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Peer-Led Team Learning: A Prospective Method for Increasing Critical Thinking in Undergraduate Science Courses

This study examined the impact of Peer-Led Team Learning (PLTL) on critical thinking gains in science and math courses at a research university in the Pacific Northwest.

In their search for more effective ways to teach college-level science, technology, engineering, and mathematics (STEM) courses, many instructors employ small groups to improve student learning outcomes. Small group learning is considered a best practice in undergraduate education (Angelo & Cross, 1993; Chickering, Gamson, & American Association for Higher Education, 1989; Cooper, MacGregor, Smith, & Robinson, 2000; Springer, Donovan, & Stanne, 1999). National associations recommend small group instruction to promote thinking skill in STEM courses (American Association for Higher Education, 1989; National Research Council, 1995; National Science Foundation, 1996; Tobin, 1993; Tobin, Tippins, & Gallard, 1994; United States Department of Education, 1990).

Peer-Led Team Learning (PLTL) is a specific form of small group learning recognized by Project Kaleidoscope as best practice pedagogy (Varma-Nelson, 2004). PLTL was first developed by Woodward, Gosser, and Weiner (1993) as an integrated method that promoted discourse and creative problem solving in chemistry at the City College of New York. The PLTL method is thoroughly described in other works (Cracolice & Deming, 2001; D. Gosser et al., 1996; Gosser et al., 2001; Gosser et al., 2003; Gosser & Roth, 1998; Woodward et al., 1993). Briefly, PLTL is characterized by a cohort-based social learning structure whereby trained undergraduates, or "peer leaders", guide 4-8 less experienced peers toward conceptual understanding through group-focused science and math problem solving (Cracolice & Deming, 2001; Gosser et al., 2003; Gosser & Roth, 1998; Lyle & Robinson, 2003). Peer leaders are not expected to be content experts or surrogate instructors; rather they are students who have successfully completed the course and have been trained in small group dynamics and learning theory. PLTL usually serves as a supplement to traditional lecture, although some replace a portion of weekly lecture with a PLTL session (Alger & Bahi, 2004; Lewis & Lewis, 2005). Student attendance may be voluntary, pass/fail, or graded. Weekly PLTL sessions are typically 1.5 – 2 hours long, during which time students explore and develop creative solutions to problems. PLTL is thought to work because students who are at similar developmental levels socially negotiate and construct individual meaning (Bruffee, 1993; Collier, 1980; Jones & Carter, 1998; McKeachie, 1990; Springer et al., 1999; Tobin et al., 1994; Vygotsky, 1978). By providing a framework that encourages questioning, analysis,

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discussion, and debate among group members, PLTL is thought to help students collaboratively build their knowledge and master course material (Gosser & Roth, 1998; Jones & Carter, 1998; Springer et al., 1999; Tobin et al., 1994; Woodward et al., 1993).

Influence of PLTL on Student Learning

The positive effects of PLTL on grade performance and student retention are well established. Previous research indicates that PLTL increases the percentage of students receiving an A, B, or C grade and decreases the percentage of students that fail, withdraw, or drop relative to traditional, non-PLTL courses (Alger & Bahi, 2004; Gafney, 2001a; Lyle & Robinson, 2003; Tien, Roth, & Kampmeier, 2002; Tien, Roth, & Kampmeier, 2004; Wamser, 2006). PLTL has been employed in organic chemistry, general chemistry, human anatomy and physiology, and other STEM courses, with grade improvements ranging from 1-29% (Gafney, 2005). PLTL has also improved student retention by as much as 12% at some institutions (Gafney, 2001a).

The positive, but variable, effects of PLTL on grade performance and retention in STEM courses are based primarily on course grade distributions using either control groups or historic grade performance before and after PLTL implementation (Cracolice & Deming, 2001; Gafney, 2001a; Gosser et al., 2003; Lyle & Robinson, 2003; Tien et al., 2002). This provides fodder for skeptics who question PLTL effectiveness and argue that studies based on student grades (Gafney, 2001a; Gunawardena, 2001; Tien *et al.*, 2002; Wamser, 2006; Zurer, 2001) do not provide sufficient evidence because of their subjectivity. For students who experience PLTL in addition to lecture (the most common method), skeptics contend that PLTL students receive higher grades and are more frequently retained because they spend more time on content and problem-solving. Conversely, skeptics argue that students who experience PLTL in lieu of some lectures (a less common method) have higher performance because they are held to mastering less content (Gunawardena, 2001).

Several different types and levels of science and math courses were chosen to determine the range over which PLTL might affect critical thinking, as well as grade performance and retention.

Some studies have tried to minimize subjectivity by using common test bank questions (Alger & Bahi, 2004), analyzing total points prior to assignment of final grades, and maintaining a consistent point threshold for a passing grade (Tien *et al.*, 2002; Wamser, 2006). Others have employed standardized instruments like the American Chemical Society (ACS) test, with mixed results. One study showed no significant differences in pre- and post-test ACS scores between PLTL and non-PLTL groups in general chemistry but did show increased lecture exam scores in the PLTL group (Alger & Bahi, 2004). Another study showed PLTL students in organic chemistry increased their standings in terms of national percentile on the ACS exam relative to a non-PLTL group (Wamser, 2006).

Perhaps of greater concern than grade or standardized test performance is the lack of evidence that shows PLTL students become better critical thinkers than non-PLTL students. PLTL will continue to be criticized until research clarifies this point. Critical thinking is a better measure of student learning than course grades or discipline-specific exams, because it is a common requirement in all STEM disciplines, and because the component skills of critical thinking (Ennis, 1985; Facione & American Philosophical Association, 1990; Walsh & Paul, 1986) can be compared across different STEM content areas, such as science or math.

Purpose of the Study

The purpose of this study was to discover if PLTL influences critical thinking in STEM courses. Several different types and levels of science and math courses were chosen to determine the range over which PLTL might affect critical thinking, as well as grade performance and retention. This multi-layered approach was selected in order to assemble a more complete picture of PLTL effectiveness in STEM courses and to compare potential critical thinking gains across these disciplines. The research questions for this study were:

1. Does PLTL affect critical thinking performance?
2. Do critical thinking gains vary by STEM discipline?
3. Which variables have the largest impact on critical thinking gains?

Methods

Study Context

PLTL was implemented in six undergraduate science and math courses at a research university in the Pacific Northwest according to established PLTL criteria (Gafney, 2001a, 2001b; Varma-Nelson, 2004). Critical thinking was assessed at the beginning and end of several organic chemistry and mathematics courses (see Table 1) using the valid and reliable CCTST (Facione, 1990). Science and math courses were included in the sample, because it was assumed both course types required critical thinking for success. PLTL was employed in some manner in all courses except Discrete Mathematics, which served as a non-PLTL comparison group for critical thinking. Participant demographics are provided in Table 1.

Implementation of the PLTL Model

The choice to use PLTL initially came from a small group of organic chemistry faculty at a research university in the Pacific Northwest that wanted to improve undergraduate critical thinking. Given the reality of teaching large lectures (over 150 students), faculty wanted to give students a more engaging experience than traditional teaching methods had provided, as well as reduce the student fail, withdraw, and drop rate, which had periodically exceeded forty percent. Chemistry faculty first identified student goals for courses based on ACS-recommended learning outcomes (American Chemical Society Committee on Professional Training, 2003a, 2003b). PLTL was chosen after several group learning models were evaluated. Conversations between chemistry and math faculty and shared learning goals eventually led to an invitation to use PLTL in four mathematics courses.

Successful implementation of PLTL required changes to faculty teaching styles. A PLTL learning community comprised of chemistry and math faculty, graduate coordinators, learning specialists, and undergraduate peer leaders was formed. In general, less emphasis was placed on individuals than on group efficacy. This required faculty to reevaluate their role in student learning, a task that proved difficult for some. Faculty provided content and problem solving expertise, organization, and scheduling for PLTL sessions and presented lectures on basic science or math concepts that were subsequently discussed during weekly peer leader training sessions. Graduate coordinators were chosen based on interest in STEM education, and, between PLTL sessions, they served as rovers in order to provide continuity and assistance. Graduate coordinators also helped train peer leaders, and observed peer leader (and faculty) implementation of PLTL during the term.

Successful implementation of PLTL required changes to faculty teaching styles.

Scheduling PLTL sessions for a large number of students was a logistical challenge. One lecture per week was replaced with a two-hour PLTL session that took place on Wednesday, Thursday or Friday. Software was used to assign four to eight students to specific peer groups based on schedule availability. PLTL attendance was mandatory for all courses, except for one section of Organic Chemistry II (optional) and Discrete Mathematics (non-PLTL comparison group). Students worked with their assigned groups for the entire term unless significant problems required transfer to another group.

Peer Leader Recruitment and Training

Peer leaders were recruited from a pool of students that had successfully completed the class and earned at least a B grade. Prospective peer leaders completed a written application and interview, which were discussed by course instructors and graduate coordinators. Interview questions were chosen from a PLTL handbook (Roth, Cracolice, Goldstein, & Snyder, 2001). Selected peer leaders received a stipend of $500 per semester. A one credit special topics course was also available for chemistry peer leaders. Math peer leaders were incorporated into an existing tutoring program.

PLTL training based on the national PLTL model (Roth *et al.*, 2001) was conducted prior to the start of the term in conjunction with the university's Center for Teaching and Learning. Discussed topics included multiple intelligences (Gardner, 1987), the key role of the peer leader, methods for building group dynamics, and methods for modeling problem solving and critical thinking. Particular emphasis was placed on ability to: (a) ask leading questions, (b) stimulate peer interaction and group problem solving, (c) balance boisterous and reserved student personalities, (d) allow sufficient wait time, and (e) treat all students with respect.

Instructors and peer leaders met weekly throughout the academic term to draft problem sets and discuss problem solving strategies. Problem sets expanded on lecture concepts and were sufficiently rigorous as to require group work. Conceptual understanding of course material was emphasized over rote memorization. Peer leaders were not informed of the "correct" solution to the problems, nor were they expected to provide one for the students. Rather, instructors discussed a range of possible ways to approach the problem set, provided hints for reasonable problem solving pathways, and suggested appropriate leading questions that peer leaders could use with their group during the week. Ongoing challenges, role-playing scenarios, testimonials from experienced peer leaders, and techniques for overcoming common conflicts (e.g., dominant students) were also addressed.

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A Typical PLTL Session

Four to eight students met weekly with their peer leader to address the problem set, which was provided at the beginning of each session. Students assembled into groups in their assigned rooms and, once they received the set, began by clarifying the intent of each problem. Then, students began to free think creative approaches to the problem by verbally describing, drawing, or representing their thought process on a whiteboard or butcher paper. Students analyzed the elements of each problem, discussed potential solution pathways, and argued over the relative merits of each approach until they reached a consensus. A peer leader roamed the room, asking leading questions to stimulate thinking, promoting group efficacy, and addressing student frustrations. Students were allowed to use any available resource, including textbooks. Each group's consensus solution was then shared out to other groups using course management software; this allowed each group to compare their work with others and to reflect on their problem solving effectiveness. Each group received process and solutions feedback from the course instructor. Course instructors further reinforced the PLTL model by including similar types of problem solving questions on exams.

Organizational and Institutional Support

The pedagogical vision, instruction, and organization provided by the learning community were necessary, but insufficient, to fully implement PLTL. Administrative support at the college and departmental levels was also necessary. Initial support was provided through internal professional development funding; however, PLTL continuation required institutional support. Previous reports by Kampmeier (2003) suggest a PLTL maximum cost per student of approximately \$100; in the current study, a target cost of \$62 per student was used. To fund PLTL after grant funds were depleted, \$25 was collected as a course fee, \$25 was matched by the College of Science, and the remaining \$12 per student was funded by the Department of Chemistry. The rationale used to justify institutional expenses included increased student retention, stronger student preparation, and increased student satisfaction.

Research Design and Data Analysis

A quasi-experimental pretest/posttest control group design was used to determine critical thinking gains in PLTL/non-PLTL and science/math groups. This design minimizes threats to internal and external validity (Campbell & Stanley, 1963) and was appropriate because intact groups were used. Remaining threats of history, maturation, pretest sensitization, selection, and statistical regression toward the mean were minimized by administering CCTST pretests and posttests 14 weeks apart, using a valid and reliable instrument to assess critical thinking (Facione, 1990) and including multiple co-variables (e.g. gender, class standing) in the statistical analysis. A frequency distribution of critical thinking gains was constructed to evaluate sample randomness.

An embedded experiment for Pre-Calculus was conducted within the context of the quasi-experimental design. Four concurrent sections of Pre-Calculus Math provided an opportunity to more specifically investigate PLTL impacts in math while controlling for instructor and course. Two instructors each taught two sections of Pre-Calculus, one of which utilized PLTL and the other of which did not. Critical thinking gains were then compared between PLTL and non-PLTL sections by instructor and course.

Influence of PLTL on Critical Thinking Gains, Grade Performance and Student Retention

Students were divided into PLTL and non-PLTL groups, or science and math groups, and the impact of PLTL on critical thinking gains was assessed. Critical thinking was determined using a paper version of the CCTST (Facione, 1990; Facione, Facione, & Giancarlo, 1992; Facione, Facione, & Insight Assessment, 2004). Raw scores were used for all analyses, but in some cases scores are reported as national percentile rank based on an equivalency conversion scale provided by the test manufacturer in order to increase clarity and relevance. Critical thinking gains were compared between PLTL/non-PLTL and science/math groups using mean, standard deviation, and effect size, as well as two-way repeated measures analysis of variance (RM ANOVA). The two-way RM ANOVA was employed due to the use of matched pre- and post-test scores and a comparison group. Gender, ethnicity, academic term, and class standing co-variables were concurrently analyzed in order to increase statistical accuracy and precision and minimize validity threats. RM ANOVA assumptions of homogeneity of variance, co-variance, and normality were evaluated using Levene's and Box's tests and by constructing a frequency distribution of critical thinking gains, respectively.

Grade performance and student retention was analyzed using percent of students receiving an A, B, or C grade in the course (%ABC), and percent of students that failed (D or F grade), withdrew, or dropped the course (%FWD). Percent ABC and % FWD were each subsequently divided into female and male categories and compared across PLTL and non-PLTL groups.

Table 1: Demographics for PLTL and Non-PLTL Groups by Course

Method	Course	N	Class Standing (%)					Gender (%)	
			Fr	So	Jr	Sr	2nd Sr	M	F
PLTL	CHEM 340	212	5	55	29	10	1	40	60
	CHEM 342	62	2	50	29	18	2	44	56
	MATH 251	25	44	28	28	0	0	8	92
	MATH 252	27	0	30	59	11	0	11	89
Non-PLTL	MATH 107	142	79	13	6	2	0	63	37
	MATH 216	84	11	37	43	7	1	86	14
Total		552	26	39	26	8	1	50	50

Table 1a: Demographics profile for the study sample

Method	Course	N	Ethnicity (%)					
			Caucasian	Asian American	Latino	African American	Native American	Other*
PLTL	CHEM 340	212	86	5	0	1	2	5
	CHEM 342	62	87	6	0	5	2	0
	MATH 251	25	84	12	0	0	0	4
	MATH 252	27	96	0	0	0	0	4
Non-PLTL	MATH 107	142	78	6	4	2	1	8
	MATH 216	84	65	17	0	1	0	17
Total		552	82	7	1	2	1	7

Course names refer to first and second term organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); first and second term mathematics for elementary teachers (MATH 251, 252), and discrete mathematics (MATH 216).
*Includes 'choose not to answer' response.

Results

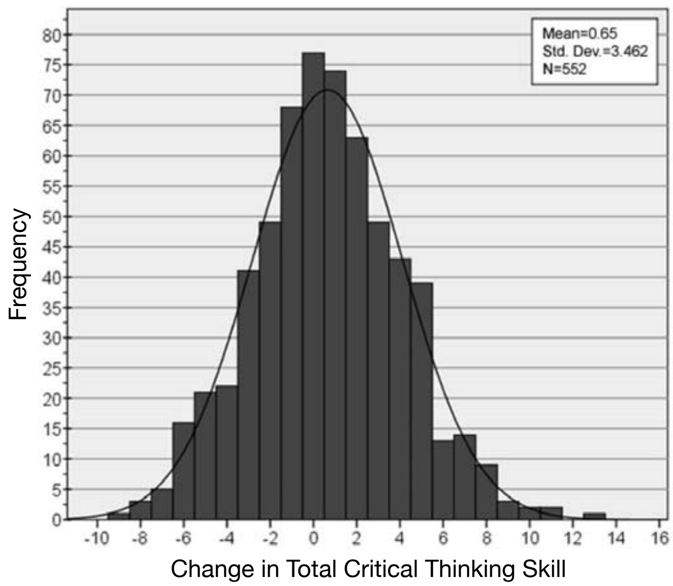
Participant Demographics

A distribution of class standing, gender, and ethnicity (see Table 1) indicated that the majority of students were sophomores and juniors except for in the Pre-Calculus course, which was comprised mainly of freshmen. Although gender distribution was an even split for the total sample, it varied considerably by course, with predominantly female class composition in the Math for Elementary Teachers course and predominantly male class composition in the Discrete Mathematics course. Over 80% of participants were Caucasian, with Asian American, Other, African American, Latino/Hispanic, and Native American students comprising the remainder in decreasing frequency (Table 1a).

Statistical Assumptions

The Levene's and Box's tests used to evaluate critical thinking gains showed that the homogeneity of variance and co-variance assumptions were met for the PLTL/non-PLTL group, $F(1, 549) = 0.100$, $p = 0.752$, and $F(3, 542) = 1.361$, $p = 0.253$, but not for the science/math group, $F(5, 545) = 5.264$, $p = 0.000$, and $F(15, 530) = 3.068$, $p = 0.000$. Figure 1 shows that the distribution of critical thinking gains approximated a standard normal curve.

Figure 1: Frequency Distribution of Critical Thinking Gains



Distribution of critical thinking for the experimental sample. Gains are indicated by difference in CCTST pretest and posttest raw scores.

Influence of PLTL on Critical Thinking Gains

A significant interaction was observed for critical thinking gains and PLTL, Wilk's $\lambda = 0.984$, $F(1, 545) = 9.068$, $p = 0.003$, power = 0.852, partial $\eta^2 = 0.016$. Table 2 shows raw score gains in PLTL and non-PLTL groups. PLTL accounted for 1.6% of the variance in critical thinking gains, with PLTL students demonstrating approximately 9 times greater gains than non-PLTL students in science but not math courses. PLTL students had an average national rank increase of 5.38 (61st to 66th national rank). Figure 2a shows critical thinking national percentile gains in PLTL and non-PLTL groups.

Gender, ethnicity, class standing, and academic term did not significantly affect critical thinking gains. In contrast, a post hoc comparison of gains relative to prior critical thinking showed that students with the highest prior skill had the largest gains in critical thinking, whereas students with low prior skill exhibited the largest decreases. Specifically, students scoring 2 standard deviations above the sample mean gained nearly 39 percentile (44th to 83rd national rank). As prior thinking skill decreased, performance dropped steadily, with gains of 18 percentile (53rd to 71st national rank) for +1 standard deviation, decreases of 2 percentile (65th to 63rd national rank) for -1 standard deviation and decreases of 23 percentile (72nd to 49th national rank) for -2 standard deviation of prior thinking skill.

Influence of Course Type on Critical Thinking Gains

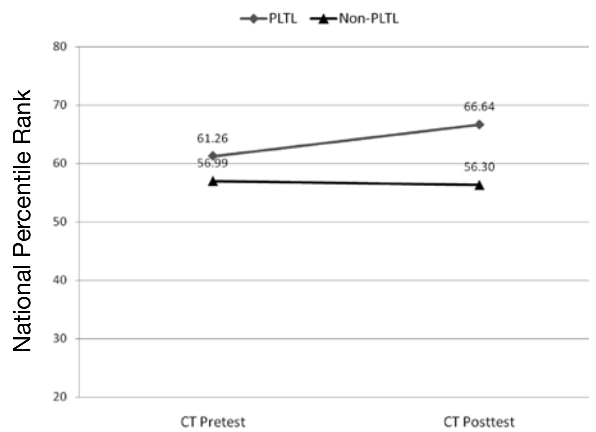
A significant interaction was also observed between critical thinking gains and course type, Wilk's $\lambda = 0.973$, $F(5, 541) = 3.049$, $p = 0.010$, power = 0.869, partial $\eta^2 = 0.027$. Science students showed average critical thinking gains of 6.27 percentile (67th to 74th national rank), whereas math students showed average gains of 0.95 percentile (53rd to 54th national rank). Course type accounted for 2.7% of critical thinking gains, which was nearly 6 times greater for science students than math students. Figure 2b shows critical thinking national percentile gains by course type.

Table 2: Influence of Method on Critical Thinking Raw Score Gains

Method	Course	N	Mean (pre)	S.D. (pre)	Mean (post)	S.D. (post)	CT Change
PLTL	Chem 340	212	19.69	5.01	21.03	4.65	1.34*
	Chem 342	62	20.52	4.73	21.42	4.92	0.9*
	Math 251	25	15.48	3.33	15.60	3.99	0.12
	Math 252	27	16.11	3.33	16.56	3.71	0.45
Non-PLTL	Math 107	142	16.73	3.91	16.94	4.00	0.21
	Math 216	84	19.31	6.20	19.14	6.40	-0.17
Total		552	18.60	5.04	19.23	5.16	0.67

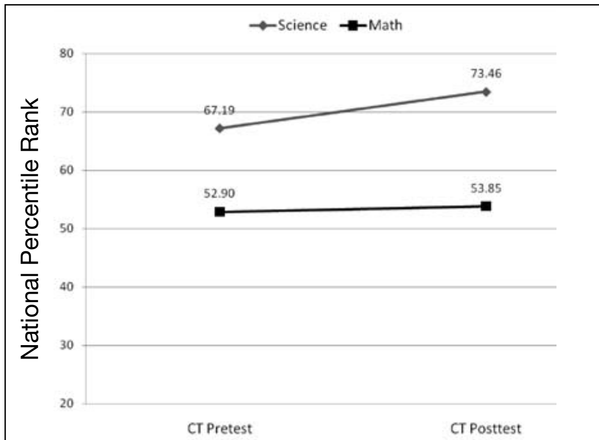
Critical thinking gains indicated by CCTST raw scores. Course names refer to organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); mathematics for elementary teachers (MATH 251, 252) and discrete mathematics (MATH 216). S.D. indicates standard deviation.
*Significant at 0.05 level.

Figure 2a: Influence of Method on Critical Thinking National Percentile Gains



Comparison of critical thinking gains between PLTL and non-PLTL groups. National percentile ranking was computed from CCTST raw scores using an equivalency scale from Insight Assessment and a linear conversion script in SPSS. Values above data points represent mean national percentile rank.

Figure 2b: Critical Thinking Gains by Course Type



Comparison of critical thinking gains between science and math groups. National percentile ranking was computed from CCTST raw scores using an equivalency scale from Insight Assessment and a linear conversion script in SPSS. Values above data points represent mean national percentile rank.

Influence of PLTL on Grade Performance and Student Attrition

Historical and PLTL grade performance was compared using %ABC to indicate achievement (see Table 3). Comparisons were based on total percent of students receiving A, B, or C grades; male and female %ABC was also determined for both science and math courses. In general, science students showed a 3% increase in total %ABC when historical (65%) and PLTL (68%) grade performance were compared. The science course grade improvement corresponded with critical thinking gains of approximately 7 national percentile. When analyzed by gender, female science students showed a 12% increase (60% historical to 72% PLTL), whereas male science students showed a 5% decrease in %ABC (70% historical to 65% PLTL). These results indicated that female science students, who on average performed less well than males prior to PLTL, erased those deficits and outperformed males when PLTL was used.

Although no significant critical thinking gains were observed for math students, they did show an 11% increase in total %ABC when historical (66%) and PLTL (77%) grade averages were compared. Female math students showed a 10% increase (67% historical to 77% PLTL), whereas male math students showed a 1% increase (64% to 65%) in %ABC. These results indicated that female math students, who on average performed at about the same level as males historically, outperformed males when PLTL was used.

Historical and PLTL attrition was also compared. For both science and math courses, total %FWD was calculated, as well as female and male %FWD. In science courses, PLTL students had 3% lower attrition than they had historically. When analyzed by gender, 12% percent fewer females

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failed, withdrew, or dropped science courses when PLTL was employed. In contrast, 5% more males dropped when in PLTL science courses. Lower attrition was seen in all math courses using PLTL; total %FWD went down 9% (33% to 26%), female %FWD decreased by 10% (33% to 23%), and male %FWD decreased by 1% (36% to 35%). Collectively, grade performance and student attrition data indicated that male-biased historical advantages were reduced or eliminated when PLTL was used. In all cases, use of PLTL served to equalize grade performance and reduce attrition gaps between males and females.

Table 3: Grade Performance and Retention by Method and Discipline

Course	Historical Baseline (1997-2000)						PLTL (2000-2001)					
	%ABC			%FWD			%ABC			%FWD		
	Total	F	M	Total	F	M	Total	F	M	Total	F	M
CHEM 340	67	63	71	33	37	29	67	67	66	33	33	34
CHEM 342	63	57	69	37	43	31	70	77	63	30	23	37
MATH 107	50	55	47	50	45	53	60	66	56	40	34	44
MATH 251	67	67	62	33	33	38	75	77	65	25	23	35
MATH 252	75	75	71	22	25	29	86	88	76	13	12	24
MATH 216*	59	66	58	41	34	42	80	71	81	20	29	19
Total Science	65	60	70	35	40	30	68	72	65	32	28	35
Total Math	66	67	64	33	33	36	73	77	65	26	23	35

Historical and PLTL grade performance and course attrition indicated by percent students passing the course (%ABC) or failing, withdrawing, or dropping (%FWD) the course, respectively. Course names refer to organic chemistry for majors (CHEM 340, 342); pre-calculus (MATH 107); mathematics for elementary teachers (MATH 251, 252); and discrete mathematics (MATH 216). *Course used as a non-PLTL comparison group.

Discussion

The purpose of this study was to discover whether PLTL could promote critical thinking in undergraduate STEM courses. Results indicated that PLTL students showed small but significantly greater critical thinking gains than non-PLTL students in science but not math courses. National percentile gains indicated PLTL had a practical influence on critical thinking, an outcome not observed in non-PLTL courses. Critical thinking gains were unaffected by gender, ethnicity, class standing or time of year; however, students with high prior thinking skill gained disproportionately more than students with low prior skill. PLTL appeared to reduce gender-based grade bias, with females receiving passing grades more frequently and dropping or failing the course less frequently than in non-PLTL courses.

PLTL appeared to help underperforming students make positive gains in critical thinking. For example, the largest gains in critical thinking in this study occurred during a second-term Organic Chemistry I course containing a high percentage of students who previously had failed the course (PLTL was not used). In these PLTL courses, average gains of 17 national percentile were seen, which is surprising since these students were 18 national percentile lower than their peers at the onset of the class. These results indicate PLTL may provide a venue for underperforming science students to develop necessary critical thinking skills.

In order to ensure fairness and consistency for all students, institutions of higher education should consider explicitly teaching critical thinking skills rather than assuming all students possess them *a priori.*

Although gender did not influence critical thinking gains, females, who had historically lower grade performance and retention in both science and math courses, were retained and received passing grades more frequently than males when PLTL was employed. Male biased grade performance and retention issues were essentially erased, and in some cases they were reversed to favor females in both science and math courses using PLTL. While it is not completely clear which particular aspects of PLTL helped, it is reasonable to suggest that the collaborative nature of PLTL supported increased female performance and retention. Conversely, males may have done less well in PLTL courses than historically due to an emphasis on collaboration instead of competition. Collectively, this data seems to indicate that PLTL helps ensure a more level playing field for student learning, regardless of gender.

Instructor commitment to PLTL also played an important role in critical thinking gains. A comparison of gains in Organic Chemistry I between successive fall terms showed highly consistent results (6.24 and 6.19 national rank increases, respectively) when both courses were taught by a strong PLTL advocate. Furthermore, when Organic Chemistry I and II were taught in successive terms by the same instructor, students showed a 6 percentile and additional 4 percentile gain for the first and second terms, respectively. It may be that students reach a saturation point for gains in critical thinking with particular instructors; however, this interpretation is speculative and will require additional research.

Frequent observations indicated that chemistry instructors integrated PLTL into courses more deeply than most of the math instructors. This may have occurred because the PLTL model is well established for chemistry courses (Baez-Galib, Colon-Cruz, Resto, & Rubin, 2005; Gosser & Roth, 1998; Gosser, Strozak, & Cracolice, 2006; Kampmeier, Wamser, Wedegaertner, & Varma-Nelson, 2006; Lewis & Lewis, 2005; Lyle & Robinson, 2003; Tien et al., 2002; Wamser, 2006; Woodward et al., 1993; Zurer, 2001), but it is less developed in mathematics. Although verbally supportive of PLTL, Pre-Calculus instructors and peer leaders seemed to have difficulty adjusting to the PLTL model, which required them to make a philosophical and pedagogical shift. PLTL had been implemented in Organic Chemistry I and II for one year prior to the rollout in math, so many chemistry peer leaders had opportunity to refine techniques that most math peer leaders were using for the first time. Many of the Pre-Calculus peer leaders also taught as tutors in other math courses, and they may have been unable to separate these differing roles. Thus, the lack of PLTL-based critical thinking gains in Pre-Calculus may have had less to do with the model than with improper implementation, insufficient support, or lack of developed materials.

It was not possible to compare PLTL effectiveness to historical performance, because no baseline measures of critical thinking were collected prior to this study. However, the notion that students with low initial skill may be at a comparative disadvantage is troubling. Considering that many STEM courses require critical thinking for success, students without the necessary prerequisite skills could face an uphill battle that becomes increasingly more difficult as they progress through an undergraduate program. In order to ensure fairness and consistency for all students, institutions of higher education should consider explicitly teaching critical thinking skills rather than assuming all students possess them *a priori*.

The relative lack of within-course controls constitutes a limitation of this study. No pre-PLTL assessment of critical thinking was performed, so it was not possible to determine whether critical thinking gains in Organic Chemistry I courses were a function of the PLTL treatment. PLTL was used in Organic Chemistry I for one year prior to this study; as such, it was not possible to wash out previous PLTL experiences in order to establish a pre-treatment critical thinking baseline. Discrete Mathematics was used in an attempt to provide some context for critical thinking in the absence of PLTL, and course type was included as an RM ANOVA co-variable to more specifically investigate critical thinking across science and math disciplines. However, there is no way to know which student critical thinking gains would have been prior to PLTL implementation.

Developing a PLTL program is not a trivial undertaking. Successful PLTL implementation requires well-trained peer leaders and committed faculty who believe in the method. Like others (Cracolice & Deming, 2001; Tien et al., 2002), this study found that administrative support (i.e., funding, section enrollment, and room scheduling, copying, etc.) is essential to successful PLTL.

Conclusions

Results of this study show that PLTL has a small but positive impact on critical thinking gains in some science courses, and that it improves grade performance and retention in science and math courses, particularly for females. While math students did not show significant critical thinking gains, it is premature to conclude that PLTL does not promote critical thinking in math. Many factors affect the development of critical thinking skills, and more study is necessary to discover their influence. These results indicate PLTL has potential to improve undergraduate critical thinking. Continued development of PLTL and related methods may serve to further enhance critical thinking gains for undergraduate learners.

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