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Assessing the Impact of a Multi-Disciplinary Peer-Led-Team Learning Program on Undergraduate STEM Education

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Abstract
There has been a national call to transition away from the traditional, passive, lecture-based model of STEM education towards one that facilitates learning through active engagement and problem solving. This mixed-methods research study examines the impact of a supplemental Peer-Led Team Learning (PLTL) program on knowledge and skill acquisition for students in introductory biology, chemistry, calculus and applied statistics courses. Results indicate program participants reliably outperform their matched pairs in courses that emphasize quantitative reasoning. Moreover, program participants report acquiring important insights about learning, collaboration, and engagement in undergraduate STEM education. These results are consistent with previous findings on PLTL and also provide insight into the roles of course context and student population on program outcomes.

Keywords
collaborative learning, cooperative learning, peer-led team learning, undergraduate stem education

Cover Page Footnote
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Introduction

In the United States over the past three decades, a national movement to transform undergraduate STEM education has evolved (NRC 1999; NRC 2003; PCAST 2012). As part of this movement, educators and policymakers alike have emphasised the need to transition away from the more traditional lecture-based model of STEM education to student-centred units in which faculty rely on research-based teaching methods to promote student learning (Handelsman et al. 2004).

Experiences in introductory units have been identified as an important focus in the transformation of STEM education (NRC 1999; PCAST 2012; Tobias 1992). As the starting point for nearly all STEM majors, and as the only exposure to STEM fields for some students, introductory units offer the first opportunity to begin building a foundation of technical and critical-thinking skills. However, students are often underprepared to successfully meet the units' demands (Arum & Roksa 2011; Coughlan & Swift 2011; Porter & Polikoff 2012). Some arrive with expectations misaligned with those of their educators (Skyrme 2007). They may not be ready or willing to spend the time necessary to master a concept, or may not even value the idea of conceptual learning (Arum & Roksa 2011). Skills like rote memorisation and last-minute studying that may have worked in high school may not yield success at the tertiary level (Lowe & Cook 2003). Retention of knowledge and deep understanding of unit material can suffer under these circumstances.

As STEM educators attempt to overcome these barriers and engage introductory students in the learning process, they are turning to research-supported approaches such as active learning (Freeman et al. 2014) and, more specifically, collaborative learning (Ruiz-Primo et al. 2011; Springer, Stanne & Donovan 1999). The aim of this study is to explore the impact of a supplemental collaborative-learning-based Peer-Led Team Learning (PLTL) program on student performance in introductory biology, chemistry, calculus and applied statistics units at a medium sized-liberal arts university and to assess student perceptions of the program.

Literature Review

Collaborative learning, broadly defined, involves groups of individuals working together to achieve a common learning goal (Barkley, Cross & Majro 2005). It is a well-established approach that has a significant positive relationship with student learning (Johnson et al. 1981; Johnson, Johnson & Smith 1998; Johnson, Johnson & Stanne 2000; Schroeder et al. 2007), self-esteem and student relationships (Johnson et al. 1998) across multiple age levels and disciplines. Consistent with these broad findings on collaborative learning, two large meta-analyses focusing specifically on the STEM disciplines have documented significant positive effects of collaborative learning on student learning (Ruiz-Primo et al. 2011), student achievement, student persistence and student attitudes (Springer et al. 1999).

"Collaborative learning" is an umbrella term that encompasses instructional approaches classified as collaborative or cooperative. Collaborative learning has its roots in constructivist learning theory and, more specifically, social constructivism (Barkley et al. 2005; Cracolice & Trautmann 2001). Constructivist theory postulates that learning is non-linear and learner-centred. Social constructivists assert that individuals construct meaning through interactions with other learners. These theories propose that it is through dialogue that individuals create meaning and modify their understanding of the world (Fosnot & Perry 2005; Svinicki 2004).

Peer-Led Team Learning: A collaborative-learning approach that affects student achievement and attitudes in STEM disciplines

PLTL is a form of collaborative learning first developed in the field of chemistry as the Workshop Chemistry Project during the 1990s (Gosser 2001). It is characterised by groups of six to eight students who meet weekly to work with a peer leader to tackle difficult concepts and problems. The peer leader is a student who has successfully completed the unit and has been trained in both group facilitation and collaborative-learning techniques (Gosser 2001); however, many different versions of the PLTL approach have been described (Gafney 2001). Today PLTL is a well-established pedagogy used in multiple disciplines (Gosser 2011), and has been identified as a "Pedagogy That Works" by Project Kaleidoscope, an Association of American Colleges & Universities centre for STEM higher-education reform (Varma-Nelson 2008).

As with collaborative learning in general, the effectiveness of PLTL in STEM disciplines has also been studied, with a focus on student performance based on exam and unit grades. A 2011 review of the literature reported an average 16% increase in A, B and C grades when students were exposed to PLTL experiences (Gosser 2011).

Results from the original Workshop Chemistry Project demonstrated significant improvement in student performance in General Chemistry I and II and Organic Chemistry (Gafney 2001). These early results have been duplicated in subsequent (chemistry-specific PLTL) studies, which have shown significant improvements in both student achievement (Drane, Micari & Light, 2014; Lewis & Lewis 2005; Popejoy & Asala 2013; Tien, Roth & Kampmeier 2002) and retention (Drane, Micari & Light 2014; Lewis 2011; Mitchell, Ippolito & Lewis 2012; Popejoy & Asala 2013).

Many studies have discussed the implementation of PLTL in other STEM units. In biology, participation in both unit-integrated PLTL groups (Peteroy-Kelly 2007; Preszler 2009) and voluntary PLTL groups (Drane, Micari & Light 2014; Tenney & Houck 2003) has been shown to have a positive influence on student performance. This effect has also been reported for introductory computer-science units (Horwitz & Rodger 2009), freshman engineering (Dane, Micari & Light, 2014; Loui & Robbins 2008), introductory applied statistics (Curran, Carlson & Turvold Celotta 2013) and various mathematics units (Drane, Micari & Light 2014; Liou-Mark, Dreyfuss & Younge 2010; Quitadamo, Brahler & Crouch 2009).

Recently, studies have begun to move beyond student performance to assess the effect of PLTL on student skills and attitudes toward the discipline. In a 2007 study, Peteroy-Kelly observed an increase in the number of students who appropriately used concept maps to demonstrate relationships among non-biological terms after a unit-based PLTL experience in introductory biology. Similarly, Quitadamo et al. (2009) reported an association between PLTL and critical-thinking gains in students taking organic chemistry units.

Purpose

The available research on the impact of collaborative learning and PLTL in STEM education suggests that they may be effective strategies for promoting learning in the undergraduate environment. This multidisciplinary, mixed-methods research study seeks to add to the existing literature on the effectiveness of PLTL on learning in STEM education, particularly in the areas of undergraduate mathematics, biology and applied statistics, as well as chemistry. Furthermore, an analysis of qualitative data will provide insight into students' experience with such a program and its impact on students' development as learners in the post-secondary educational environment.

STEM Learning Community Program Description

In 2010, a STEM Learning Community (LC) Program was formed at private, medium-sized, liberal-arts university in the midwest of the United States to serve students enrolled in introductory biology, chemistry, mathematics and statistics units. The LC Program aims to improve the depth and breadth of student learning, facilitate positive attitudes toward content, strengthen the academic experience and improve retention in STEM disciplines. Approximately 200 students have been served per semester since the program's inception.

Program Structure

Modeled after PLTL (Gosser 2001), the STEM LC Program differs from traditional PLTL in three important ways. First, unlike traditional PLTL programs, participation is voluntary. Second, LC faculty members play varying roles in the development of LC materials. Third, while PLTL models support group sizes of six to eight students, LCs at this university serve up to 12 students per group.

Many students who elect to enroll in the STEM LC Program are first-year students who anticipate having difficulty in the unit and hope that this program will help them to master the material. The weekly two-hour LC meetings are facilitated by STEM LC leaders: students who have taken and demonstrated strong proficiency in the associated unit and who collaborate effectively with other learners. Throughout the academic year, leaders receive training in collaborative-learning tools, group-facilitation techniques and working with diverse populations.

A faculty Department Liaison in each of the disciplines meets weekly with the LC leaders, assisting with development of collaborative-learning activities and serving as the first point of contact for the leaders should problems arise within the group. LC liaisons also participate in STEM LC Program planning, but a program coordinator oversees the program, develops and provides leader trainings, oversees program logistics (such as time cards and payroll for LC leaders), and collaborates at least monthly with the LC liaisons.

Program Logistics

Student enrolled in units served by the LC Program are introduced to the program during the first week of classes and can enroll during the second week of classes. Once enrolled in an LC, students are expected to attend and actively participate at all meetings. Depending on the discipline, students are allowed one or two unexcused absences. Any student who meets the attendance requirement earns an incentive for participation. This incentive varies by discipline, but has a minor impact on overall grade in the unit (e.g. one or two quiz or homework scores dropped).

Research Methods

This study used a mixed-methods, matched-pairs design in which LC Program participants were matched with students taking the same unit, often with the same instructor, who were not in the program. The intent of the matching process was to pair LC Program participants with highly similar students in terms of ability, motivation and experience over the course of the semester so that the impact of the STEM LC Program on learning could be investigated. Both quantitative and qualitative data were collected and analysed.

This study addressed three research questions:

1. Is there a difference between LC participants and their matched pairs on learning outcomes?
2. Does the STEM LC Program affect students differentially, depending on initial level of achievement in the unit?
3. How do students experience the STEM LC Program, and what do students perceive to be the major benefits and drawbacks of this experience?

Learning throughout each unit was measured by individual performance on in-class exams. Outcomes were compared within each discipline using related sample t-tests to identify significant differences in performance ($\alpha = .05$) on each exam. To determine whether the STEM LC Program affected students differentially based upon initial levels of unit achievement, students were divided into "grade groups" based on the grade or score earned on the first exam given in the unit; performance on subsequent exams for each grade group was examined. To gauge students' experiences within the STEM LC Program, open-ended responses to an end-of-semester STEM LC Program evaluation were coded by two independent evaluators. Codes were then cross-validated by the researchers and condensed into major themes relating to STEM LC Program experience.

Quantitative Results

Statistics

Statistics I is an introductory unit in applied statistics that emphasises the application, analysis, interpretation and presentation of descriptive and inferential statistics. Topics broadly include working with categorical and quantitative data, examining relationships, study design and sampling strategies, probability, sampling distributions and confidence intervals and hypothesis tests. Four exams, including a non-cumulative final exam, are given in this unit. Statistics I is offered in the fall and spring semesters; students are typically non-majors in their second year of university taking the unit to fulfill a graduation requirement. LC students in statistics were matched with non-LC statistics students based primarily on their score on the first exam, with consideration given to unit section and the students' gender; all students in statistics I had the same instructor for the unit and completed the same exams. Figure 1 and Table 1 summarise the results for the analysis of Statistics I.

The exam I means for the two groups were highly similar, with the LC students (n = 122) earning an average of 80.7% and their matched pairs earning an average of 81.0%. Additionally, the exam results were highly correlated ($r(120) = .988$, $p < .001$; $r^2 = .976$). All analyses indicate that LC students and their matched pairs were highly similar in terms of overall understanding of statistics I material at the time of exam I. Statistical analysis indicates that LC Program participants in Statistics I developed reliably greater mastery over unit content than their matched counterparts who did not participate in the program, earning descriptively higher scores on each exam. Moreover, the observed differences were statistically significant on exam II ($t(121) = 2.585$, $p = .011$), exam III ($t(121) = 4.23$, $p < .001$) and the final exam ($t(121) = 2.640$, $p = .009$).

When the students were divided into groups based on their grade on exam I, the LC Program participants, with one exception (C group, exam IV), descriptively outperformed their matched pairs. The differences in performance were statistically significant for the A students on exam III ($t(33) = 3.305$, $p = .002$); the B students on exam III ($t(41) = 2.119$, $p = .040$); the C students on exam II ($t(19) = 2.233$, $p = .038$) and exam III ($t(19) = 2.451$, $p = .024$); and the D/F students on exam II ($t(25) = 2.553$, $p = .017$) and the final exam ($t(25) = 3.636$, $p = .001$). Perhaps most striking is the 12.4% difference separating the D/F LC participants from their matched pairs on the final exam in Statistics I.

Figure 1. Difference in percentage earned on exams for Statistics I matched pairs

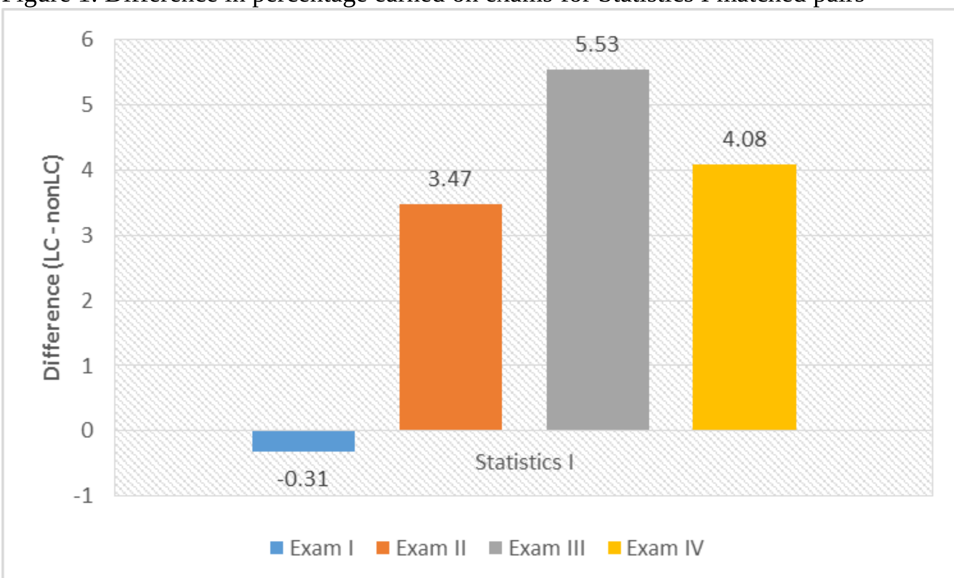


Table 1. Percentages earned on exams, by grade group, in Statistics I

Matching Grade Earned (n)	*Statistics I* Exam I	Exam II	Exam III	Exam IV
Grade of A (34)				
LC	93.78	88.51	86.68**	89.80
Non-LC	93.62	87.07	79.68**	86.23
Grade of B (42)				
LC	84.96	80.06	75.28*	81.91
Non-LC	84.94	79.13	70.50*	79.71
Grade of C (20)				
LC	75.49	77.95*	70.69*	68.08
Non-LC	75.07	71.89*	64.82*	70.04
Grade of D/F (26)				
LC	60.81	70.10*	61.71	70.51***
Non-LC	62.84	61.84*	57.17	58.10***

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Biology

Biology I and Biology II are the first two core units for the biology major and are prerequisites for all upper-level biology courses. Students generally take Biology I in the fall and Biology II in the spring. Biology I topics include fundamental principles in heredity (including Mendelian and quantitative genetics), evolution, population genetics and population ecology. Biology II topics include the structure and function of a cell, the central dogma, DNA replication, cellular energetics and cellular communication. Each unit includes four exams. The fourth exam in Biology I is not cumulative and the fourth exam in Biology II is cumulative for Biology II material only. Exams in each unit are written by the course instructor and are not necessarily the same between unit sections. Students in these units are typically first-year students intending to major in biology, chemistry, biochemistry, neuroscience or exercise science. The results of the data analysis for Biology I and Biology II are summarised in Figure 2 and Table 2.

Biology I. The students enrolled in Biology I had various instructors and were matched primarily on their grade on exam I, taking into account the student's unit instructor, section and gender. The exam I outcomes for the Biology I LC and non-LC groups were highly similar, with both groups (n = 141) earning an average of 83.3%. Additionally, exam I results were highly correlated ($r(139) = .987$, $p < .001$; $r^2 = .974$). All analyses indicate that LC students and their matched pairs were very similar in terms of their understanding of concepts covered on exam I in Biology I. Statistical analysis indicates that Biology I LC Program participants often developed greater mastery over content than their matched counterparts who did not participate in the program. On exams II and III, the LC Program participants earned higher averages than their matched pairs. Moreover, these differences were statistically significant ($t(140) = 2.873$, $p = .005$ and $t(140) = 2.782$, $p = .006$, respectively).

When the students were divided into groups based on exam I grade, the LC Program participants descriptively outperformed their matched pairs the majority of the time. The difference in performance was significantly stronger for the LC participants in the A group on exam II ($t(31) = 2.430$, $p = .021$) and the B students on exam III ($t(64) = 2.180$, $p = .033$). Of note is that LC participants in the D/F grade group scored significantly lower on exam I, the matching exam, than their non-LC counterparts. However, this statistically significant difference disappeared by exam II, when the LC participants outperformed their matched pairs by more than nine percentage points ($t(7) = 2.046$, $p = .080$).

Biology II. The students enrolled in Biology II also had various instructors and were matched primarily on their exam I grade, taking into account the student's unit instructor, section and gender. The average exam I outcome was highly similar among the 111 Biology II students, with LC and non-LC students earning 79.95% and 80.04%, respectively. Additionally, the exam I results were significantly correlated for LC and non-LC students ($r(109) = .976$, $p < .001$; $r^2 = .953$). These analyses indicate that the LC Program participants and their matched counterparts were highly similar in their knowledge and understanding of introductory material in Biology II.

Overall, statistical analysis showed that the performance of the LC group in Biology II remained highly consistent with that of the matched pairs throughout the semester. Descriptively, the average percentage earned on exams II, III and IV was nearly identical for the two groups, and inferential analyses comparing the LC participants with their matched pairs were statistically non-significant ($p > .05$). When the Biology II students were divided into groups based on their exam I grade, the LC Program participants descriptively outperformed their matched pairs 50% of the time, and no statistically significant differences in performance following exam I were identified ($p > .05$).

Figure 2. Difference in percentage earned on exams for Biology I and II matched pairs

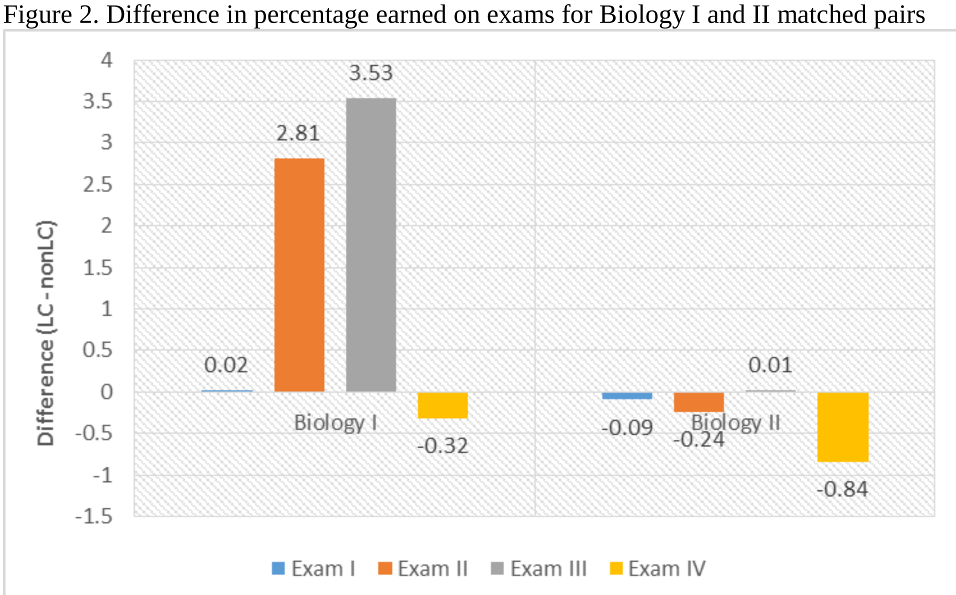


Table 2. Percentages earned on exams, by grade group, for Biology I and II

Matching Grade Earned (n_{BI}, n_{BII})	*Biology I* Exam I	*Biology I* Exam II	*Biology I* Exam III	*Biology I* Exam IV	*Biology II* Exam I	*Biology II* Exam II	*Biology II* Exam III	*Biology II* Exam IV
Grade of A (32, 24)								
LC	93.48	92.07*	85.33	88.46	94.00	91.44	92.31	89.32
Non-LC	93.48	89.13*	85.48	89.11	93.04	90.58	90.36	87.40
Grade of B (65, 32)								
LC	84.93	84.52	81.98*	84.71	85.19	82.63	83.56	78.35
Non-LC	84.97	82.27	78.64*	83.90	85.19	84.59	85.13	82.07
Grade of C (36, 38)								
LC	75.54	77.54	74.96	80.23	75.63	76.12	77.39	73.40
Non-LC	75.53	75.25	68.60	81.49	75.42	76.13	76.53	74.59
Grade of D/F (8, 17)								
LC	63.75*	81.00	71.94	75.87	59.88	64.74	67.09	62.53
Non-LC	67.06*	71.84	65.00	79.91	62.29	63.74	68.76	61.06

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

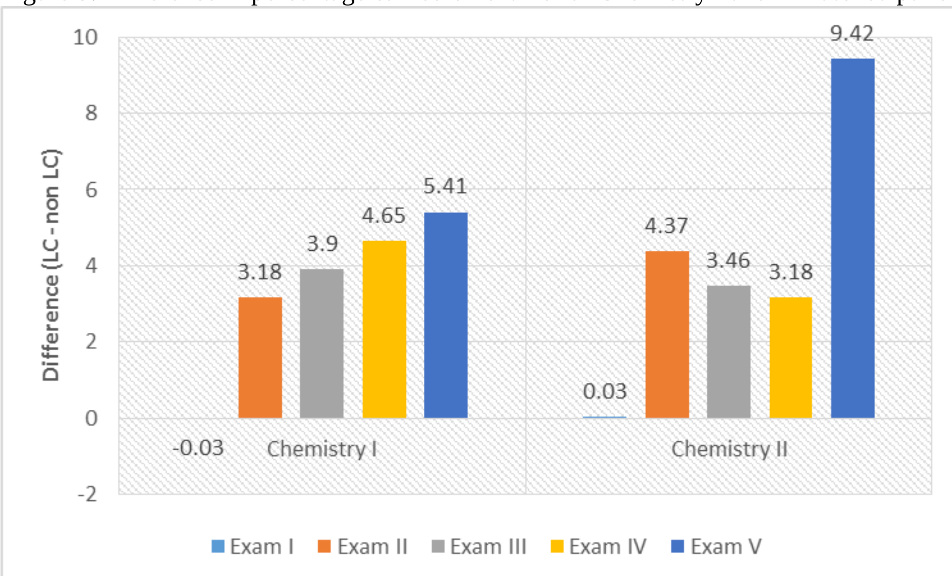
Chemistry

Chemistry I and II comprise a two-semester general-chemistry sequence. Chemistry I is a co-requisite for Biology I, just as Chemistry II is a co-requisite for Biology II. This class typically serves first-year students intending to major in the sciences (including exercise science) or complete a pre-health-professions series of units. All instructors during both semesters follow a common syllabus and textbook; however, instructors write their own exams, except for the Toledo Chemistry Placement Examination (standardised American Chemical Society [ACS] exam) and final exams. Chemistry I topics include unit conversions, the concept of the mole, gas laws, thermochemistry, the model of the atom and theories of bonding. Chemistry II topics include intermolecular forces, solution chemistry, equilibrium, acid-base chemistry, and thermodynamics and electrochemistry. Four exams are given in each unit. The final exam in Chemistry I is cumulative, and the Chemistry II final exam is cumulative over both units. Further, the final exam in Chemistry II is the ACS Division of Chemical Education Examination: General Chemistry [2005]. LC students in chemistry were matched with non-LC chemistry students based on both the Toledo exam (an American Chemical Society chemistry placement exam) and exam I, with consideration given to the student's unit section and gender. All results for Chemistry I and II are shown in Figure 3 and Table 3.

Chemistry I. Students enrolled in Chemistry I had various instructors and were matched primarily on their Toledo scores, taking into account the student's instructor, section and gender. Because exam I outcomes were highly variable for students with similar Toledo scores, student pairings with a difference greater than 10 percentage points in exam I outcome were eliminated from the analysis. This measure ensured that all analyses were based upon highly similar and comparable matches and that grade groupings were homogeneous. As a result, 59 matched pairs were retained for analysis of Chemistry I learning outcomes. The scores on the first exam of the semester for the Chemistry I LC and non-LC matched pairs were very similar and strongly correlated ($r(57) = .944$, $p < .001$; $r^2 = .891$); this result suggests that the LC participants and their matched pairs were highly comparable in terms of their understanding of unit content at the start of the semester.

Statistical analysis indicates that Chemistry I LC participants developed descriptively greater mastery over unit content than their matched counterparts; LC students performed between 3.18 and 5.41 percentage points higher than their matched pairs on exams II, III, IV and V.

Figure 3. Difference in percentage earned on exams for Chemistry I and II matched pairs



Additionally, LC Program participants in Chemistry I earned significantly higher averages than their matched pairs ($\alpha = .05$) on exams III, IV and V. When the students were divided into "grade groups" based on their Toledo score, the Chemistry I LC Program participants descriptively outperformed their matched pairs without exception. Although the grade-group sample sizes were small, ranging from seven to 30, the difference in performance was statistically significant for the C students ($n = 14$) on exams III ($t(13) = 2.530$, $p = .025$) and IV ($t(13) = 2.293$, $p = .039$), and for the D/F students ($n = 7$) on the final exam ($t(6) = 4.686$, $p = .003$).

Chemistry II. The students enrolled in Chemistry II also had various instructors and were matched primarily on their exam I scores; additional considerations were the student's instructor, section and gender. A total of 108 matched pairs were retained for the analysis of Chemistry II learning outcomes. The average exam I outcome was similar overall for the two groups at roughly 79.1%. Again, the exam I results were strongly correlated for LC and non-LC students ($r(106) = .999$, $p < .001$; $r^2 = .998$). All analyses indicate that the Chemistry II LC Program participants and their matched counterparts were highly comparable in their knowledge and understanding at the outset of the unit.

Paired-samples statistical tests showed that the performance of the LC group remained consistently and significantly higher than that of the matched pairs throughout the semester. The strongest difference between the two groups was observed on the final exam, the ACS Division of Chemical Education Examination: General Chemistry. LC Program participants in Chemistry II significantly outscored their matched pairs on the ACS, ($t(107) = 4.916$, $p < .001$). When the Chemistry II students were divided into grade groups, the LC Program participants descriptively outperformed their matched pairs on all but one exam (D/F group on exam IV), while significant differences in performance were observed for the A group on the ACS exam ($t(21) = 4.460$, $p <$

.001), the B group on the ACS exam ($t(33) = 2.075$, $p = .046$) and the C group on exams II ($t(32) = 2.691$, $p = .011$) and IV ($t(32) = 2.555$, $p = .016$) and the ACS exam ($t(32) = 3.056$, $p = .004$).

Table 3. Percentages earned on exams, by grade group, for Chemistry I and II

Matching Toledo Score (n_{CI}, n_{CII})	*Chemistry I*					*Chemistry II*				
	Exam I	*Exam II*	*Exam III*	*Exam IV*	*Exam V*	*Exam I*	*Exam II*	*Exam III*	*Exam IV*	*ACS*
≥ 42 (8, 21)										
LC	87.13	85.19	88.75	90.56	82.72	93.88	88.48	88.79	88.52	70.76***
Non-LC	87.06	83.63	87.25	84.63	78.06	93.74	85.95	84.38	86.95	51.10***
34 – 41 (30, 34)										
LC	81.83	77.98	82.91	82.27	75.00	84.82	82.06	79.50	79.62	56.61*
Non-LC	82.75	75.95	81.03	81.72	71.77	84.97	78.32	76.54	75.63	49.46*
27 – 33 (14, 33)										
LC	70.06	74.39	84.09*	83.44*	70.04	74.68	76.77*	75.36	78.53*	51.47**
Non-LC	69.54	69.36	76.49*	75.46*	62.91	74.64	69.74*	70.89	71.53*	40.55**
≤ 26 (7, 22)										
LC	60.57	63.93	78.64	68.80	61.46**	61.52	69.13	71.20	67.85	44.42
Non-LC	57.76	57.71	70.71	54.77	49.32**	61.33	66.15	69.55	70.68	44.35

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

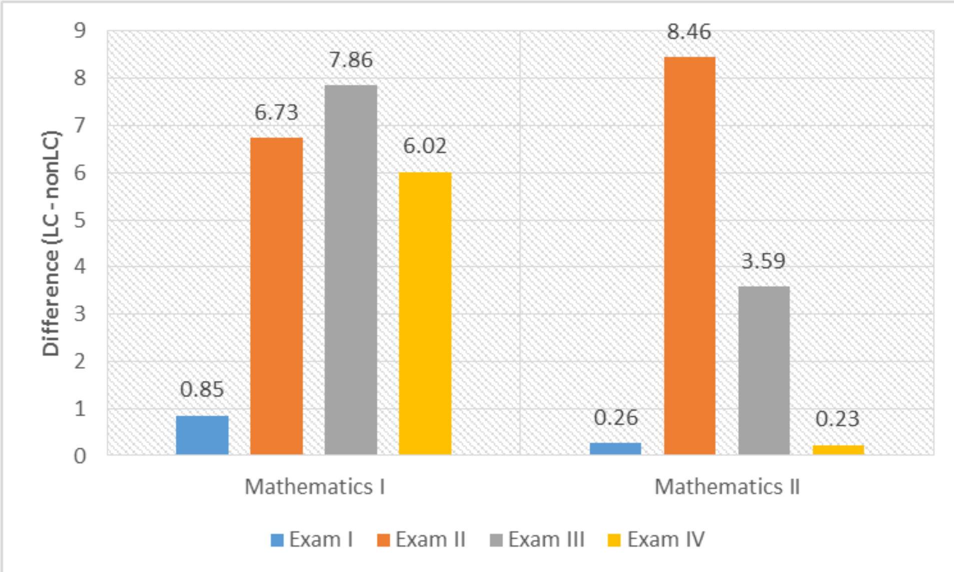
Mathematics

Mathematics I and II form a two-semester sequence that combines the content of a standard calculus I unit with pre-calculus material. It is designed for students who need or want to take calculus, but whose pre-calculus backgrounds are not strong enough to expect success in a standard calculus I unit. Most students are first-year students who hope to major in sciences or engineering. Multiple sections of each unit are offered each semester. Most sections of Mathematics I and II have three midterm exams and a common cumulative final exam, which is constructed each semester by the group of instructors who teach the unit.

Mathematics I. Students participating in Mathematics I had various instructors and were matched on their exam I scores with students enrolled in the same section. The exam I outcomes for the Mathematics I LC and non-LC groups were nearly identical, with the LC Program students ($n = 42$) earning an average of 80.9% and their matched counterparts earning 80.0%. Additionally, the exam I results were highly correlated ($r(40) = .979$, $p < .001$; $r^2 = .958$). These analyses suggest that LC students and their pairs were highly similar in terms of their understanding of and ability to apply introductory unit concepts. The results for Mathematics I and II are shown in Figure 4 and Table 4.

Statistical analysis indicates that Mathematics I LC Program participants developed significantly greater mastery over unit content than their matched counterparts. The LC students significantly outperformed their matched pairs on exam II ($t(41) = 2.827$, $p = .007$), exam III ($t(41) = 2.637$, $p = .012$) and exam IV ($t(41) = 2.444$, $p = .019$). When the students were divided into grade groups based on their exam I grades, the LC Program participants descriptively outperformed their matched pairs on every exam comparison. However, the difference in performance was statistically significant for just the D/F group of students on exam II ($t(8) = 2.837$, $p = .022$) and exam IV ($t(8) = 2.370$, $p = .045$).

Figure 4. Differences in percentage earned on exams for Mathematics I and II matched pairs



Mathematics II. Mathematics II students also enrolled in this unit with various instructors and were matched on their exam I scores within the same section. The average exam I outcome for Mathematics II students was highly similar to that for Mathematics I, with an average percentage of 81.2% for LC participants ($n = 37$) and 80.9% for their matched pairs ($n = 37$). Additionally, the exam I results were strongly correlated for LC and non-LC students ($r(35) = .977$, $p < .001$; $r^2 = .955$).

Overall, statistical analysis shows that the performance of the LC group was descriptively stronger than that of their matched pairs on exams II and III, and less notably on exam IV. This difference was statistically significant on exam II, $t(36) = 3.054$, $p = .004$. When these same 37 students were divided into groups based on their exam I grades, the LC Program participants descriptively outperformed their matched pairs on a majority of the subsequent exams. Perhaps notable are the differences, although statistically insignificant, for the C group, in which LC participants outscored their matched pairs by roughly 8% for exam II, 9% for exam III and 9% for exam IV. There was only one statistically significant comparison for Mathematics II students; this was for the eight students who made up the D/F group, where LC participants bettered the percentage earned by their matched pairs on exam II by nearly 16.0%, $t(7) = 2.614$, $p = .035$.

Table 4. Percentages earned on exams, by grade group, in Mathematics I and II

Matching Grade Earned (n_{MI}, n_{MII})	*Mathematics I* *Exam I*	*Exam II*	*Exam III*	*Exam IV*	*Mathematics II* *Exam I*	*Exam II*	*Exam III*	*Exam IV*
Grade of A (14, 12)								
LC	94.36	88.07	88.07	84.70	94.21	88.40	84.44	80.98
Non-LC	92.38	84.02	74.27	82.29	94.21	81.79	83.29	82.77
Grade of B (7, 7)								
LC	83.79	82.50	81.29	75.23	85.18	78.40	71.30	64.91
Non-LC	83.68	76.50	75.33	67.09	86.21	74.13	73.85	71.26
Grade of C (12, 10)								
LC	74.87	76.56	71.76	72.93	75.93	69.02	68.90	66.36
Non-LC	74.79	71.75	68.96	71.18	74.14	61.23	59.76	57.66
Grade of D/F (9, 8)								
LC	65.53	79.08*	69.78	67.82*	64.63	74.63**	68.00	61.44
Non-LC	64.86	65.06*	62.96	52.17*	64.75	58.88**	62.32	63.00

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Qualitative Results

To provide an understanding of students' perceptions of the workings of the STEM LC Program, all program participants completed a one-page survey at the end of each semester. Researchers were most interested in what students saw as benefits and drawbacks to participation, and how participation affected their study and learning habits.

Benefits. The survey asked, "Describe the primary benefits (if any) of participation in a STEM LC."

Many participants reported that they had enhanced their understanding of unit material, and learned concepts more thoroughly than they would have otherwise. Comments like "It helped me have a deeper understanding of the material," from a biology participant, and "The STEM LC helped me out *a ton*! I began understanding concepts a lot more," from a mathematics student, were typical.

Participants frequently listed improved time management or additional time spent on the unit as another benefit. LCs allowed students to review the material more than they would have on their own, and provided a structured time for studying, ultimately resulting in more time dedicated to the unit. One chemistry student gave this response: "STEM was a great way to set aside two hours of study time each week for chemistry…." A biology student reported, "I studied biology for two hours every Wednesday night. I might not have focused on it for two hours otherwise." Similarly, a statistics student wrote, "I liked having an allotted amount of time that I could focus specifically on stats.… Even when I was busy I knew this was the time I dedicated to stats." Another reported, "It helped me stay current with the class. I did not fall behind as I usually do in stats."

Students also valued the opportunity to meet and work with others in a structured community environment. They met classmates whom they otherwise would likely not have met. They recognised that working together provided them with new perspectives about the material and different problem-solving methods. Comments like, "Learning from more than one person, more than one person's insight, and more people to study with", from a biology student, or "[LC] helped me appreciate the value of studying with others," from a statistics student, were common. One mathematics student reported benefitting from "hearing other classmates' questions and what was problematic for them". A chemistry student wrote, "I met people with whom I could study the [unit] material outside of class and LC…."

Participants cited the opportunity to ask questions of both peers and leaders in the LC setting. Some, like the biology student who wrote that the LC provided a "safe environment [in which] to get help and ask questions," acknowledged feeling more comfortable asking the questions they really wanted answered. Many participants, like this mathematics student, simply reported that their STEM LC was "a place to ask questions on difficult problems/concepts".

Additionally, our students valued the regular review of unit content that this program provides, especially as preparation for exams. Two biology participants responded, "great review session and firms up knowledge" and "the constant review helped me to succeed on tests"; these responses were typical.

Lastly, students who participated in the chemistry, mathematics and statistics LCs recognised that they benefitted from doing the additional practice problems. As a statistics student responded, "it was helpful to get extra questions and help figuring them out." Another reported doing "more practice problems and [realising] that is the most beneficial way to study".

Drawbacks. The survey asked, "Describe the primary drawbacks (if any) of participation in a STEM LC."

The most commonly cited disadvantages fell into three categories: time commitment, lack of focus and group decision-making. While recognising the benefit of the regular, scheduled time devoted to the subject, many students reported that two hours was too large a commitment during some weeks. A statistics student wrote, "two hours was too much to commit to when I had other assignments.". A mathematics LC member wrote that it was a "long session, [and I] would rather have two short sessions." However, a chemistry student felt that the two-hour weekly meeting afforded only "limited time for all questions to be answered". Ten percent of those who reported that the time commitment was a disadvantage also volunteered that participation was "well worth it" in spite of the time demand, or acknowledged that they "benefitted from each meeting", as two chemistry participants put it.

A lack of focus or participation by certain group members had frustrated LC participants in each discipline. One chemistry student noted, "Sometimes we would get off track talking about things other than chemistry." Another, from statistics, wrote, "LC sometimes got side-tracked and I felt like I wasn't getting any help." A biology student simply stated, "A learning community that doesn't participate is frustrating."

LC members also recognised that lack of control of the group's agenda and activities was a drawback. They reported that at various times, the groups moved too quickly or too slowly, and spent too much or too little time on various topics. A mathematics participant noted that "people are at different points in learning the material", and a chemistry student that "we don't always do things that I have trouble with." Another chemistry student summed up the sentiment: "What you want to work on isn't always what the group wants to work on."

Program Impact. The survey asked, "Describe the impact of the STEM LC experience on the way you study and learn in STEM [units]."

Because the majority of students in the science and mathematics units are first-year students (often with poor study skills) who hope to major in STEM areas, the LC Program goals include improved study habits that could also extend to other classes. Students did, in fact, report that they now studied differently as a result of participation in the STEM LC Program. This included knowing better what to study, spending more time actually studying, starting test preparation earlier, asking more questions, participating more, keeping current with the unit work and (in chemistry and mathematics) doing more problems, and, as a mathematics LC member noted, doing them in different ways. One biology student stated, “Learning community made me see what things I understand clearly and what things I definitely need to study more and in a more effective way”. A chemistry student shared that the LC “ helped me develop good study habits and taught me to study earlier”; a mathematics student wrote, “It has helped me learn how to dissect problems into pieces I understand.”

LC members reported that they now collaborated and worked in study groups outside of LC meetings more as a result of their experience in the program. Common responses included “It showed me that talking to people helps me learn”, from biology, and “I’ve truly learned the importance of working with others and how helpful it is”, from chemistry. It appears that students are, as we had hoped, extending their LC tools to other classes, which can be seen from comments like, “it has helped me form study groups not only in chemistry, but [in] other [units] as well”.

Finally, many of our students recognised that they learn material more thoroughly and focus more on concepts as a result of their participation in the STEM LC program. One biology student reported that, “rather than staring at notes and memorising material, we actually learned and UNDERSTOOD the material”. A statistics student reported that “[STEM LCs] helped me to understand what I was learning instead of memorising formulas”.

Discussion

STEM education reform remains a goal of higher education. The evolution of this reform has moved from a teacher-based model towards a student-centred model (Weimer 2002). Active and collaborative learning pedagogy and techniques encourage learners to more thoughtfully engage with unit material as they create more-meaningful knowledge. The LC Program described in this paper, modeled after PLTL, represents an effort to better engage students and foster deeper understanding in introductory classes across multiple disciplines.

Quantitative results

Statistics. Consistent with results of several recent studies examining the impact of PLTL in STEM education (Horwitz & Rodger 2009; Loui & Robbins 2008; Liou-Mark et al. 2010; Petroy-Kelly 2007; Preszler 2009; Quitadama et al. 2009; Tenney & Houck 2003), participation in the STEM LC Program appeared to positively affect student learning. Statistics I students who enrolled in the STEM LC Program performed significantly better, as a group, than their matched pairs on all formal measures of student learning used in this study. Moreover, the STEM LC experience may have had the most impact on Statistics I students at risk for failing to meet minimum learning objectives: Statistics I LC participants who earned a grade of C or D/F on exam I significantly outperformed their matched pairs on the final two exams (out of three for the semester) in the unit. This may provide evidence that Peer-Led LC programs may be particularly effective in targeting students who are underprepared to successfully meet the demands of introductory statistics units (Arum & Roksa 2011; Coughlan & Swift 2011; Porter & Polikoff 2012).

Biology. There were marked differences in the impact of the STEM LC Program on student performance between Biology I and Biology II. Consistent with previous PLTL-based studies in biology (Peteroy-Kelly 2007; Preszler 2009; Tenney & Houck 2003), students enrolled in Biology I LCs outperformed non-LC students on two of the three unit exams. In Biology II, however, no significant difference in performance was observed for any unit exam. The different results between the Biology I and Biology II data suggest that the STEM LC Program does not work equally well in all classes.

Biology I and Biology II differ in the types of content covered. Biology I is a quantitative, problem-solving-based unit most similar to the other disciplines in this study. In contrast, Biology II is highly conceptual. It is possible that the STEM LC Program is currently better equipped to help students develop their quantitative skills in Biology I than the more conceptual reasoning skills required in Biology II. Whether this is unique to this specific program or more widespread is less clear. While enhanced conceptual-reasoning skills in biology and critical-thinking skills in organic chemistry have been reported for PLTL participants (Peteroy-Kelly 2007; Quitadamo et al. 2009), most published PLTL studies to date have focused on academic performance (measured by exam and unit grades) and less on the acquisition of specific learning skills.

Chemistry. Chemistry I and II showed statistically significant improved test scores for LC members on nearly all exams, including both final exams. This is not surprising, as PLTL models have proven successful in the general-chemistry classroom (Gosser, Kampmeier & Varma-Nelson 2010; Hockings, DeAngelis & Frey 2008). Of significant note was the particularly large improvement for students in Chemistry II on the standardised ACS General Chemistry exam. This exam, which tests across both semesters, should assess students' chemistry knowledge with less bias than individual instructors' exams. Lewis and Lewis (2005) similarly noted an improvement on an ACS exam after the first semester of chemistry for students participating in a PLTL-type program. Improvement on the ACS (organic) final exam has also been seen in the organic-chemistry classroom (Wamser 2006). However, these types of results are not universal (Mitchell et al. 2012; Lewis 2011).

When scores were divided into subgroups according to grade, nearly all LC subgroups outperformed non-LC counterparts. In Chemistry I, statistically significant differences were observed for C and D/F subgroups only in the second half of the semester (Table 3). These results point to the positive impact of the LC Program on more at-risk students, later in the semester. It is not surprising that no significant gains were found on Exam II, considering that this test covers material that is already familiar to many students.

In contrast, Chemistry II covers material that is less familiar for most students. This may account for the statistically significant differences in the final-exam performance of the A, B and C subgroups. Unlike Chemistry I, however, the D/F matched pairs scored similarly on the final exam. This may be due to decreased motivation as these students realised their efforts might not affect their overall unit grades.

Mathematics. Consistent with the general findings, and more specifically with a very recent study of the effectiveness of PLTL in mathematics (Reisel, Jablonski & Munson 2013), LC participants in Mathematics I and II outperformed their matched pairs on all exams. These differences lacked statistical significance, though, due to small sample size. One factor contributing to the small sample size could be a lack of large-scale student "buy-in" to join mathematics learning communities.

A recent study by Reisel et al. (2013) may provide some insight to why mathematics students at this level tend to choose not to participate in the LC program. The authors noted larger effects of PLTL participation on unit grade performance for calculus students than for precalculus students. They attributed this to lower motivation and effort. A similar phenomenon may have been affecting our Mathematics I and II students.

Qualitative results

Qualitative analysis of the program shows similar themes across the four disciplines in which LCs were implemented. LC participant comments suggests that STEM LC students believe their LC experience improved their time management skills and provided necessary opportunities for practice within the discipline. Furthermore, the STEM LC Program helped students realize that true learning is about understanding of concepts and relationships and not simply memorization of facts, definitions, or equations. Many participants reported a realization of the value of collaborative problem solving through their experience in the program. These results lend support the theories of Peteroy-Kelly (2007) who suggested that PLTL helps students develop conceptual understanding and Quitadamo et al. (2009) who propose that such programs may aid the development of critical thinking.

Study Limitations

This non-random, mixed-method study demonstrated that participants in STEM LCs out-performed non-participants on most exams, across disciplines; however, there was variability in performance data within the same unit, between semesters and between disciplines. This variability could be due in part to the non-random nature of the study design, but may also be attributed to several confounding factors in the analysis, including instructor differences in multiple sections of a unit, students' prior involvement in the LC Program and the diversity of students' experiences as participants.

STEM LCs were offered to students enrolled in numerous sections of the same units. In all units except applied statistics, multiple instructors were involved in teaching the class sections. While these instructors worked from a broad common syllabus, they may have emphasised different material. In addition, individual instructors wrote their own exams with varying emphases. In this study, LC participants were matched with non-LC participants in their same unit section; however, all unit data were pooled for analysis. Variation across sections may have contributed to the variable data described in this study, particularly for mathematics and biology, where section differences are most pronounced.

Students' prior experience with the LC Program was not controlled for in this study. It is possible that after participating in an LC during a first-semester unit, students begin to focus more on concepts and adopt LC study tools in subsequent units. While cultivation of these behaviors is a goal of the program, this "second-semester effect" may be partially responsible for some of the smaller differences observed between participants and non-participants in second-semester biology and mathematics units.

Finally, given the nature of the LC Program, students had diverse experiences during their participation. While each LC was limited to 12 students, the actual size varied from four to 12. Community size affects group dynamics and the type of activities that the leader can facilitate. Furthermore, the LC leaders' experiences varied in the number of semesters they had served in the program and, more importantly, their competence in facilitating, rather than teaching, their groups. For all these reasons, any student participant's experience in an LC likely differed from that of his or her classmates, and this certainly would have contributed to variability in performance.

Implications for Practice

The structure of a PLTL-based multi-disciplinary program will vary widely based on institutional culture and support, and its success requires the careful consideration of program logistics and the particular unit content and characteristics.

Importance of institutional support

The success of any PLTL-based multi-disciplinary program is contingent on support from upper administration, from each department and, most importantly, from the course instructors and peer leaders (Gosser 2001). In this study, support came not only in the form of funding for the program but also through "buy-in" for the program and its theoretical underpinnings. Each participating department and the dean's office contributed funding, which was used to pay student facilitators, provide stipends to faculty liaisons and provide a course release to the program coordinator. Regarding "buy-in", unit instructors and peer facilitators alike recognised the value of collaborative learning and of the program itself. Each unit instructor was asked to introduce the program and encourage his or her students to participate. In addition they were often asked to work with a faculty liaison or student leader on specific unit material during the semester. If unit instructors do not value the program, student perceptions are affected, and the students may choose not to participate. Peer leaders must also recognise the value of collaborative learning and be willing to serve as group facilitators instead of tutors, despite pressure from the group members to tutor them.

During the early years of a PLTL-based program, such as the one described in this study, the program is not yet a part of the student culture. For this reason, students may be reluctant to participate. They may not recognise the value of the program or may worry that it will be too time-consuming. Importantly, there are no students who have been through the program and can speak about their own experiences. To encourage students to participate in the program examined in this study it was necessary to offer them a unit incentive. While this incentive had a minimal impact on student grades, it convinced students to participate in the program. It is possible that the incentive could be eliminated in the future, but it was an important component to get the program started.

Course diversity

This program was offered to introductory STEM students in multiple units across four disciplines. Some, like Mathematics and Chemistry, spend more time on algorithmic problem-solving. Others, like Biology II, are less quantitative. Additionally, the student population of a first-semester course is likely to be different from that of the second. Methods and techniques appropriate for each unit's content, students' background and instructors' emphases need to be employed for optimal impact during PLTL sessions.

Conclusions

The results of this study indicate that an LC Program can improve student performance in introductory STEM units, particularly those that emphasise quantitative reasoning and applications. In addition, students across disciplines within this particular study reported that they valued their participation in the program, and that they gained an appreciation for conceptual learning and collaborative problem-solving.

As STEM educators continue the work of helping students grapple with sometimes confusing and complicated ideas, collaborative-learning techniques, and PLTL in particular, remain useful tools. Providing a time and space for students to more deeply relate to unit material, under the leadership of more advanced and experienced peers, creates opportunities for insight and the development of supportive relationships. The potential then exists for students to work closely with each other, learning more together than apart, beyond these introductory classes and into their professional lives.

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