided with several peer leaders revealing in interviews that they had grown to be more concerned with students' learning growth than transmitting information.

During approximately the same time frame, Brown et al.[99−101] conducted a series of intertwined studies to determine the impact of peer leader style on general chemistry PLTL student discourse. Given identical PLTL materials, the researchers found that students led by a facilitative peer leader "acknowledged, built upon, and elaborated on each other's ideas" with equal involvement.[101] In contrast, students with an instructional peer leader tended to work individually, be answer-focused, and participated unequally. Lastly, the researchers suggested that student discourse was related to problem structure. Namely, the researchers recommended that PLTL problems encourage students to discuss concepts and relevant experiments, not merely utilize equations or formulas.[102] Instructional peer leader behavior can be corrected by training the peer leaders to be facilitative during the weekly peer leader training.

Ten studies have endeavored to assess the effect of PLTL leadership experience on the peer leaders themselves. Johnson, Robbins, and Loui[72] reported that engineering peer leaders' journals revealed a progression from focusing on trying to be content experts to seeking effective facilitation techniques by the end of the semester. Murray[76] reported a significant increase in knowledge of statistics and research methods knowledge of PLTL-trained psychology mentors compared to non-PLTL-trained mentors on a 100-item instrument, although Cronbach's alpha was not reported for the instrument. Six of these studies about the impact of the PLTL experience on peer leaders utilized questionnaires to enable the peer leaders to self-report perceived learning gains.[3,42,43,68,103,104] Tenney and Houck[42] reported that peer leaders attributed greater content learning, exam preparedness, and improved interpersonal skills to their PLTL involvement, while Stewart, Amar, and Bruce[3] reported that peer leaders perceived increases in leadership skills, confidence, and content knowledge. Similarly, Hug, Thiry, and Tedford[68] reported a significant increase in peer leaders' perception of their decision-making skills, facilitation skills, and content knowledge, while Báez-Galib et al.[104] reported peer leaders' perceived gains in content understanding, communication skills, and study habits Furthermore, Gafney and Varma-Nelson[43] described that at least 92% of former peer leader survey respondents positively rated their peer leader experience for appreciation of small-group learning and different learning styles; gained confidence in presenting and working as a team; and a greater appreciation of what it takes to be a teacher. Both current and former peer leaders expressed that they thought their teaching skills were improved by being peer leaders.[42,43,80] In fact, Tenney and Houck[80] credited the influence of PLTL on their academic culture as the reason the institution saw an increase in the percentage of chemistry majors declaring intentions to teach as a career after PLTL implementation because the peer leader experience was so rewarding. Similarly, Stewart, Amar, and Bruce[3] reported that one-third of their peer leaders expressed a growing interest in teaching. Peer leaders reported gains in their content mastery and learning from multiple viewpoints in two studies.[43,103] Although there were no significant changes in overall of subscale scores between peer leaders and qualified nonpeer leaders who were administered the California Critical Thinking Skills Test (CCTST),[103] the CCTST instrument is not content-specific. Furthermore, the researchers reported that peer leaders' pretest mean score was higher than the national average already. Therefore, a STEM-content-specific critical thinking skills assessment would provide a means for assessing the impact of peer leading on the types of critical thinking that are valuable in STEM fields. Snyder and Wiles'[103] finding contrasts the earlier content-specific pretest/post-test PLTL student study which revealed that there was a statistically significant interaction between critical thinking skills and PLTL involvement.[6] In Amaral and Vala's study,[9] students who had been deemed underprepared for a first-semester general chemistry course based on pretest results were enrolled in an introductory chemistry course. A subset of the introductory chemistry students who were later selected to become peer leaders for the introductory chemistry course proceeded to earn higher grades and persist in more subsequent chemistry courses than nonpeer leaders. Therefore, the small community of learning formation, frequent content review, increased confidence, and exposure to different approaches to learning may impact peer leaders in ways that the CCTST does not measure. Gafney and Varma-Nelson[43] stated that nearly 90% of the participants in their study who had earned their undergraduate degree were enrolled in medical or graduate school, employed in a science field, or engaged in teaching. Likewise, Flores et al.[65] reported that the six-year graduation rate for peer leaders of gateway math and science courses for engineers was 48% higher than the overall undergraduate graduation rate (97% vs 49%). However, the comparison of graduation rates of peer leaders and nonpeer leaders with similar academic backgrounds would be more compelling, since peer leaders tend to be excellent students.

■ VARIANTS OF THE PLTL MODEL AS A MEANS OF PROGRAM EVALUATION

Analysis of the literature has revealed five types of PLTL variants of the standard PLTL model: (1) a hybrid of PLTL and process-oriented guided inquiry learning (POGIL), named peer-led guided inquiry (PLGI); (2) online PLTL; (3) PLTL in the chemistry laboratory; (4) utilization of in-class peer leaders instead of recent completers of the course; (5) increased students-to-peer-leader ratio.

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 5. Summary of Peer-Led Guided Inquiry (PLGI) Studies

Study Authors with Reference Numbers	Findings
Lewis and Lewis[107]	(1) PLGI attendance is significantly correlated to higher course exam and final grades; (2) PLGI students performed significantly higher on course and final exams than non-PLGI students, controlling for SAT scores
Lewis and Lewis[40]	(1) Improved performance on the ACS, regardless of student SAT subscores or class SAT average; (2) Neutral impact on students with differing demographics
Kulatunga, Moog, and Lewis[109]	(1) Students are more likely to elaborate on their reasoning when coconstructing arguments in a group rather than making individual arguments; (2) Frequency of constructing individual arguments does not necessarily correlate to a students' course grade
Kulatunga, Moog, and Lewis[112]	(1) Convergent questions lead students to produce higher-level arguments, while students tend to only provide an answer (claim) to direct questions; (2) Students can produce productive discourse with peer leader facilitation when provided prompts to elicit data, warrants, and backing

Peer-Led Guided Inquiry

PLGI (Table 5), is a melding of PLTL with another social constructivist pedagogy: POGIL.[105,106] Lewis and Lewis (2005) reported a significant correlation between PLGI workshop attendance and higher course and final exam grades.[107] Additionally, PLGI students performed significantly higher on the course and final exams than non-PLGI students, controlling for SAT scores, although the pedagogy has neutral differential effectiveness for students with different demographics.[40] This result is particularly important because female or underrepresented minority students could be disadvantaged by a collaborative learning pedagogy if gender- or ethnicity-based stereotypes influence student discussion dynamics.[40,108] In fact, there are no studies which indicate that participation in either PLTL or PLGI is harmful for females or minorities, but there are several PLTL studies that indicate differential effectiveness for females and minorities. Perhaps the rotating assignment of student roles that is an integral part of both POGIL and PLGI[105] deters students from interacting in gender- or ethnicity-based roles within the groups, thus lifting any stereotype-based disadvantages for students.

Next, Kulatunga, Moog, and Lewis[109] reported that students are more likely to elaborate on their reasoning when coconstructing arguments in a PLGI group than when making individual arguments. Their subsequent discourse analysis study of peer leader behavior on students' demonstration of Toulmin's argumentation pattern (TAP) (Figure 1).[110] The researchers reported that convergent questions, which require students' synthesis of given information to create a response,[111] led students to produce higher-level arguments, while direct peer leader questions, which require students to state previously provided information,[111] tended to lead students to merely provide an answer or claim.[112] Thus, the findings from the PLGI studies indicate: (1) the melding of PLTL with POGIL is affiliated with increased student performance and (2) peer leader behavior influences students' participation patterns.

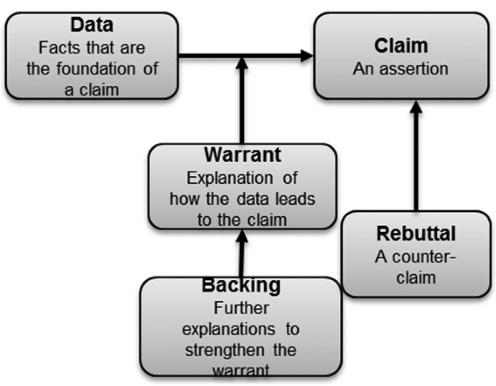


Figure 1. Toulmin's argumentation pattern (TAP).

Online Peer-Led Team Learning

The PLTL literature included two approaches to transition PLTL to an online setting (Table 6). First, synchronous online collaborative groups were created in the PLTL variant called cyber Peer-Led Team Learning (cPLTL).[48,50] The researchers evaluated the impact of replicating the general chemistry PLTL in an online setting by utilizing a web conferencing program as the means for online students to interact with their peer leaders and each other in synchronous PLTL workshops. In this setup, students were able to see and hear one another via webcam as well as see one another's worksheets by the use of a document camera as they collaborated in real time. Discourse analysis revealed instances in which students built on one another's ideas to construct meaning, which demonstrated that social constructivism was occurring in the online setting.[50] Both cPLTL and PLTL program evaluation research were performed on a limited subset of the student population called comparison groups, in which peer leaders led one section each of PLTL and cPLTL during the same semester. This study design feature of comparison groups was particularly important because it prevented the possibility of peer leader differences being attributed as setting differences. The researchers reported that the students in the comparison groups earned comparable mean student course grades and scores on the ACS First-Semester General Chemistry Exam. However, the researchers also uncovered some interesting differences in the dynamics of PLTL and cPLTL, including: (1) greater use of online resources by cPLTL students; (2) lower incidence of off-task behavior by cPLTL students; and (3) higher probability of cyber students discussing problem-solving process prior to answer-checking than their PLTL counterparts. Furthermore, the implementation of Workshop Zero, a noncontent meeting of the cPLTL students prior to the first workshop for technological and pedagogical training, arose as an additional critical component for cPLTL implementation.[48,83] Later, hardware and software evaluations were performed to identify web conferencing platforms and devices that could replicate the cPLTL experiences for a lower cost to students and institutions.[113,114]

The second online variant featured Moodle-based asynchronous discussion groups in which students shared their ideas about controversial healthcare issues and created weekly summaries.[115] Students were tasked with taking turns as discussion leaders from week to week. Although the researchers claimed that the student collaborations were an example of PLTL, there were at least two crucial components of PLTL

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

Table 6. Summary of Online Peer-Led Team Learning (PLTL) Studies

Study Authors with Reference Numbers	Findings
Feder et al.[113]	(1) Adobe Connect, Zoom, and Google Hangouts were the most compatible conferencing platforms for both Android and iOS smartphones and tablets; (2) The PocketCam application is a low-cost alternative to an iPevo document camera
Mauser et al.[48]	(1) Comparable student performance across settings; (2) Preliminary discourse analysis revealed: (a) Peer questioning and collaboration; (b) Articulation of problem-solving process; (c) Critical thinking/reflection; (3) Greater use of online resources and less off-task behavior in cPLTL
McDaniel[114]	(1) Adobe Connect was the best fee-based web conferencing platform; (2) Google Hangouts was the most functional free web conferencing platform, although additional applications would be needed to use a polling feature or record sessions
Pittenger and LimBybliw[115]	(1) Students communicated that the discussion groups, particularly when they acted as the discussion leaders, were a very positive experience; (2) Implementing a peer review process for end-of-semester proposals was the most impactful activity to decrease instructor workload, not the discussion groups
Smith et al.[50]	(1) Comparable mean student course grades and ACS exam scores; (2) Differences in social dynamics: (a) Reward/recognition; (b) Personal accountability; (c) Focus on problem-solving process vs answer-checking ; (d) Frequency of off-task behavior; (e) Use of online resources

Table 7. Summary of Laboratory Peer-Led Team Learning (PLTL) Studies

Study Authors with Reference Numbers	Findings
Foroudastan[73]	Increased retention rate since implementing PLTL (95% for PLTL students)
McCreary et al[116]	Workshop students had significantly better descriptions of experimental goals and length/clarity of responses, but comparable quality of data analysis/logical reasoning
Shapiro et al.[61]	(1) Instructor-led and peer leader-led performance data was aggregated as PLTL data; (2) No significant difference in gene annotation skills for PLTL and non-PLTL students; (3) Students were more likely to seek technical and conceptual assistance from peer leaders than classmates
Weaver et al.[15]	(1) 75% of students who opt-in to the CASPiE program are female; (2) Students appreciated participating in meaningful research, not confirmatory experiments, but needed more support to understand primary literature

which were absent from the design: collaborative problem-solving (which is distinctly different than collaborative summarizing) and weekly training of dedicated peer leaders. The researchers did not include an assessment of the impact of their implementation on students' grades, as compared to previous versions of the course.

Peer-Led Team Learning in Laboratories

The third variant of the PLTL model consisted of implementing PLTL in a laboratory (Table 7). The Center for Authentic Science Practice in Education (CASPiE) created a collaboration between research scientists and teaching faculty to generate research modules that could be accomplished in 6–8 week sessions in addition to contributing to ongoing, publishable research efforts. Moreover, CASPiE team developed a network of Internet-accessible, research-quality instruments that the students could utilize for sample analysis. The PLTL pedagogy informed the integration of peer leaders as laboratory group mentors who fostered the students' development as scientists, including: explaining laboratory notebook techniques, discussing the evaluation and interpretation of data; brainstorming experimental design; reading scientific papers; considering scientific misconduct and ethics; preparing an abstract, presentation, or poster; familiarizing students with the peer review process; and asking students reflective questions each week to contextualize the laboratory techniques.[15] Early findings from the CASPiE program indicated that there was increased students' awareness of the nature of scientific research, even though participants found that understanding primary literature was challenging. Thus, the CASPiE initiative was a particularly interesting variant of PLTL because it demonstrated that PLTL pedagogy can inform the mechanism of peer mentoring in research groups.

Three other initiatives integrated PLTL in a course-related laboratory setting.[61,73,116] In the first case, PLTL was implemented in a multisemester experimental vehicles program,[73] which has increased an engineering program's retention rate (95% for PLTL students). PLTL workshops were also implemented in several sections of general chemistry laboratory,[116] where undergraduate peer leaders facilitated groups of eight laboratory students, in lieu of faculty or a graduate teaching assistant. The peer leaders questioned pairs of students with prepared reflection prompts in addition to performing the normal supervisory/explanatory activities of a teaching assistant. Furthermore, special emphasis was placed on the development of four aspects of student development as scientists, including: understanding the organizational structure of an experiment; assessing the quality of measurements; explaining results; and applying lab skills to novel situations.[116] After the researchers coded and statistically compared PLTL and non-PLTL students' laboratory reports, they reported that the non-PLTL students had comparable descriptions of data analysis and logical reasoning quality, but the PLTL students' laboratory reports were significantly better in several categories, including: descriptions of experimental procedure; awareness of factors for high quality; goals for preparing for lab; application to specific experiment; accuracy of chemistry; clarity of writing; and length of responses.[116] Lastly, PLTL was implemented in a bioinformatics computer laboratory course, but the impact of the implementation was indeterminable since the data for instructor-led and peer-led sections were aggregated in the publication.[61] Nevertheless, the findings from three of these four studies suggest that the PLTL model is beneficial in a laboratory setting in addition to its traditional roots in lecture-based courses.

In-class Peer Leaders

Schray et al.[117] modified the standard PLTL model by assembling their roster of organic chemistry peer leaders as a combination of typical peer leaders, who are recent completers of the course, and current enrollees of the course, which they called "in-class peer leaders". The rationale of the researchers was that hiring a sufficient quantity of qualified and reliable peer leaders can sometimes be problematic,[66] while enlisting current,

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686–1702

promising members of the course would preserve the dynamic in which peer leaders act as social and academic role models in a way that utilization of a faculty member would not. Both types of peer leaders were trained identically, at a presemester retreat and weekly. The researchers reported that there was no significant difference in students' grades, regardless of peer leader type. Yet, student perception surveys suggested the typical and in-class peer leaders behaved differently even though they were trained together. Typical peer leaders were more likely than their in-class counterparts to "teach" students instead of facilitating discussions.[117] This phenomenon needs to be further investigated to determine if the two types of peer leaders should be trained separately. In addition, the researchers did not address how they ensured that in-class peer leaders and nonpeer leader classmates had equitable assessments, given the extra content training provided to in-class peer leaders.

Increased Student-to-Peer-Leader Ratio

Lyon and Lagowski[47] and Preszler[5] each modified the typical PLTL model with respect to both workshop duration and the ratio of students per peer leader: Lyon and Lagowski's general chemistry 60 min workshops featured 25 students per peer leader, while Preszler's biology 65 min workshops featured 24 students per peer leader. Both programs subdivided the students into small groups of 4−5, just as Lewis and Mitchell, Ippolito, and Lewis reported for their PLTL implementation.[7,49] Additionally, Lyon and Lagowski allowed students to elect whether to register for workshops, but attendance was mandatory once the students elected to participate in the program, just as Hockings, DeAngelis, and Frey;[84] Mitchell, Ippolito, and Lewis;[49] and Shields et al.[53] studies had reported. These researchers confirmed that there was no significant difference in pretest scores of their experimental and control groups. Both Lyon and Lagowski and Preszler studies reported significant increases in PLTL students' course grades. Furthermore, Preszler reported that the greatest improvement in course grades was realized for female and URM populations. The findings of these studies reinforce the suggestion that there appears to be flexibility in both the duration of workshops and the number of students per peer leader, as long as the student subgroups are kept small.

■ DIRECTIONS FOR FUTURE RESEARCH AND IMPLICATIONS FOR PRACTITIONERS

Student Success Measures as a Means of Program Evaluation

Several best practices for using student success measures as a means of program evaluation emerge from an analysis of PLTL literature. First, quantitative and mixed methods studies should report confidence intervals, degrees of freedom, and Cohen's *d* effect sizes in addition to population sizes, means, and standard deviations for the evaluated performance parameters. These values will enable future researchers to perform meta-analyses to assess the reproducibility of findings across disciplines and settings. Second, experimental or quasi-experimental research designs in which students are concurrently enrolled in the course[7,45] rather than comparing sequential semesters of student data,[5,14,44,47,49,51,55−60,66,84,86] minimizes the possibility that students experienced course-related differences other than the academic intervention being assessed, such as formative assessment practices, textbook, or instructor. Likewise, it is important when performing statistical analyses to control for any pre-existing differences in the demographics or preparedness of PLTL and non-PLTL populations.[3]

Reporting of pass rates, in the form of % ABC versus % DFW rates, have been an expected representation of academic impact of the intervention, although the utilization of a validated instrument, such as a nationally normed content-specific exam like those available through the ACS Exams Institute, is beneficial because it would address the question of whether course content coverage is comparable in PLTL and non-PLTL settings. Then, converting students' scores to Z scores[45] would enable researchers and faculty to compare the impact of an academic intervention across exam versions and populations in a more reliable manner. Unfortunately, comparable instruments are either not available or not favored by faculty in other STEM disciplines (B. Sorge, A. Gavrin, N. Pelaez, and K. Marrs, personal communications, February 3, 2016; T. Holme, personal communication, February 16, 2016). Therefore, course grades may be a more acceptable evaluation metric across STEM disciplines, since these are culturally valued.

The Lyle and Robinson study[57] is particularly important in both the body of PLTL literature as well as educational program evaluation in general in the current research climate in which qualitative studies in the psychological sciences, which would include education literature, have been criticized for lack of reproducibility of results.[118] These researchers re-evaluated the PLTL program evaluation data from earlier studies and reaffirmed the statistical significance of the PLTL implementations. Moreover, the similarity of PLTL program evaluation findings across a variety of settings and disciplines suggests the reproducibility of PLTL's effectiveness.[57]

Furthermore, increasing student retention through the formation of communities of learning is a stated goal of PLTL implementations, yet few PLTL studies have reported an analysis of metrics about student retention in STEM disciplines across course sequences or increases in graduation rates of STEM students after implementation of PLTL programs. Future PLTL program evaluation studies should include this important longitudinal information.

Reasoning and Critical Thinking as a Means of Program Evaluation

Evaluating the impact of PLTL on students' development of reasoning and critical thinking skills is the largest untapped area for future research. The Peteroy-Kelly[59] and Quitadamo, Brahler, and Crouch[6] studies indicated statistically significant improvement in the reasoning and critical thinking skills of students. However, the community of discipline-based faculty and researchers need tighter definitions for the concepts of "reasoning skills" and "critical thinking" in order to develop or utilize appropriate instruments and plan meaningful research studies. Newly developed assessments for metacognition, cognitive development, and problem-solving approach should be leveraged to compare the learning and development gains of PLTL and non-PLTL students. Alternatively, rubrics could be developed to evaluate students' organization of concepts during in-workshop brainstorming or concept-mapping activities as well as students' communication of experimental process, conclusions, and next steps for laboratory courses or undergraduate research efforts. Likewise, PLTL and non-PLTL students' dialogue or written responses could be classified according to Marzano's Taxonomy[119,120] to analyze students' development of higher-order thinking skills, similar to the method that the PLGI researchers[109,121] evaluated students'

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

argumentation skills as defined by Toulmin's argumentation pattern.

Student Perceptions as a Means of Program Evaluation

Several studies reported substantial proportions of students and peer leaders perceiving learning gains which they attributed to PLTL involvement,[3,55,59,60] but Chan and Bauer[96] reported that PLTL students' scores on the Attitude to the Subject of Chemistry (ASCI) and the Chemistry Self-Concept Inventory (CSCI) were not significantly different from the scores of non-PLTL students who had participated in a variety of interventions. Therefore, perhaps nonchemistry, discipline-specific versions of the ACSI and CSCI instruments should be developed for students who participate in PLTL, in concert with the assessment of students' perception of their sense of problem-solving, metacognition, and cognitive development, just as Bauer[92] adapted the Self-Description Questionnaire III[122] and established reliability and validity of the instrument in his setting to develop the CSCI. Then, the impact of PLTL implementation, various models for peer leader training, and multiple versions of PLTL question formats could be evaluated with respect to scientific discipline, content, setting, ethnicity, generational college status, and gender with respect to students' perception of their ability to learn the course content.

Research on Peer Leaders

Three critical recommendations for peer leaders should be shared with peer leaders during their training (Table 8), based on a synthesis of six relevant PLTL studies:[66,99−102,123] be punctual; be facilitative; and be empowering. Second, instruments like the Chemistry Self-Concept (CSI) and Attitude toward Chemistry (ACSI) have not been used yet to evaluate the impact of the peer leader experience. Likewise, peer leaders' multicourse retention or choice of career in STEM should be re-evaluated across disciplines and institution sizes, in a manner similar to that of Gafney and Varma-Nelson,[43] to demonstrate the reproducibility of findings, just as Lyle and Robinson had performed with program evaluation data.[57] Lastly, an evaluation of PLTL problem structure versus student dialogue/behaviors should be performed, while including characterizations of the peer leaders' style.

Table 8. Literature Based Recommendations for Peer Leaders

Recommendation	Explanation	Relevant Studies
Be punctual	Peer Leaders set the tone for the workshops	
	Tardy/absent peer leaders are linked to diminished—or even eliminated—student learning benefits in PLTL	66
Be facilitative	Students of a "facilitative" peer leader tend to: participate equally; work together; acknowledge, build upon, and elaborate each other's ideas; and exhibit collective knowledge-building	99−102
Be empowering	Peer Leaders' support of students' autonomy (independence/self-sufficiency) is linked to greater gains in students' conceptual learning	123

Variants of the Peer-Led Team Learning Model Research

Kulatunga, Moog, and Lewis[109,112] provide a model for how Toulmin's argumentation pattern[110] can be leveraged to classify students' construction and coconstruction of arguments in POGIL and PLGI settings. Additional research is needed to identify or develop analytical frameworks to evaluate individual or coconstructed articulation of content knowledge in PLTL and other social constructivist pedagogies, like PLTL, which present content in lecture first, rather than follow the learning cycle.[124] Furthermore, their research on the impact of prompt style on students' discourse patterns should lead to further research in which workshop-based curriculum for various STEM disciplines is developed and evaluated for its ability to scaffold student content learning and argumentation skill development.

Thus, far, evaluation of the synchronous online version of PLTL, cPLTL, has revealed that cPLTL and PLTL students earn comparable course grades in both general chemistry courses at Indiana University-Purdue University Indianapolis and biology courses at Purdue and Florida International Universities.[48,50] Additional research is required to evaluate the effectiveness of this PLTL variant in diverse institution types and STEM disciplines. Also, the impact of integrating cPLTL into online classes should be compared to hybrid course implementations (cPLTL as a complement to lecture-based courses).

Smith et al.[50] reported that Workshop Zero is a critical component of implementing cPLTL in order to specifically train cPLTL students prior to the semester how to both utilize the technology and interact with one another effectively during workshops in the online environment. This finding raises the question of whether PLTL students, also, would benefit from training in how to interact with one another in a face-to-face collaborative workshop setting. This would be an example of a best practice from an online learning environment informing practice in the face-to-face classroom setting.[125]

McCreary's[116] findings suggest that rubrics could be developed to assess laboratory students' and interns' interim laboratory reports for both nature of science understanding as well as the interpretation of the results from their specific experiments performed. Moreover, some CASPiE students articulated that they struggled with both reading primary literature and developing cross-disciplinary understanding.[15] The PLTL paradigm of peer leader training could inform faculty who lead research groups regarding the training of senior undergraduate and graduate research students in how to assess and mentor the scientific development of novices.

Schray et al.'s[117] findings that students' grades were comparable when facilitated in the PLTL workshops by either type of trained peer leader, recent completers of the course or classmates, but in-class peer leaders being less likely to "teach." Based on the findings of Kulatunga, Moog, and Lewis,[112] all peer leader training should reinforce how questioning style impacts student behavior. The lingering question remains, however: how should assessments be modified to maintain equity between in-class peer leaders and other students in the course?

■ CONCLUDING REMARKS

Five varieties of program evaluation research emerged from this analysis of the PLTL literature: measures of student success; student perceptions; reasoning and critical thinking skills; research on peer leaders; and variants of the typical PLTL model. Based on this analysis, the six "critical components" of PLTL that had been published in *Peer-Led Team Learning: A Guidebook*[16] are reinforced, but there may be more flexibility in both the duration of workshops (50−65 min versus 1 1/2−2 h) and acceptable ratio of students to peer leaders than the PLTL literature had recommended, as long as there are consistent workshop participation and appropriately challenging, con-

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

ceptual materials. Likewise, the cPLTL online variant of PLTL demonstrates that the PLTL model is flexible toward the setting of implementation as long as the synchronous, collaborative, peer-led solving of appropriately challenging problems aspects of the model are preserved. Although nearly a quarter of a century has passed since the first Workshop Chemistry sessions were implemented in the City Colleges of New York, PLTL continues to offer opportunities for ongoing qualitative, quantitative, and mixed methods research to evaluate the academic impact of the PLTL pedagogy.

The creation of PLTL leadership opportunities for students of varying gender, ethnicities, and socio-economic status provides both transformative career experiences for the students themselves as well as role models for students which can enhance their science self-efficacy. Since there is a national goal to produce an additional one million STEM college graduates over this decade,[126] implementing PLTL in STEM classrooms is one approach to attaining our national goal to not only produce one million STEM college graduates over this decade[126] without recruiting STEM students more extensively, but also strive for our nation's STEM graduates to be as diverse as our overall population.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00862.

A tabular summary of the Peer-Led Team Learning studies with their findings (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: pvn@iupui.edu.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank Brian Coppola, Terri Tarr, Anusha Rao, and Jordan Cagle for reviewing this manuscript and providing helpful comments. We also thank Indiana University-Purdue University Indianapolis for their support.

■ REFERENCES

(1) Gosser, D.; Roth, V.; Gafney, L.; Kampmeier, J.; Strozak, V.; Varma-Nelson, P.; Radel, S.; Weiner, M. Workshop chemistry: Overcoming the barriers to student success. *Chem. Educ.* **1996**, *1* (1), 1−17.

(2) Gosser, D. K., Jr.; Kampmeier, J. A.; Varma-Nelson, P. Peer-Led Team Learning: 2008 James Flack Norris Award Address. *J. Chem. Educ.* **2010**, *87* (4), 374−380.

(3) Stewart, B. N.; Amar, F. G.; Bruce, M. R. M. Challenges and rewards of offering peer led team learning (PLTL) in a large general chemistry course. *Aust. J. Educ. Chem.* **2007**, *67*, 31−36.

(4) Drane, D.; Smith, H. D.; Light, G.; Pinto, L.; Swarat, S. The Gateway Science Workshop Program: Enhancing Student Performance and Retention in the Sciences Through Peer-Facilitated Discussion. *J. Sci. Educ. Technol.* **2005**, *14* (3), 337−352.

(5) Preszler, R. W. Replacing lecture with peer-led workshops improves student learning. *CBE-Life Sci. Educ.* **2009**, *8*, 182−192.

(6) Quitadamo, I. J.; Brahler, C. J.; Crouch, G. J. Peer-Led Team Learning: A prospective method for increasing critical thinking in undergraduate science courses. *Sci. Educ.* **2009**, *18* (1), 29−39.

(7) Lewis, S. E. Retention and reform: An evaluation of peer-led team learning. *J. Chem. Educ.* **2011**, *88* (6), 703−707.

(8) Horwitz, S.; Rodger, S. H.; Ryder, B.; Sweat, M.; et al. Using peer-led team learning to increase participation and success of under-represented groups in introductory computer science. *SIGCSE Bull.* **2009**, *41* (1), 163−167.

(9) Amaral, K. E.; Vala, M. What teaching teaches: Mentoring and the performance gains of mentors. *J. Chem. Educ.* **2009**, *86* (5), 630−633.

(10) Woodward, A. E.; Weiner, M.; Gosser, D. Problem solving workshops in general chemistry. *J. Chem. Educ.* **1993**, *70* (8), 651.

(11) Gosser, Jr., D. K. *Peer-led team learning: Origins, research, and practice*; Linus Learning: Ronkonkoma, NY, 2015.

(12) *SIGSE Atlanta 2014 Paper Submission Guidelines*. http://sigcse2014.sigcse.org/authors/papers.php (accessed May 2016).

(13) Frontiers in Education *2015 Review Criteria*. http://fie2015.fie-conference.org/review-criteria (accessed May 2016).

(14) White, P.; Rowland, A. B.; Pesis-Katz, I. Peer−led team learning model in a graduate−level nursing course. *J. Nurs. Educ.* **2012**, *51* (8), 471−475.

(15) Weaver, G. C.; Wink, D.; Varma-Nelson, P.; Lytle, F.; Morris, R.; Fornes, W.; Russell, C.; Boone, W. J. Developing a new model to provide first and second-year undergraduates with chemistry research experience: Early findings of the center for authentic science practice in education (CASPiE). *Chem. Educ.* **2006**, *11*, 125−129.

(16) Gosser, D. K.; Cracolice, M. S.; Kampmeier, J. A.; Roth, V.; Strozak, V.; Varma-Nelson, P. *Peer-Led Team Learning: A Guidebook*; Prentice Hall: Upper Saddle River, NJ, 2001.

(17) Varma-Nelson, P.; Cracolice, M. S. *Peer-led team learning: General, organic, and biological chemistry*; Prentice Hall: Upper Saddle River, NJ, 2001.

(18) Kampmeier, J. A.; Varma-Nelson, P.; Wedegaertner, D. K. *Peer-led team learning: Organic chemistry*; Prentice Hall: Upper Saddle River, NJ, 2001.

(19) Gosser, D. K.; Strozak, V.; Cracolice, M. S. *Peer-led team learning: General chemistry*, 2nd ed.; Prentice Hall: Upper Saddle River, NJ, 2006.

(20) Roth, V.; Goldstein, E.; Marcus, G. *Peer-Led Team Learning: A Handbook for Team Leaders*; Prentice-Hall: Upper Saddle River, NJ, 2001.

(21) Kampmeier, J. A.; Varma-Nelson, P.; Wamser, C. C.; Wedegaertner, D. K. *Peer-led team learning: Organic chemistry*, 2nd ed.; Prentice Hall: Upper Saddle River, NJ, 2006.

(22) Bodner, G. M.; Orgill, M. *Theoretical Frameworks for Research in Chemistry/Science Education*; Pearson: Upper Saddle River, NJ, 2007.

(23) Watson, J. Social constructivism in the classroom. *Support Learn.* **2001**, *16* (3), 140−147.

(24) Vygotsky, L. S. *Minds in Society: The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, MA, 1978.

(25) Bodner, G. M. Constructivism: A Theory of Knowledge. *J. Chem. Educ.* **1986**, *63* (10), 873−878.

(26) Driver, R.; Asoko, H.; Leach, J.; Mortimer, E.; Scott, P. Constructing scientific knowledge in the classroom. *Educ. Res.* **1994**, *23* (7), 5−12.

(27) Kampmeier, J. A.; Varma-Nelson, P. In *Chemist's Guide to Effective Teaching*; Pienta, N. J., Cooper, M. M., Greenbowe, T. J., Eds.; Pearson: Upper Saddle River, NJ, 2009; Vol. *II*, pp 122−145.

(28) Bandura, A. *Social Learning Theory*; Prentice Hall: Eaglewood, NJ, 1977.

(29) Singh, V.; Vinnicombe, S.; James, K. Constructing a Professional Identity: How Young Female Managers Use Role Models. *Women Manag. Rev.* **2006**, *21* (1), 67−81.

(30) Buunk, A. P.; Peiró, J. M.; Griffioen, C. A Positive Role Model May Stimulate Career-Oriented Behavior. *J. Appl. Soc. Psychol.* **2007**, *37* (7), 1489−1500.

(31) Lockwood, P.; Kunda, Z. Superstars and me: Predicting the impact of role models on the self. *J. Pers. Soc. Psychol.* **1997**, *73* (1), 91−103.

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

(32) Rogers, E. M. *Diffusion of Innovations*; Free Press: New York, NY, 2003.
(33) Varma-Nelson, P. Peer-Led Team Learning. *Metrop. Univ.* **2006**, *17* (4), 19−29.
(34) Blake-Beard, S.; Bayne, M. L.; Crosby, F. J.; Muller, C. B. Matching by race and gender in mentoring relationships: Keeping our eyes on the prize. *J. Soc. Issues* **2011**, *67* (3), 622−643.
(35) Stout, J. G.; Dasgupta, N.; Hunsinger, M.; McManus, M. a. STEMing the tide: using ingroup experts to inoculate women's self-concept in science, technology, engineering, and mathematics (STEM). *J. Pers. Soc. Psychol.* **2011**, *100* (2), 255−270.
(36) Cole, D.; Espinoza, A. Examining the Academic Success of Latino Students in Science Technology Engineering and Mathematics (STEM) Majors. *J. Coll. Stud. Dev.* **2008**, *49* (4), 285−300.
(37) Marx, D. M.; Ko, S. J.; Friedman, R. A. The "Obama Effect": How a salient role model reduces race-based performance differences. *J. Exp. Soc. Psychol.* **2009**, *45* (4), 953−956.
(38) Varma-Nelson, P.; Coppola, B. P. In *Chemist's Guide to Effective Teaching*; Pienta, N., Cooper, M. M., Greenbowe, T., Eds.; Pearson: Saddle River, NJ, 2005; pp 1−14.
(39) Lynch, S. *Equity and science education reform*; Lawrence Erlbaum Associates: Mahwah, NJ, 2000.
(40) Lewis, S. E.; Lewis, J. E. Seeking effectiveness and equity in a large college chemistry course: An HLM investigation of peer-led guided inquiry. *J. Res. Sci. Teach.* **2008**, *45* (7), 794−811.
(41) Gafney, L.; Varma-Nelson, P. *Peer-Led Team Learning: Evaluation, dissemination and institutionalization of a college level initiative*; Springer: Dordrecht, Netherlands, 2008.
(42) Tenney, A.; Houck, B. Learning about leadership: Team learning's effect on peer leaders. *J. Coll. Sci. Teach.* **2004**, *33* (6), 25−29.
(43) Gafney, L.; Varma-Nelson, P. Evaluating Peer-Led Team Learning: A Study of Long-Term Effects on Former Workshop Peer Leaders. *J. Chem. Educ.* **2007**, *84* (3), 535−539.
(44) Alger, T. D.; Bahi, S. An experiment in improving scores on ACS course-specific examinations at southern utah university. *Progress. Peer-Led Team Learn.* **2004**, *5* (2), 7−10.
(45) Chan, J. Y. K.; Bauer, C. F. Effect of peer-led team learning (PLTL) on student achievement, attitude, and self-concept in college general chemistry in randomized and quasi experimental designs. *J. Res. Sci. Teach.* **2015**, *52* (3), 319−346.
(46) Hockings, S. C.; DeAngelis, K. J.; Frey, R. F. Peer-Led Team Learning in General Chemistry: Implementation and Evaluation. *J. Chem. Educ.* **2008**, *85* (7), 990−996.
(47) Lyon, D. C.; Lagowski, J. J. Effectiveness of facilitating small-group learning in large lecture classes: A general chemistry case study. *J. Chem. Educ.* **2008**, *85* (11), 1571−1576.
(48) Mauser, K.; Sours, J.; Banks, J.; Newbrough, J. R.; Janke, T.; Shuck, L.; Zhu, L. Cyber Peer-Led Team Learning (cPLTL): Development and implementation. *Educ. Rev. Online* **2011**, 1−17.
(49) Mitchell, Y. D.; Ippolito, J.; Lewis, S. E. Evaluating peer-led team learning across the two semester general chemistry sequence. *Chem. Educ. Res. Pract.* **2012**, *13* (3), 378−383.
(50) Smith, J.; Wilson, S. B.; Banks, J.; Zhu, L.; Varma-Nelson, P. Replicating Peer-Led Team Learning in cyberspace: Research, opportunities, and challenges. *J. Res. Sci. Teach.* **2014**, *51* (6), 714−740.
(51) Drane, D.; Smith, H. D.; Light, G.; Pinto, L.; Swarat, S. The gateway science workshop program: Enhancing student performance and retention in the sciences through peer-facilitated discussion. *J. Sci. Educ. Technol.* **2005**, *14* (3), 337−352.
(52) Lewis, S. E. Investigating the longitudinal impact of a successful reform in general chemistry on student enrollment and academic performance. *J. Chem. Educ.* **2014**, *91* (12), 2037−2044.
(53) Shields, S. P.; Hogrebe, M. C.; Spees, W. M.; Handlin, L. B.; Noelken, G. P.; Riley, J. M.; Frey, R. F. A transition program for underprepared students in general chemistry: Diagnosis, implementation, and evaluation. *J. Chem. Educ.* **2012**, *89* (8), 995−1000.
(54) Rein, K. S.; Brookes, D. T. Student Response to a Partial Inversion of an Organic Chemistry Course for Non-Chemistry Majors. *J. Chem. Educ.* **2015**, *92* (5), 797−802.
(55) Tien, L. T.; Roth, V.; Kampmeier, J. a. Implementation of a peer-led team learning instructional approach in an undergraduate organic chemistry course. *J. Res. Sci. Teach.* **2002**, *39* (7), 606−632.
(56) Wamser, C. C. Peer-led team learning in organic chemistry: Effects on student performance, success, and persistence in the course. *J. Chem. Educ.* **2006**, *83* (10), 1562−1566.
(57) Lyle, K. S.; Robinson, W. R. A statistical evaluation: Peer-led team learning in an organic chemistry course. *J. Chem. Educ.* **2003**, *80* (2), 132−134.
(58) Akinyele, A. F. Peer-led team learning and improved performance in an allied health chemistry course. *Chem. Educ.* **2010**, *15* (10), 353−360.
(59) Peteroy-Kelly, M. A. A discussion group program enhances the conceptual reasoning skills of students enrolled in a large lecture-format introductory biology course. *J. Microbiol. Biol. Educ.* **2007**, *8* (1), 13−21.
(60) Finn, B. K.; Campisi, J. Implementing and evaluating a peer-led team learning approach in undergraduate anatomy and physiology. *J. Coll. Sci. Teach.* **2015**, *044* (06), 38−44.
(61) Shapiro, C.; Ayon, C.; Moberg-Parker, J.; Levis-Fitzgerald, M.; Sanders, E. R. Strategies for using peer-assisted learning effectively in an undergraduate bioinformatics course. *Biochem. Mol. Biol. Educ.* **2013**, *41* (1), 24−33.
(62) Reisel, J. R.; Jablonski, M.; Munson, E. V.; Hosseini, H. Analysis of the impact of formal peer-led study groups on first-year student math performance. In *American Society for Engineering Education Annual Conference*, San Antonio, TX, June 9−10, 2012; pp 1−13.
(63) Reisel, J. R.; Jablonski, M. R.; Munson, E.; Hosseini, H. Peer-led team learning in mathematics courses for freshmen engineering and computer science students. *J. STEM Educ.* **2014**, *15* (2), 7−16.
(64) Reisel, J.; Jablonski, M.; Munson, E. A Study of the Impact of peer-led team learning on the first-year math course performance of engineering students. *American Society for Engineering Education* **2013**, 1−15.
(65) Flores, B.; Becvar, J.; Darnell, A.; Knaust, H.; Lopez, J.; Tinajero, J. Implementing peer-led team learning in gateway science and mathematics courses for engineering majors. *American Society for Engineering Education* **2010**, 2−9.
(66) Merkel, J. C.; Brania, A. Assessment of peer-led team learning in calculus I: A five-year study. *Innov. High. Educ.* **2015**, *40*, 415−428.
(67) Biggers, M.; Yilmaz, T.; Sweat, M. Using collaborative, modified peer led team learning to improve student success and retention in intro CS. *SIGCSE Bull.* **2009**, *41*, 9−13.
(68) Hug, S.; Thiry, H.; Tedford, P. Learning to love computer science: peer leaders gain teaching skill, communicative ability and content knowledge in the CS classroom. In *Special Interest Group for Computer Science Education*, Proceedings of the 42nd ACM technical symposium on Computer science education, Dallas, TX, March 9−11, 2011; ACM: New York, NY, 2011; pp 201−206.10.1145/1953163.1953225
(69) Alo, R. A.; Beheshti, M.; Fernandez, J.; Gates, A. Q.; Ranjan, D. Work in progress: Peer-led team learning implementation in computer science. In *ASEE/IEEE Frontiers In Education Conference*, Milwaukee, WI, October 11−12, 2007, pp S4A − 7−S4A − 8.
(70) Roach, S.; Villa, E. Enhancing peer-led team learning in computer science through cooperative learning. In *American Society for Engineering Education Annual Conference*, Pittsburgh, PA, June 22−25, 2008, pp 1−10.
(71) Utschig, T. T.; Sweat, M. Implementing Peer Led Team Learning in first-year programming courses. In *IEEE Frontiers in Education Conference*, Saratoga Springs, NY, October 22−25, 2008, pp F3C − 13−F3C − 18.
(72) Johnson, E. C.; Robbins, B. A.; Loui, M. C. What do students experience as peer leaders of learning teams? *Adv. Eng. Educ.* **2015**, 1−22.

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

(73) Foroudastan, S. Enhancing undergraduate performance through peer-led team learning (PLTL). *American Society for Engineering Education* **2009**, 1−12.
(74) Mottley, J. G.; Roth, V. Peer-led team learning: Adjunct to lectures in an electrical engineering course for non-majors. *Institute of Electrical and Electronics Engineers* **2013**, 1027−1032.
(75) Pazos, P.; Drane, D.; Light, G.; Munkeby, A. A peer-led team learning program for freshmen engineering students: Impact on retention. In *American Society for Engineering Education Annual Conference*, Honolulu, HI, June 24−27, 2007, pp 2−12.
(76) Murray, J. D. Peer learning and its application to undergraduate psychology instruction. In *Promoting Student Engagement*; Miller, R. L., Amsel, E., Beins, B. C., Keith, K. D., Peden, B. F., Miller, R. L., Eds.; Society for the Teaching of Pyschology, 2011; Vol. *1*, 166−169.
(77) Cracolice, M. S.; Deming, J. C. A new teaching model focuses on student achievement through active learning: Peer-led team learning. *Sci. Teach.* **2001**, *68* (1), 20−24.
(78) Durlak, J. A. How to Select, Calculate, and Interpret Effect Sizes. *J. Pediatr. Psychol.* **2009**, *34* (9), 917−928.
(79) Grissom, R. J.; Kim, J. J. *Effect Sizes for Research: A Broad Practical Approach*; Erlbaum: Mahwah, NJ, 2005.
(80) Tenney, A.; Houck, B. Peer-Led Team Learning in Introductory Biology and Chemistry Courses: A Parallel Approach. *J. Math. Sci. Collab. Explor.* **2003**, *6*, 11−20.
(81) Snyder, J. J.; Carter, B. E.; Wiles, J. R. Implementation of the Peer-Led Team-Learning instructional model as a stopgap measure improves student achievement for students opting out of laboratory. *CBE-Life Sci. Educ.* **2015**, *14*, 1−6.
(82) Amstutz, M.; Wimbush, K.; Snyder, D. Effectiveness and student demographics of peer-led study groups in undergraduate animal science courses. *North Am. Coll. Teach. Agric. J.* **2010**, *54* (1), 76−81.
(83) Smith, J.; Wilson, S. B.; Banks, J.; Zhu, L.; Varma-Nelson, P. Replicating Peer-Led Team Learning in cyberspace: Research, opportunities, and challenges. *J. Res. Sci. Teach.* **2014**, *51* (6), 714−740.
(84) Hockings, S. C.; DeAngelis, K. J.; Frey, R. F. Peer-led team learning in general chemistry: Implementation and evaluation. *J. Chem. Educ.* **2008**, *85* (7), 990−996.
(85) Gafney, L. In *Peer-Led Team Learning: A Guidebook*; Gosser, D. K., Cracolice, M. S., Kampmeier, J. A., Roth, V., Strozak, V. S., Varma-Nelson, P., Eds.; Prentice Hall: Upper Saddle River, NJ, 2001, pp 75−93.
(86) Hooker, D. Small peer-led collaborative learning groups in developmental math classes at a tribal community college. *Multicult. Perspect.* **2011**, *13* (4), 220−226.
(87) Holme, T.; Bretz, S. L.; Cooper, M.; Lewis, J. E.; Paek, P.; Pienta, N.; Stacy, A.; Stevens, R.; Towns, M. Enhancing the role of assessment in curriculum reform in chemistry. *Chem. Educ. Res. Pract.* **2010**, *11*, 92−97.
(88) Loui, M. C.; Robbins, B. A.; Johnson, E. C.; Venkatesan, N. Assessment of peer-led team learning in an engineering course for freshmen. *Int. J. Eng. Educ.* **2013**, *29* (6), 1440−1455.
(89) Drane, D.; Micari, M.; Light, G. Students as teachers: effectiveness of a peer-led STEM learning programme over 10 years. *Educ. Res. Eval.* **2014**, *20* (3), 210−230.
(90) Cohen, D. The Use of Concept Maps to Represent Unique Thought Processes: Toward More Meaningful Learning. *J. Curric. Superv.* **1987**, *2* (3), 285−289.
(91) Facione, P. A. *Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction. Research Findings and Recommendations*; Insight Assessment: Millbrae, CA, 1990.
(92) Bauer, C. F. Beyond "Student Attitudes": Chemistry Self-Concept Inventory for Assessment of the Affective Component of Student Learning. *J. Chem. Educ.* **2005**, *82* (12), 1864−1870.
(93) Seymour, E.; Wiese, D. J.; Hunter, A.-B.; Daffinrud, S. In *National Meeting of the American Chemical Society*, San Francisco, CA, March 26−31, 2000, pp 1−40.
(94) Curran, E. M.; Carlson, K.; Celotta, D. L. T. Changing attitudes and facilitating understanding in the undergraduate statistics classroom: A collaborative learning approach. *J. Scholarsh. Teach. Learn.* **2013**, *13* (2), 49−71.
(95) Cook, T. D.; Campbell, D. T. *Quasi-experimentation: Design and analysis issues*; Houghton Mifflin Company: Boston, MA, 1979.
(96) Bauer, C. F. Attitude toward Chemistry: A Semantic Differential Instrument for Assessing Curriculum Impacts. *J. Chem. Educ.* **2008**, *85* (10), 1440−1445.
(97) Pazos, P.; Micari, M.; Light, G. Developing an instrument to characterise peer-led groups in collaborative learning environments: Assessing problem-solving approach and group interaction. *Assess. Eval. High. Educ.* **2010**, *35* (2), 191−208.
(98) Streitwieser, B.; Light, G. When undergraduates teach undergraduates: Conceptions of and approaches to teaching in a peer led team learning intervention in the STEM disciplines: Results of a two year study. *Int. J. Teach. Learn. High. Educ.* **2010**, *22* (3), 346−356.
(99) Brown, P.; Sawyer, K.; Frey, R. Peer-led team learning in general chemistry: Investigating the discourse of peer leaders and students. In *Mid-western Educational Research Association Conference*, St. Louis, MO, 2009.
(100) Brown, P.; Sawyer, K. R.; Frey, R. Investigating peer-leader discourse in peer-led team learning in general chemistry. In *American Educational Research Association Conference*, San Diego, CA, April 13−17, 2009.
(101) Brown, P.; Sawyer, K. R.; Frey, R. F.; Luesse, S.; Gealy, D. What are they talking about? Findings from an analysis of the discourse in peer-led team learning in general chemistry. *International Conference of the Learning Sciences* **2010**, *1*, 773−777.
(102) Sawyer, K.; Frey, R. F.; Brown, P. Knowledge building discourse in Peer-Led Team Learning (PLTL) groups in first-year general chemistry. In *Multivocality in the Analysis of Group Interactions*; Suthers, D. D., Lund, K., Rosé, C. P., Teplovs, C., Law, N., Eds.; Springer Science + Business Media: New York, New York, USA, 2013; pp 191−204.
(103) Snyder, J. J.; Wiles, J. R. Peer-led team learning in introductory biology: Effects on critical thinking skills. *PLoS One* **2015**, *10* (1), 1−18.
(104) Báez-Galib, R.; Colón-Cruz, H.; Resto, W.; Rubin, M. R. hem-2-Chem: A One-to-One Supportive Learning Environment for Chemistry. *J. Chem. Educ.* **2005**, *82* (12), 1859−1863.
(105) Farrell, J. J.; Moog, R. S.; Spencer, J. N. A guided inquiry general chemistry course. *J. Chem. Educ.* **1999**, *76* (4), 570−574.
(106) Eberlein, T.; Kampmeier, J.; Minderhout, V.; Moog, R. S.; Platt, T.; Varma-Nelson, P.; White, H. B. Articles Pedagogies of Engagement in Science: A Comparison of PBL, POGIL, and PLTL. *Biochem. Mol. Biol. Educ.* **2008**, *36* (4), 262−273.
(107) Lewis, S. E.; Lewis, J. E. Departing from lectures: An evaluation of a peer-led guided inquiry alternative. *J. Chem. Educ.* **2005**, *82* (1), 135−139.
(108) Cohen, E. G. In *Working for Equity in Heterogeneous Classrooms: Sciological Theory in Practice*; Cohen, E. G., Lotan, R. A., Eds.; Teachers College Press: New York, NY, 1997; pp 61−76.
(109) Kulatunga, U.; Moog, R. S.; Lewis, J. E. Argumentation and participation patterns in general chemistry peer-led sessions. *J. Res. Sci. Teach.* **2013**, *50* (10), 1207−1231.
(110) Toulmin, S. *The Uses of Argument*; Cambridge University Press: Cambridge, England, 1958.
(111) Hanson, D. *Instructor's guide to process-oriented guided -inquiry learning*; Pacific Crest: Lisle, IL, 2006.
(112) Kulatunga, U.; Moog, R. S.; Lewis, J. E. Use of Toulmin's argumentation scheme for student discourse to gain insight about guided inquiry activities in college chemistry. *J. Coll. Sci. Teach.* **2014**, *43* (5), 78−87.
(113) Feder, E.; Khan, I.; Mazur, G.; Vernon, T.; Janke, T.; Varma-Nelson, P. Accessing collaborative online learning with mobile technology in Cyber Peer-Led Team Learning. *Educause Rev. Online*, 2016, *51* (2). http://er.educause.edu/articles/2016/4/accessing-collaborative-online-learning-with-mobile-technology-in-cyber-peer-led-team-learning (accessed May 2016).

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702

(114) McDaniel, J.; Metcalf, S.; Sours, J.; Janke, T.; Newbrough, J. R.; Shuck, L.; Varma-Nelson, P. Supporting student collaboration in cyberspace: A cPLTL study of web conferencing platforms. *Educause. Rev.* **2013**, *36*, 1−8.

(115) Pittenger, A. L.; LimBybliw, A. L. Peer-led team learning in an online course on controversial medication issues and the US healthcare system. *Am. J. Pharm. Educ.* **2013**, *77* (7), 150.

(116) McCreary, C. L.; Golde, M. F.; Koeske, R. Peer instruction in the general chemistry laboratory: Assessment of student learning. *J. Chem. Educ.* **2006**, *83* (5), 804−810.

(117) Schray, K.; Russo, M. J.; Egolf, R.; Lademan, W.; Gelormo, D. Are in-class peer leaders effective in the peer-led team-learning approach? *J. Coll. Sci. Teach.* **2009**, *38* (4), 62−67.

(118) Open Science Collaboration. Estimating the reproducibility of psychological science. *Science*, **2015**, *349* (6251), aac4716.10.1126/science.aac4716

(119) Toledo, S.; Dubas, J. M. Encouraging higher-order thinking in general chemistry by scaffolding student learning using Marzano's Taxonomy. *J. Chem. Educ.* **2016**, *93* (1), 64−69.

(120) Marzano, R. J. *Designing a New Taxonomy of Educational Objectives*; Corwin Press, Inc.: Thousand Oaks, CA, 2001.

(121) Kulatunga, U.; Lewis, J. E. Exploration of peer leader verbal behaviors as they intervene with small groups in college general chemistry. *Chem. Educ. Res. Pract.* **2013**, *14* (4), 576.

(122) Marsh, H. W.; O'Neill, R. Self Description Questionnaire III: The construct validity of multidimensional self-concept ratings by late adolescents. *J. Educ. Meas.* **1984**, *21* (2), 153−174.

(123) Black, A. E.; Deci, E. L. The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Sci. Educ.* **2000**, *84* (6), 740−756.

(124) Abraham, M. R.; Renner, J. W. The Sequence of Learning Cycle Activities in High School Chemistry. *J. Res. Sci. Teach.* **1986**, *23* (2), 121−143.

(125) Browne, C.; Fetrow, J. *Online and Face-to-Face Education*, https://www.insidehighered.com/blogs/higher-ed-beta/online-and-face-face-education?width=775&height=500&iframe=true (accessed Jan 1, 2016).

(126) Olson, S.; Riordan, D. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. *Report to the President*, President's Council of Advisors on Science and Technology: Washington, D.C., 2012. https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-executive-report-final_2-13-12.pdf (accessed May 2016).

DOI: 10.1021/acs.jchemed.5b00862
J. Chem. Educ. 2016, 93, 1686−1702