JOURNAL OF RESEARCH IN SCIENCE TEACHING VOL. 39, NO. 7, PP. 606–632 (2002)

Implementation of a Peer-Led Team Learning Instructional Approach in an Undergraduate Organic Chemistry Course

Lydia T. Tien,[1] Vicki Roth,[2] J.A. Kampmeier[1]

[1]*Department of Chemistry, University of Rochester, Rochester, New York 14627*

[2]*Learning Assistance Services, University of Rochester, Rochester, New York 14627*

Received 21 May 2001; Accepted 18 October 2001

Abstract: This study focuses on the implementation of a peer-led team learning (PLTL) instructional approach for all students in an undergraduate organic chemistry course and the evaluation of student outcomes over 8 years. Students who experienced the student-centered instruction and worked in small groups facilitated by a peer leader (treatment) in 1996–1999 were compared with students who experienced the traditional recitation section (control) in 1992–1994. Quantitative and qualitative data show statistically significant improvements in student performance, retention, and attitudes about the course. These findings suggest that using undergraduate leaders to implement a peer-led team learning model that is built on a social constructivist foundation is a workable mechanism for effecting change in undergraduate science courses. © 2002 Wiley Periodicals Inc. J Res Sci Teach 39: 606–632, 2002

Various science councils advise that the classroom should incorporate group activity because it influences how students learn and reinforces the collaborative nature of the scientific enterprise (American Association for the Advancement of Science, 1989; National Research Council, 1996, 1999; National Science Foundation, 1996). This emphasis on student-centered instruction marks a shift from the traditional instructor-centered paradigm, which provides few opportunities for students to become actively engaged in the learning process. In contrast, students working in small groups have opportunities to negotiate meaning and construct conceptual understanding in a community of learners (Brown & Campione, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Small-group instructional methods have been implemented in undergraduate science, mathematics, engineering, and technology (SMET) education (e.g., Brown & Blackburn, 1999;

Contract grant sponsor: NSF/DUE; Contract grant numbers: 9450627, 9455920.
Correspondence to: J.A. Kampmeier; E-mail: kamp@chem.rochester.edu
DOI 10.1002/tea.10038
Published online in Wiley InterScience (www.interscience.wiley.com).

Dinan & Frydrychowski, 1995; Goldschmid & Goldschmid, 1976; Groccia & Miller, 1996; Kelvin, 1993; Paulson, 1999; Rosenthal, 1995). Students experience positive interdependence as they work through problems in a collaborative setting (Johnson, Johnson, & Smith, 1991). Meta-analyses of the impact of small-group learning in undergraduate SMET have demonstrated significant positive effects on student achievement, attitudes, and persistence (Bowen, 2000; Johnson, Johnson, & Smith, 1998; Springer, Stanne, & Donovan, 1999). Despite the demonstrated benefits, Seymour and Hewitt (1997) observed few systemic attempts to incorporate small-group learning in freshman or sophomore SMET classes. Some of the reasons why the majority of undergraduate science courses continue to be taught predominantly in a lecture format include the instructors' concern that they will lose control of the classroom, the belief that interactive learning comes at the expense of content, and the insistence that evidence of greater student achievement precede change (Cooper, 1995; Frederick, 1994).

Student-assisted teaching mobilizes undergraduate students, an underused resource, to provide small-group learning environments without some of the perceived drawbacks mentioned above. (See Miller, Groccia, & Miller, 2001, for an overview of various student-assisted teaching models.) This article reports the results of a peer-led team learning (PLTL) approach (Gosser & Roth, 1998; Sarquis et al., 2001; Woodward, Gosser, & Weiner, 1993) that has been developed, refined, and disseminated in undergraduate chemistry courses around the country. The PLTL model was developed, in part, to address high attrition rates and faculty concerns about student learning in introductory chemistry courses by providing an environment in which students are immersed in an intellectual community, learn to communicate scientific ideas, and work in a problem-solving team (Gosser et al., 1996). (For an overview of the instructional model, see Sarquis et al., 2001. A comprehensive report of the research and development work on the model is available in Gosser et al., 2001.)

The PLTL instructional model preserves the lecture and introduces a new structure, the PLTL Workshop, that requires active engagement of the students with specially constructed material and with each other. Undergraduate students who recently completed the course take on the role of peer leader to facilitate group work for a team of six to eight students. The peer leader is not a teacher or an answer giver; the role of the leader is to guide and mentor. The work of the small group focuses on materials that prompt students to grapple with ideas and apply their conceptual understanding. The instructor tightly integrates the weekly Workshop into the basic structure of the course for the benefit of all of the students in the course. Although peer leaders are expert students, they are not experts in the subject domain or experienced in facilitating productive problem-solving discussions and have been socialized into passive instructional models in previous courses. Thus, leader training is a critical component of the PLTL approach. Course instructors and education specialists work collaboratively to educate the undergraduate leaders to engage all of the students in the Workshop and guide the student–student interactions and problem solving process in productive directions. The leader-training component of PLTL provides a forum for discussing pedagogical ideas and practical applications to prepare leaders to facilitate student-centered instruction. (For leader training materials, refer to Roth, Marcus, & Goldstein, 2001.)

The PLTL Workshop model includes several critical components: organizational arrangements (e.g., size of group), peer leadership and training, materials that are challenging at an appropriate level, and integration with the overall course (Gafney, 2001). The present study evaluates the impact of the overall peer-led team learning environment on student performance, retention in the course, and student attitudes in a first-semester organic chemistry course during an 8-year span. Our premise is that the group activity in the Workshop will promote individual performance and attitudes.

Theoretical Perspective

The PLTL instructional model is grounded in constructivism with the principle that "student understanding is actively constructed through individual and social processes" (National Research Council, 1996, p. 28). The small-group classroom is viewed as a scientific community in which the construction of personal knowledge is mediated by social processes among the individuals (Driver et al., 1994). The PLTL Workshop provides an active and collaborative learning environment for students to discuss, debate, build, and present their understanding and hear the perspectives of their peers. Through the interpersonal interactions as students work together solving problems, ideas are shared, evaluated, and refined, and each individual translates the experience into robust, useable knowledge (Brown & Campione, 1994; Brown, Collins, & Duguid, 1991; Roschelle, 1992).

The role of discourse in learning is at the heart of the scientific enterprise. Consider the development of understanding at a research group meeting where scientists convene to discuss the meaning of their observations and refine their ideas. In scientific practice, empirical results are interpreted, and conclusions are reached through the process of conflict, discussion, and argument as ideas and models are refined and revised. In the classroom, conceptual understanding is "dependent on the opportunity to socially construct, and reconstruct, one's own personal knowledge through a process of dialogic argument" (Driver, Newton, & Osborne, 2000, p. 298). Understanding develops through the course of communicating ideas and interacting with others. As such, instructional models embedding the notion that knowledge is socially constructed have been implemented (e.g., Brown et al., 1991; Collins, Brown, & Newman, 1989; Hatano & Inagaki, 1991). The element of peer discussion is important for "sharing, clarifying, and distributing knowledge among peers" (Rivard & Straw, 2000, p. 585). Another key process observed in student discussion is "connected discourse," the elaboration of students' ideas which leads to more sophisticated reasoning (Hogan, Nastasi, & Pressley, 2000).

A fundamental component underlying many student-assisted learning environments is the facilitation of student interaction by a peer. According to Vygotsky (1978, p. 86), the zone of proximal development is defined as the "distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." Student-assisted instructional models take advantage of the help students can offer one another in learning conceptually rich material. As a near equal, the peer leader is closer to the students' zones of proximal development than the course instructor and thus interacts in ways that are not available to the instructor. The peer also possesses a breadth of experience with the course and content knowledge that a current student could not and has a critical role as a more capable peer in promoting student interaction and exchange of ideas. By encouraging the participation of all students, the peer supports the integrity and autonomy of each student. Conceivably, all students, including women and underrepresented minority groups, have greater opportunities to participate and contribute in the cooperative learning environment (Belenky, Clinchy, Goldberger, & Tarule, 1986; Ibarra, 2001).

The PLTL model shares elements of the cooperative learning model (Johnson & Johnson, 1999; Johnson, Johnson, & Smith, 1991) as students work together to accomplish a shared goal. The PLTL model integrates positive interdependence and face-to-face interaction but also uses the more advanced peer to facilitate the small-group work and encourage individual accountability (e.g., prompting students to explain their understanding to a classmate). The PLTL model does not incorporate formal procedures to teach skills to group members (e.g., Hanson & Wolfskill, 2000), to promote group processing, or to assign roles to individuals. In addition, the work of the group is not graded; the PLTL intervention is group activity to improve individual performance.

The PLTL Workshop approach also bears some similarities with other undergraduate student-assisted learning approaches such as supplemental instruction (Arendale, 1994; Lockie & Van Lanen, 1994; Lundberg, 1990), study group programs (McCuen, 1996; Plecha, 1998), and Emerging Scholars programs (Alexander, Burda, & Millar, 1997; Duncan & Dick, 2000; Garland & Treisman, 1993). The collaborative problem-solving sessions are facilitated by undergraduate or graduate student leaders and often integrate learning strategies with course content. These approaches include a training component to equip student leaders with strategies for learning and studying. However, supplemental instruction and study groups are academic assistance programs that are typically not integrated within the course and do not engage the faculty member. Emerging Scholars programs are designed to support primarily women and minority students, groups with traditionally high attrition rates, and to foster a community of learners in and out of the classroom. The PLTL approach is sharply differentiated from these programs because the Workshop is an integrated and fundamental part of the course structure, constructed by the course instructor for all of the students in the course.

The PLTL model is distinct from other chemistry instructional reforms. Like the guided inquiry method (Farrell, Moog, & Spencer, 1999), the PLTL model emphasizes the active engagement of the students and the social construction of individual understanding. However, the PLTL approach preserves the lecture time and introduces the PLTL Workshop as an integral part of the course. Other chemistry faculty have also introduced cooperative and active learning opportunities into small-enrollment lecture courses (Dinan & Frydrychowski, 1995; Paulson, 1999). The course instructor, as opposed to an undergraduate peer, facilitated the group work in each case; however, this is not always practical.

Method

Study Context

This study focuses on student experiences in a first-semester organic chemistry course at a small Eastern research university in the United States. Results from only one institution implementing PLTL in an organic chemistry course are presented here to limit the variability. Organic chemistry has a reputation for being a challenging course with a competitive culture. Students often come into the course intimidated and anxious, and the course instructor faces traditional problems with attrition and student learning. Many of the students enrolled in the course are pursuing premedical or biological studies and are taking the course to satisfy a requirement. Only a small percentage of the enrolled students are pursuing a major in chemistry.

Before 1995, students attended lecture for 2.5 hours per week (taught by the instructor) and a recitation section for 1.25 hours per week (taught by a chemistry graduate student satisfying the departmental teaching requirement). In the traditional recitation section, the graduate student teaching assistant (TA) answered students' questions and was responsible for knowing what material students were expected to know, for anticipating areas that may give students trouble, and for being able to explain how to solve assigned problems (Nyquist & Wulff, 1996). The activity was typically driven by student questions regarding problems from the text and old exams and was complemented by TA initiative to present minilectures or to review how to do model problems. There was little, if any, promotion of student–student interaction or discussion. The activity was instructor-centered as students took on a passive receptive role in the question and answer format. The training of the teaching assistants was composed of a presemester session in which the graduate students were given some general ideas about teaching a traditional recitation section and met with the course instructor to discuss ideas about teaching organic chemistry. In addition, the TAs met weekly with the course instructor for 1 hour; this meeting emphasized administrative issues and gave the instructor the opportunity to communicate specific topic areas he wanted the graduate students to stress in the following week's recitation.

In 1995, a pilot test of the PLTL approach was implemented, including the credit-bearing training course for the peer leaders; the instructor gave students the choice of signing up for either the weekly recitation or the Workshop. The Workshop, constructed on the PLTL model, met for 1.5–2 hours. Forty percent of the students selected the Workshop that semester, and the remainder opted for the recitation section. Each recitation had about 20–25 students assigned, whereas about 8 students were assigned to each Workshop section. Recitation and Workshop students selected a section according to the times they were available. There was no attempt to form groups based on ability or ethnic diversity. Most of the organic chemistry students had previous experience with a recitation section in general chemistry, introductory biology, or calculus courses. The Workshop problems were distributed to all students in the course and were used to structure the Workshop activities. The recitation TAs were provided with the Workshop materials and encouraged to implement the problems in their sessions. A comparison of student performance indicated that Workshop students earned significantly higher course grades than traditional recitation students, $t\ (288) = 3.23$, $p < .01$.

Based on the preliminary evidence of the effectiveness of the PLTL approach during the pilot year, the Workshop was scaled up for the entire course in 1996, and the traditional recitation section was eliminated. Because of a possible volunteer effect, the 1995 cohort is not included in the performance analyses described below. The pre- and post-1995 groups were designated as the control (traditional recitation section, 1992–1994) and treatment (PLTL Workshop, 1996–1999) groups. Over this period, the class sizes ranged from 260 to 380. The same instructor taught the course using *Organic Chemistry*, Third and Fourth editions, by McMurry (1996), from which the instructor assigned text readings and problems for every class. The instructor was consistent with his lecture style, course goals, content (Chapters 1–11, 17, and 18 in the McMurry textbook), grading (i.e., number of total possible points and number of points necessary to earn a C^- final grade), and the style and rigor of the five examinations administered during the semester to the individual students.

The course was an exploration of the relations among structure, properties, and reactivity of organic compounds. A mixed functional group/mechanistic approach was used. Students were required to build an empirical database and conceptual understanding, with the ultimate goal of being able to think independently and productively to solve problems about structure, mechanism, and synthesis in organic chemistry. At the same time, the instructor used organic chemistry as a vehicle for developing and refining transferable intellectual skills: reasoning from experimental observations to reliable conclusions, recognizing patterns and connections in complexity, and deconstructing complex issues into manageable pieces.

The examinations mirrored the course goals. Each examination contained short-answer questions and two-tier problems that required students to provide answers to questions and explanations of their reasoning. For example, one problem asked students to choose which of two compounds, $(CH_3)_2C=C(CH_3)_2$ or $(CH_3)_2CH\text{–}C(CH_3)=CH_2$, has the larger (more exothermic) heat of hydrogenation and to explain the basis for their choice. An example of a two-tiered mechanistic problem asked students to predict whether 2-bromo-2-methylpropane or 2-bromobutane is formed faster when a mixture of equimolar amounts of 2-methylpropene and 1-butene is reacted with HBr in ether; students were then asked to write equations to describe a mechanism for these reactions, explain how their mechanism is consistent with observed products, and explain how their mechanism is consistent with the observed rate difference.

The course instructor developed the Workshop problems to follow lectures so that the Workshop material explored concepts already discussed in lecture. Well-designed workshop problems were central to the model. First, the Workshop problems and activities were integrated with the other aspects of the course; they built from the lectures and the text and anticipated the exams. Second, the materials compelled students to grapple with their conceptual understanding. The Workshop materials were not drill problems. In accord with the course goals, the emphasis was on the ideas, reasoning, and conceptual understanding, not just on the problem-solving product or the answer. Third, the Workshop materials were challenging at an appropriate level (Vygotsky, 1978) and encouraged collaboration among the students during the problem-solving process. (For examples of the Workshop materials used in the course, refer to Kampmeier, Varma-Nelson, & Wedegaertner, 2001.)

The leader-training component of the PLTL program focused on issues regarding group work, pedagogy, and content. Peer leaders learned how to establish autonomy-supportive learning environments; this involves working with the students to define the norms in the group work. Because peer leaders were responsible for building cohesive teams of students, promoting communication within groups, and resolving conflicts in a productive manner, the training included group dynamics and group skills, student motivation, and diversity in the classroom. (See Roth, Marcus, & Goldstein, 2001, for leader training materials.)

The pedagogical component of leader training included readings and discussions of cognitive and metacognitive ideas from the literature. Peer leaders were required to participate in training activities that encompassed these teaching and learning theories and their applications to the conceptual material. The cognitive apprenticeship model (Collins, Brown, & Newman, 1989) provided a framework for instruction that emphasized the value of making explicit the thinking underlying expert problem solving. Although peer leaders are intelligent novices who possess an understanding of organic chemistry, they may not have the expertise to articulate their knowledge and problem-solving skills. As a part of the training, leaders reflected and practiced problem-solving strategies in the context of Workshop problems that provided the basis for the leaders' plans to guide the students' discussions the following week. The course instructor supplemented the leaders' individual reflections by providing an overview of how he thought through each problem and what he wanted students to learn when he constructed the specific workshop problem.

Furthermore, peer leaders were educated in tactics that encouraged individual reflection and monitoring during the problem-solving process. Research has demonstrated that metacognition is valuable for the development of collaborative reasoning skills (Hogan, 1999) as well as development of conceptual understanding and problem-solving success (Baird, Fensham, Gunstone, & White, 1991; Rickey, 1999; White & Frederiksen, 1998). One approach to promote reflection was the pair problem-solving approach (Whimbey & Lochhead, 1986), in which one student thinks out loud while solving a problem and the other student listens and poses questions to encourage verbalization or ask for clarification. In addition, the questions that King (1990) incorporates into reciprocal questioning and those questions embedded in Schoenfeld's (1985) mathematical problem-solving class (e.g., "What are you doing? Why are you doing it? Where do you think it will get you?") served as exemplars to guide peer leaders in their interaction with students.

In summary, there are a number of variables that distinguish the Workshop and traditional recitation section. First, the class size of the Workshop (~8 students) is considerably smaller than the recitation (~20–25 students). Second, the materials in the Workshop were developed and provided by the course instructor, whereas the students or recitation TAs selected the problems from the text or old exams. Consequently, although students in the Workshop covered the same problems, there was no consistency in the problems covered among the various recitation sections. Third, typically an undergraduate peer who recently completed the course facilitated the Workshop, whereas a graduate student possessing a more extensive knowledge base taught the recitation. Fourth, the training that peer leaders received included facilitating group interactions, giving authority to the students to work corporately to solve problems, and emphasizing problem-solving ideas and tactics. In contrast, the weekly meeting of recitation leaders primarily emphasized content and administrative issues. Fifth, the learning experience in the Workshop was modeled on a social constructivist perspective, whereas the transmission/demonstration model was prevalent in the recitation.

This article evaluates the impact of the Workshop experience as a whole compared with the traditional recitation. The Workshop and recitation were both complex learning environments; thus, our unit of analysis is the overall experience in either the Workshop or the traditional recitation as determined by a number of quantitative and qualitative measures. Accordingly, the overall learning environments will be considered in interpreting any differences in outcomes between the treatment and control groups.

This study used a mixed methods design, incorporating both quantitative and qualitative techniques. Quantitative analyses were used to investigate the hypothesized relationships between the PLTL experience and student performance and attitudes. All quantitative analyses were performed using a commercially available statistical package (SPSS). Qualitative data collected through student and leader surveys, peer leader reflective journals, and interviews provided insight and support for interpreting the quantitative results (Chi, 1997; Patton, 1990).

Participants

Undergraduate students enrolled in the first-semester organic chemistry from 1992 to 1994 and 1996 to 1999 were included in the evaluation ($n = 2157$). All students enrolled in 1992–1994 ($n = 942$, 485 male, 457 female) served as the control group (traditional recitation section). All students in the course from 1996 to 1999 were considered the treatment (PLTL Workshop) group ($n = 1215$, 565 male, 650 female). The control group included 9.5% underrepresented minority students (students of African American, Hispanic, or Native American descent), compared with 14.0% of the Workshop group. Underrepresented minority students (students of African American, Hispanic, or Native American descent) averaged 12.0% of the organic class during 1992–1994 and 1996–1999, representative of 11.2% of the sophomore class during the same period. Participation in the recitation or the Workshop session was expected though not mandatory; points were neither awarded nor withheld for participation. Attendance at the weekly Workshops was high. During 1996–1998 period, 75% of students who completed the organic chemistry course attended at least 10 of 13 Workshop sessions during the semester. Attendance was not recorded for the traditional recitation sessions. Therefore, we made no attempt to segregate the data for actual participation in the Workshop or recitation.

Prior Equivalency Variables

To determine any preexisting differences between the Workshop and control cohorts, math (SATM) and verbal (SATV) SAT scores were evaluated. Overall, Workshop students (mean [M] $= 642$, standard deviation [SD] $= 75$, $n = 1122$) scored significantly higher on the SATM than the control students ($M = 623$, $SD = 73$, $n = 854$), $t\,(1974) = -5.80$, $p < .01$. In addition, the

Workshop students scored higher on the verbal portion of the SAT, $t\,(1974) = -4.98$, $p < .01$; the mean performance of the Workshop cohort was 617 ($SD = 82$), whereas the control cohort averaged 599 ($SD = 83$). These differences reflect changes in the institution's admission policies beginning with students in the 1997 cohort. Correlation analyses indicated that SATM ($r = 0.23$, $p < .01$) and SATV ($r = 0.15$, $p < .01$) performance were significant predictors of overall performance in the course. Because of the preexisting differences between the Workshop and control groups, students' SATM and SATV scores served as covariates to adjust for group differences in the dependent variable. The national changes in SAT scoring which began in 1996 are not sufficient to explain the increase in scores observed between the Workshop and control groups. For instance, a renormed SATM would be adjusted from 623 to 631, whereas the Workshop students outscored the control group by a greater margin, 642 to 623.

Surveys, Attendance, and Interviews

At the end of each semester, students were asked to complete a survey to capture student attitudes and opinions about the course. Quantitative analyses of Likert-scale items are reported. This article also reports attendance data for the Workshop and its correlation to student performance.

In addition, all undergraduate peer leaders during the 1999–2000 academic year were invited to participate in a 40- to 60-minute semistructured interview. One of the authors (LT) conducted interviews with 31 of 39 peer leaders (79.5% participation rate). Interviews were conducted at the end of the Fall 1999 term and the end of the Spring 2000 term. The first set of interviews was completed with 15 peer leaders (8 women, 7 men) at the end of the Fall 1999 term; primarily, students who were not continuing on as a Workshop leader in the Spring 2000 term were asked to participate at this time. All 17 peer leaders at the end of the Spring 2000 term were asked to participate in the interview; 14 of 17 students (10 men, 4 women) complied. Finally, two of the leaders interviewed were organic graduate students (one man, one woman) who had not experienced the PLTL model as students in the course.[1] The undergraduate peer leaders (1 sophomore, 25 juniors, and 3 seniors) represented a range of academic majors (16 natural science, 4 social science, and 9 students with a double major in natural science and humanities/social sciences). The semistructured interview protocol, adapted and expanded from pilot interviews during the 1998–1999 academic year, explored leader attitudes about PLTL, the role of the leader, and the nature of the team problem-solving activity and student interaction during the Workshop. Although not specifically probed, an unanticipated outcome of the interviews was that the leaders' responses provided a glimpse into the impact of the leader-training course. With the student's permission, the interviews were audiotaped and notes were taken during the interview. The transcripts and notes were then analyzed to identify common themes that emerged from the data.

Results and Discussion

This study tested the hypotheses that peer-led team learning in an organic chemistry course would (a) improve student performance, (b) lead to better retention rates, and (c) result in more favorable attitudes toward a traditionally challenging course. In summary, Workshop students earned significantly higher total points on exams which translated into higher course grades and demonstrated significantly higher retention rates compared with control recitation students. The attendance, survey, and interview data showed that students thought that the Workshop helped them learn organic chemistry; they found it socially engaging, intellectually stimulating, and, above all, a productive use of their time. The qualitative data also suggested how the structure of the Workshop may have led to the learning gains; that is, the Workshop learning environment encouraged interaction among students, prompted students to explain their understanding, and placed greater responsibility on the student compared with the recitation experience. (The PLTL approach has been implemented in different courses taught by a number of faculty members in over 40 institutions representing community colleges, technical colleges, liberal arts colleges, urban commuter campuses, public and private colleges and universities, and research universities. For performance and attitudinal data from other schools, refer to Gafney, 2001.)

Course Performance

Student performance was measured by examining total points earned and final grades in the course based on four exams and a cumulative final. No grades for group work or participation were awarded as each student in the recitation and Workshop was individually accountable for his or her learning as demonstrated on the course exams. Graduate students assigned to the course graded all exams as directed by the instructor. From 1993 to 1999, the total possible points for the course was 900. In 1992, a student could earn a maximum of 1150 points, so the students' scores were adjusted according to a 900-point scale. (Analyses of variance [ANOVA] with and without the 1992 dataset yielded similar results. All findings reported in this article include the 1992 cohort.)

Students' total points earned in the course were treated as the dependent variable and group (Workshop or control) as the independent variable. Students who did not receive a grade, withdrew from the course, or audited the course were not included in this analysis. Workshop students significantly outscored their control counterparts, $t\,(1807) = -13.30$, $p < .01$, an effect size of 0.64σ. (See Table 1 for a breakdown by class year.) Effect size, a measure of the impact of the independent variable, was determined by the difference of means divided by the standard deviation of the control group.

The SAT scores (Math and Verbal) were entered into the ANOVA model as covariates to account for changes in the institution's admission policies and adjust for the preexisting

Table 1
Student performance in organic chemistry, total points earned, 1992–1994 and 1996–1999

Group	*n*	*M*, Total Points	*SD*
Control			
1992	233	445.5[a]	124.7
1993	242	455.6	129.6
1994	297	513.1	124.4
Overall	772	474.7[b]	129.7
Workshop			
1996	306	547.3	143.6
1997	284	564.6	129.6
1998	230	573.4	120.3
1999	217	547.2	132.2
Overall	1037	557.8[b]	132.7

[a]Adjusted from a 1150-point scale to a 900-point scale (see text).

[b]$p < .01$ for the overall means, Workshop vs. control.

Table 2
Performance in organic chemistry, gender and ethnicity, by treatment

Group	n	M[a], Total Points[b]	SE	Effect Size
Male				
Workshop	415	544.1	9.4	
Control	347	478.6	13.2	
Overall	762	511.4	8.1	0.50σ
Female				
Workshop	483	523.8	8.7	
Control	320	441.1	12.8	
Overall	803	482.4	7.8	0.64σ
Majority				
Workshop	784	565.2	4.6	
Control	615	483.0	5.1	
Overall	1399	524.1	3.4	0.63σ
Underrepresented minority				
Workshop	114	502.7	12.2	
Control	52	436.6	17.7	
Overall	166	469.7	10.9	0.54σ

[a]Adjusted mean based on Math and Verbal SAT covariates.

[b]A student could earn a maximum of 900 points.

differences between the groups. (See Table 2 for a breakdown of adjusted means.) Workshop students continued to outscore the control students when total points were adjusted for SAT scores, $F(1, 1555) = 44.1, p < .01$, an effect size of 0.56σ. The ANCOVA analyses also showed significant differences for gender ($p < .05$), as males outperformed females, and for ethnicity ($p < .01$), as the majority students outperformed underrepresented minority students. No interactions between Workshop and gender/ethnicity were observed. Overall, the PLTL Workshop had a comparable impact on female (0.64σ) and male performance (0.50σ) and the performance of majority (0.63σ) and underrepresented minority (0.54σ) students.

There are concerns in the literature that SAT scores are poor predictors of undergraduate performance of underrepresented minority students (Cameron, 1989; Vars & Bowen, 1998). If this is true for the students in the Workshop and recitation cohorts, it is possible that the use of SAT scores as covariates does not provide a complete picture of the impact of the PLTL Workshop environment on underrepresented minority students. The performance of underrepresented minority students is discussed with respect to retention below.

To give some perspective to the higher total points earned by Workshop students compared with control students, students' course grades were compared. The final grades were translated such that a grade of A corresponded to 4.0, A^- corresponded to 3.7, B^+ corresponded to 3.3, and so forth. This analysis has some limitations as the instructor's cutoff for only the C^- grade varied <5% in 1992–1999; however, his cutoffs did become more stringent with time. In addition, grades are not strictly a continuous variable. Of the 1821 students with final grades, the mean performance of the Workshop cohort was significantly higher than that of the control cohort, $t(1819) = -5.56, p < .01$. The average final grade for the Workshop cohort was 2.82 (SD= 1.03) compared with 2.54 (SD = 1.17) for the control cohort. After adjusting for SAT score differences, students participating in Workshops earned significantly higher grades compared with their control counterparts, $F(1, 1565) = 7.2, p < .01$. Workshop students earned an average grade of B/B$^-$, whereas control students earned an average grade of B$^-$/C$^+$. A significant difference was observed for ethnicity ($p < .01$), as majority students outperformed underrepresented minority students, but not for gender ($p = .11$).

In summary, the ANOVA analyses confirm that Workshops significantly impact performance for all students. Previous research demonstrated the positive effects of cooperative learning as directed by the organic chemistry instructor as measured by final exam performance (Dinan & Frydrychowski, 1995; Dougherty, 1997). In contrast, the results presented here demonstrate the significant impact of the PLTL model on students' overall performance when the small groups are facilitated by undergraduate students and show that such gains are sustainable over a 4-year period as new peer leaders become involved each year.

For the following reasons, we posit that exam performance reflects student understanding and development of problem-solving skills. First, the instructor did not purposely change his exam style or degree of difficulty over the course of the study. Two chemistry graduate students conducted independent evaluations of the second exam administered each semester during the time span of the study (1992–1994 and 1996–1999). Each exam covered the same content, generally, and the problems were not the same from year to year. The graduate students' findings agreed, showing slight random variations from year to year, but no significant differences in the types of problems or level of difficulty. In addition, the instructor's explicit goals for the course included the development of conceptual understanding and problem-solving skills. The exams reflected these goals as the questions required students to apply concepts and ideas to new situations and, oftentimes, to explain their reasoning in the two-tiered format. It was not sufficient to provide the right answer; a student also had to communicate the rationale for the response (as illustrated earlier).

Whereas we have evaluated the overall Workshop experience, we think that two factors have an especially important role in deepening students' conceptual understanding and developing problem-solving skills: the peer leader's direction and support and student–student interaction. Peer leaders provide a firm scaffold for beginning students who are confronted with challenging problems. When the group reaches an impasse, the peer leader is available to pose questions or provide direction for more fruitful interactions. In a separate study, student perceptions of peer leader support were an important determinant of students' subjective experience and objective performance in the course (Black & Deci, 2000).

The second key contributor to the learning gains builds on work done by Chi and colleagues (1989), which demonstrated that high-performing students were good self-explainers, whereas low-performing students were poor self-explainers. Previous research demonstrated a causal relationship between training in self-explanation and self-regulation strategies and problem-solving performance (Bielaczyc, Pirolli, & Brown, 1995; Chi, De Leeuw, Chiu, & LaVancher, 1994). The Workshops require students to think out loud, reflect upon how principles apply, and monitor their understanding and misunderstanding. As students discuss and debate their understanding with one another, they are learning to articulate their thought processes. Consequently, their explanation skills develop and understanding deepens in response to classmate and peer leader feedback and interaction. One peer leader provided the following description of the activity in her Workshop:

> . . .this Workshop seemed to work better because they all did not know the answers already. They all actually worked together to find the answers.. . .I think that this Workshop also worked well because at times the students were at disagreements.. . .This forced them to back up their answers and justify them to convince the others in the Workshop. I think that this led to overall a greater understanding of the concepts.

Student Success and Retention

The previous analysis focused on overall course performance, but another approach is to assess student success. The success rate, also defined as retention, was calculated by dividing the number of students earning a grade of C^- or above by the total number of students registered in the course after the add/drop period.[2] Of the 2157 students enrolled in the course, 1821 students received final grades. The remaining 336 students audited ($n = 6$), withdrew ($n = 305$), or did not receive grades ($n = 25$). Whereas the previous analyses only included students who received a final grade, the success data in Table 3 include all students who were officially in the course regardless of outcome. Although only 66.1% of the control group earned a minimum grade of C^-, 77.0% of Workshop students met this criterion ($p < .01$, one-tailed Fisher's exact test). This is an important change: in human terms, it means that about 25 more students per year were able to continue from first- to second-semester organic chemistry, as the C^- grade is the minimum acceptable grade for continuing on to the second-semester course. Some may argue that a grade of C^- as criterion for success is rather liberal. Analyses using a more rigorous criterion of a grade of B^- or above yielded similar results: 55% of the Workshop students earned the B^- minimum grade compared with 45% of the control group. Similar gains have been observed in peer-led study group programs (McCuen, 1996; Pedersen, 1994) and cooperative learning settings in organic chemistry (Dougherty, 1997).

It seems reasonable that improved performance would be linked to higher retention rates. That is, more PLTL students would remain in the course if their grades were higher. Comparison of the control and Workshop groups showed that 17.4% of the control group ($n_{\text{Control}} = 968$) withdrew or did not receive a final grade, whereas only 14.2% of the Workshop group ($n_{\text{Workshop}} = 1198$) withdrew or did not receive a final grade ($p = .02$, one-tailed Fisher's exact test). Of the students who completed the course, 80.1% of the control cohort completed the course with a minimum grade of C^- compared with 89.6% of the Workshop cohort ($p < .01$, one-tailed Fisher's exact test). A χ^2 analysis indicated an overall shift in performance; that is, the percentages of students earning A, B, and C grades increased ($p < .01$). The results demonstrate that the PLTL intervention improves course retention.

Table 3
Student success rate in organic chemistry, 1992–1994 and 1996–1999

Group	*n*	Success[a] (%)	Points to Earn C^-[b]
Control			
1992	276	67.4	351
1993	288	65.3	370
1994	378	65.9	385
Overall	942	66.1	
Workshop			
1996	361	75.9	390
1997	312	83.3	388
1998	280	75.4	390
1999	262	72.5	390
Overall	1215	77.0	

[a]Success rate was calculated by summing all students with grades of C^- and above and dividing by the total number of students enrolled in the course including students who withdrew or did not receive final grades.

[b]A student could earn a maximum of 900 points.

Student success was also explored as a function of gender and ethnicity. Success rates for male students increased from 69.7% to 76.1% ($p = .01$, one-tailed Fisher's exact test), whereas female students saw gains from 62.4% to 77.7% ($p < .01$, one-tailed Fisher's exact test). The success rate of the majority population improved from 67.6% to 79.5% ($p < .01$, one-tailed Fisher's exact test), whereas the underrepresented minority group also demonstrated marked gains from 47.1% to 58.2% ($p = .06$, one-tailed Fisher's exact test). Figure 1 shows an overview of student success. The success data suggest that the PLTL Workshop had a significant impact on retention rates for all groups. Organic chemistry is notorious for being a competitive course; however, the team-building process in the Workshop does not support a competitive culture and instead encourages students to work together. The gains in retention reinforce researchers' recommendations for changes in the competitive classroom culture so that women and members of underrepresented groups can participate equally in the SMET classroom (Ibarra, 2001; Seymour, 1995; Seymour & Hewitt, 1997; Tobias, 1990).

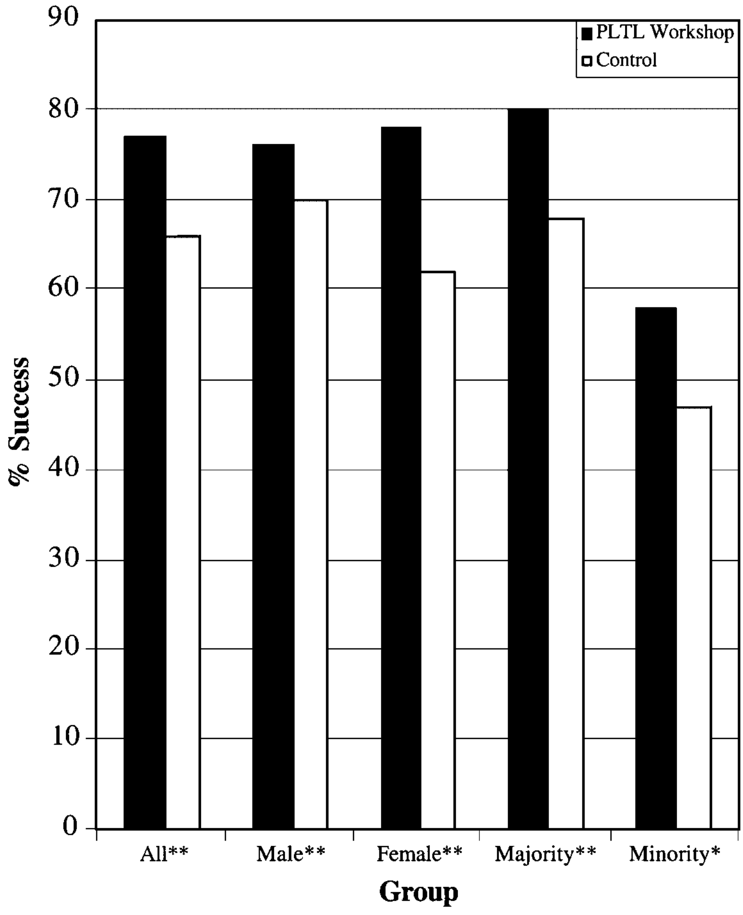

Figure 1. Student success, Workshop vs. control, for all students ($n_{WS} = 1215$; $n_{Con} = 942$), by gender ($n_{WS\ male} = 565$; $n_{Con\ male} = 485$; $n_{WS\ female} = 650$; $n_{Con\ female} = 457$), and by ethnicity ($n_{WS\ majority} = 973$; $n_{Con\ majority} = 808$; $n_{WS\ minority} = 158$; $n_{Con\ minority} = 85$). The success rate was calculated by summing all students with grades of C^- and above and dividing by the total number of students enrolled in the course including students who withdrew or did not receive final grades. $*p < .10$, $**p < .01$.

One explanation for the improved achievement and success rates in the Workshop cohort is that the smaller Workshop size provides individual attention and assistance that the larger recitation cannot. However, we do not think that class size alone is responsible for the documented gains. The literature provides mixed results relating undergraduate class size to achievement (Glass & Smith, 1979; Williams, Cook, Quinn, & Jensen, 1985). We think that decreasing class size must be accompanied by opportunities for socially mediated interactions to construct and refine one's understanding. In addition, we think that the support for autonomous learning, as provided by the peer leader, is an important determinant for the observed differences in success rates and achievement (Black & Deci, 2000). The peer-led structure provides an autonomy-supportive environment that fosters independent thinking and development of ideas.

Attendance

Attendance records were available for the 1996, 1998, and 1999 PLTL cohorts. Not surprisingly, students who attended more Workshop sessions achieved higher course grades. Students who completed the course and attended at least 10 of 13 workshop sessions earned significantly higher course grades ($M = 2.98$, $SD = 0.92$, $n = 564$) compared with students who attended fewer than 10 of 13 sessions ($M = 2.28$, $SD = 1.19$, $n = 164$), $t\,(726) = 7.99$, $p < .01$, an effect size of 0.59σ.

Analysis showed that a greater percentage of students earning grades of A and B attended at least 10 of the 13 Workshop sessions during the semester (87% and 81%, respectively), whereas students earning grades of C and D attended the Workshops with a much lower frequency (71% and 68%, respectively). This demonstrates that students do not consider the PLTL Workshop remedial. The data also suggest that students recognize the learning value of the PLTL Workshop and continue to make attendance a priority throughout the semester. Unfortunately, attendance was not recorded for the traditional recitation sections comprising the control group. In general, the anecdotal experience at our institution is that attendance is much lower than the Workshop figures reported here and usually declines as the semester progresses, even when attendance at recitation is a factor in a student's grade. Attendance in the Workshop was much higher than that observed in other peer-assisted learning programs (<30%), where attendance was optional (McCuen, 1996; Plecha, 1998).

Student Attitudes

Student attitudes about the organic chemistry course were evaluated with various survey instruments. The surveys provide insight into student perceptions of their overall learning experience. Three different surveys were administered during 1992–1999.

A university survey asked for student opinion about the course and the instructor. The Workshop and control students similarly rated the course with a score of 4.0 (of 5) and the instructor with a score of 4.4. It is not surprising that no significant differences were observed for the institutional instrument because the items did not probe the different experiences of the two groups. These results indicate that both groups of students viewed the course and the instructor favorably.

A second set of surveys was developed and administered as a part of the PLTL Workshop project (Gafney, 2001). Beginning in 1995, students were specifically asked to evaluate their Workshop or recitation experience (Likert scale of 1–5). Comparative data (Workshop vs. recitation) are only available for the 1995 cohort. Survey Items 1–3 (Table 4) showed no significant differences between the Workshop and control groups concerning the problems and

Table 4
Student attitudes, Workshop vs. control, 1995 cohort

Survey Item	*M*, Workshop[a]	*M*, Control[b]	p[c]
1. Interacting with the recitation/Workshop problems increased my understanding of chemistry	4.27	4.48	.22
2. The recitation/Workshop problems are well correlated with lecture	4.38	4.20	.26
3. Interacting with the recitation/Workshop leader increased my understanding of chemistry	4.21	3.98	.28
4. Interacting with other students in the recitation/Workshop increased my understanding of chemistry	4.04	3.09	<.01
5. I regularly explain problems to other students in recitation/ Workshop	3.45	2.71	<.01
6. The recitation/Workshop gave me a new understanding about how to do academic work as part of a team	3.60	2.60	<.01

[a] $n = 92$.

[b] $n = 45$.

[c] Calculated from two-tailed unpaired t tests.

interaction with the teaching assistant (in the recitation) or peer leader (in the Workshop). Specifically, both groups of students reported that working with problems deepened their understanding of the subject matter and that the problems were well correlated with lecture. Because these were goals of the instructor, these results are not surprising. In addition, Item 3 (''Interacting with the Recitation/Workshop leader increased my understanding of chemistry'') indicated that both the Workshop and control groups valued the interactions with their facilitators, regardless of their identity as a graduate recitation TA or undergraduate Workshop leader.

Survey Items 4–6 revealed significant differences concerning the level and type of student interaction in the Workshop or recitation. Response to Items 4 (''Interacting with other students increased my understanding of chemistry'') and 5 (''I regularly explain problems to other students'') indicate that the Workshop had a greater emphasis on student–student interaction and encouraged students to explain their reasoning to one another. One long-term benefit is reflected in Item 6 (''The Recitation/Workshop gave me a new understanding about how to do academic work as part of a team''). These survey responses provide evidence that the PLTL focus on students working together was met. The potential benefits are immense as these students use team skills in subsequent study and work.

In 1996, the survey results indicate that Workshop students continued to recognize the benefits of the PLTL approach. (Table 5 presents a list of items that students rated highly with an average score of 4 or higher.) Students overwhelmingly endorsed Workshops in 1996 as 89% agreed or strongly agreed that they ''would recommend workshop courses to other students'' ($M = 4.46$).

In 1998 and 1999, Workshop students completed an adaptation of the Student Assessment of Learning Gains (SALG), a survey instrument designed to elicit students' feedback of how much they gained from the class, and to relate their gains to particular aspects of the class pedagogy (Seymour & Gutwill, 2000). The SALG instrument has been deemed reliable and valid for collecting self-reported data on student learning (Seymour, Wiese, Hunter, & Daffinrud, 2000). The completion rates were 54.3% in 1998 and 49.8% in 1999. Students were asked to evaluate the effect of 33 items on their learning using a Likert scale. Possible items included the Workshop

Table 5
Workshop student attitudes, 1996 cohort

Survey Item	M^a
1. The Workshop materials are well connected to the lectures	4.52
2. I would recommend a Workshop course to others	4.46
3. Interacting with the Workshop problems increased my understanding of chemistry	4.44
4. In the Workshop, I am comfortable asking questions about material I do not understand	4.31
5. Interacting with other students in the Workshop increased my understanding of chemistry	4.15
6. I believe the Workshops are improving my grade	4.11

[a] $n = 166$.

experience, lecture activities, and exams. The results varied little from one year to the next. The top 10 rated items correspond to Items 1–10 in Table 6, whereas Items 11 and 12 were included to provide contrast (lecture vs. workshop; interaction with instructor vs. peer leader). The students rated only 5 of the 33 items highly with an average score of 4 or higher; 3 of the top 5 were associated with the PLTL experience: the Workshops, the Workshop problems, and the quality of contact with the Workshop leader. The SALG responses provide further support that Workshop students found the PLTL experience valuable to their overall learning experience.

Students reported that the Workshop experience was the most important aid to learning organic chemistry ($M = 4.4$), whereas the lectures rated a distant 12th. In light of the earlier positive evaluations of the instructor (4.4 of 5.0), the SALG results emphasize the high regard that students have toward the Workshop. In addition, students felt that the individual attention they received in the Workshop (Item 5, $M = 4.0$) was more valuable to their overall learning than their interaction with the instructor in the large lecture class (Item 11, $M = 3.5$). These results are not surprising because providing meaningful interactions in a large lecture course is an ongoing challenge to instructors.

Table 6
Workshop student attitudes, 1998 and 1999 cohorts

Survey Item: How Much Did Each of the Following Aspects of the Class Help Your Learning?	M^a
1. Workshops	4.4
2. Workshop problems	4.4
3. Text readings	4.2
4. The previous exams	4.2
5. Quality of contact with the Workshop leader	4.0
6. Working with peers	3.9
7. The way this course with taught overall	3.9
8. How the lecture, reading, problem assignments, and Workshops fit together.	3.8
9. Personal support of the Workshop leader	3.7
10. Text problems	3.7
11. Quality of contact with the teacher	3.5
12. Lectures	3.3

[a] $n = 282$.

Overall, the three survey instruments revealed student perceptions of the organic chemistry course. Before and after implementation of the PLTL Workshop, students placed similar value on the overall course and the instructor. However, the survey results indicated that the Workshop placed a greater emphasis on student–student interaction. Students valued the collaborative nature of the Workshop experience; not only did they feel that Workshops improved their learning, they also had more opportunities to generate explanations. Students appreciated the Workshops in helping them learn organic chemistry and would recommend a Workshop course to others.

Student Views of the PLTL Workshop

Given that the PLTL experience improved student performance in organic chemistry and the survey outcomes suggested some basis for the learning gains, peer leaders were interviewed to gain insight into what actually occurred in the PLTL classroom to foster such gains. Peer leaders were chosen because they have a dual perspective of the Workshop experience, as former students and current leaders. Because the peer leaders are outstanding college students, they constitute a group of sophisticated observers of higher education. The interview responses were supplemented by journal entries that peer leaders submitted describing the problem-solving activity and the student response in the weekly Workshop.

Three common ideas emerged from the interviews and written assignments as keys to learning in the PLTL environment: (a) the Workshop as a community of learners, (b) negotiating meaning, and (c) acquiring expert thinking skills. These themes, coming from the peer leaders' perspective, are consistent with the goals of the PLTL model.

First, the peer leaders stressed the idea of the Workshop as a community of learners. Although the format varied from working in pairs to working in one group, the underlying emphasis was that no student was alone in the problem-solving task. Instead, all of the students served as resources for one another in an intimate setting. Some of the peer leaders shared these comments: "Students like the small, close feeling in workshop"; "The small group environment makes it easier to ask questions [and] exposes them to other people's perspectives on how to solve difficult problems"; "Students like the way that discussions are held in an open forum, and that everyone has to understand a concept before the group moves on"; and "They respect each other's varying abilities, and realize that just because someone is not as strong as you might be that they still have something to contribute." One peer leader remarked that the Workshop format was "novel to these students," a striking commentary on the typical college experience. In general, the feedback from the peer leaders mirrored observations from students participating in small-group learning; Towns and colleagues (2000) concluded that the collegial atmosphere of the small group promoted positive interdependence which facilitated learning.

The second theme that emerged was that Workshop provided opportunities for the students to negotiate and refine their understanding of ideas and concepts introduced in the lecture and the text. According to the peer leaders, the students like how the Workshop "reinforces and explains what they did in class and that they have to figure the answers out themselves," enables them to hear "different views to solve problems," and gives students responsibility as they "work off each others' ideas and explain things to each other." One peer leader spoke from his perspective as a Workshop student saying, "we get to have the input and it makes us think rather than just get the answers."

Some leaders discussed how they prompted students to reflect and justify their reasoning to each other. One peer leader shared how her students interacted when disagreement arose:

> On one of the problems, the students had disagreed on the solution to the problem. The majority of the kids accepted an incorrect answer.. . .I asked each student to explain their understanding of the problem to the class.. . .People were changing their answers back and forth.. . .I was very pleased by the outcome of the workshop. By seeing that the students disagreed and were able to give explanations of their answers, albeit incorrect, it showed that the students were engaged in what was occurring in the workshop and were actually thinking about the problem.

Negotiating meaning begins with understanding what the problem is asking and continues as students grapple with the relevant concepts needed to solve the problem. The following quote describes how one peer leader initiated the discussion:

> . . .you need to. . .help them break down a problem that they see [as] this great big giant hole with no idea of how to go from the beginning to the answer.. . .Something we did early on, and, but after a few weeks they started doing it themselves and I didn't need to do it anymore, was be like, ''Okay, let's slow down, read back through the problem a bit at a time, and say, what are the big words in here that maybe not everybody in the room understands?'' And sometimes, I'd play devil's advocate then. If they're like, ''Oh no, we understand it all,'' I'd be like, ''All right, so what's this? What's racemization? I don't think I know that word.'' And you know, somebody would say, ''Oh, that's when the stereochemistry switches.'' Somebody else would be like, ''It doesn't have to switch. It's like, it equalizes out.'' And I go, ''What do you mean it equalizes out?'' And you just get them talking. And once they realize what the question's really asking and kind of break it down into small chunks, then it's a lot easier to solve. Sometimes. . .I have to as a leader kind of help them break things down and still let them solve it.. . .Just help them see what the little parts are so that they can get the little answers and then fit them together to make the big answer.

The previous quotation illustrates two ideas emphasized in the leader training class. First, the class brainstormed ways that the leader could guide students to consider four aspects of the problem-solving process: understanding a problem, developing a plan, implementing the plan, and evaluating progress (Polya, 1973). Schoenfeld's research (1985) in mathematical problem solving demonstrated that most problem solvers devote little time to the first two steps and spend the bulk of their time implementing a strategy without evaluating its validity or considering alternative routes. The quotation above demonstrates how one peer leader prompted his students to understand the problem before moving on to developing a plan. Second, the training class discussed the idea of scaffolding students and then gradually removing the support. In the language of cognitive apprenticeship (Collins, Brown, & Newman, 1989), the peer leader faded the support as students internalized the skill. The quotation, ''Something we did early on, and, but after a few weeks, they started doing it themselves and I didn't need to do it anymore,'' demonstrates the leader's removal of support once students took the initiative for trying to understand the problem without prompting from their leader. Many leaders discussed how they provided the necessary prompts to help students break the problem down into manageable parts. For instance, peer leaders talked about giving appropriate hints (''I've learned a lot about just doing the Workshops and. . .maybe giving hints. It's a tricky thing to do. . .there's always the temptation to give them a really good hint, so they'll get through the problem quicker'') and asking intermediate questions (''If they look at the problem and. . .have no idea. . .I would ask a rather leading question toward the first step. . .'So what can you tell me about this concept?'. . .It was [questions] that would get them there or get them to be able to realize it themselves'').

One peer leader felt that students' confidence was built up as a result of explaining their reasoning: "It's always good to have them explain why they got the answer they got, and it helps to make them more confident in their work." Prior research has demonstrated that prompting students to reflect on their understanding (Rickey, 1999; Schoenfeld, 1985) and generate explanations (Bielaczyc et al., 1995; Chi et al., 1989; Chi et al., 1994; King, 1990, 1992; Webb & Farivar, 1994) improves student learning. The peer leader's perception of increased confidence may be the result of such learning gains.

Learning to negotiate meaning within a group context has also been observed in physics (Roth & Roychoudhury, 1994) and mathematics (Schoenfeld, 1985). However, although established instructors taught these classes, the leaders' comments demonstrate the ability of peer leaders to facilitate and guide discussion as students engage in and make sense of the problem-solving process.

The third idea that emerged from the peer leader interviews was the emphasis on expert thinking skills. Schoenfeld (1985) described the importance of conveying expert thinking strategies in mathematical problem solving. Similarly, peer leaders shared their organic chemistry heuristics with their students. For instance, one peer leader shared that mechanism problems involve "little tricks of the trade. And if you point out those little steps, a lot of it is how you set up the problem.. . .You've learned from your mistakes, and [you] pass on that knowledge to them." Another leader shared his tip for approaching mechanism problems: "If you're stuck, think about making this bond, or breaking this bond because that's at the root of everything."

Another peer leader described what she did to help her students attack a Starburst problem, a multipart synthesis problem that presented the starting material in the center with arrows going outward to a number of different possible products.

> When the students first saw the Starburst they seemed frightened of the "large scary spider web.". . .I told them some little things they should keep in mind while attacking a synthesis problem. For example, I told them to first compare the reactant and product to see what is similar and different between the two. Next, they should ask themselves, "Where is the most likely reactive site of the reactant that will yield the appropriate product?" It seems that they started thinking about the problem in little chunks.

Additional general thinking strategies in approaching the synthesis problems included working backward or working forward. One peer leader shared,

> If the. . .problem is too hard to work forwards, you know, then you work backwards. If you look at the first starting material and the product, and you say to yourself, "This doesn't make sense.. . .I'm sitting here for five minutes and I don't see how I can do this. I don't see how I get there." Then you say, "Well, if I just have the product, what are steps that lead to that product? And what are steps that lead to that step? What are steps that lead to that step?" You work your way backwards to the starting material. That's a general skill.

Whereas some of the heuristics encompassed setting up a problem and were problem-specific, others were more generalizable. For instance, students learned to value the problems in which observation and deduction strategies were embedded and asked for more such problems. Another leader described a metacognitive process of monitoring one's problem-solving process:

> If I have a synthesis problem that I can't figure out, I just stop, cross out that way, and think, "How do I get from there to there?" It's the whole thinking outside the box. You just stop what you're doing, what you've been working on, and you try a different perspective.

Such control and monitoring strategies are invaluable to a problem solver's success (Hogan, 1999; Rickey, 1999; Schoenfeld, 1985).

Another leader was a strong proponent of the postmortem, an approach described by Schoenfeld (1985) to prompt students to reflect upon the problem as a whole and to consider the take-home points.

> I am a really big fan of the so-called post mortum [sic]. I think we often get so focused on a small aspect of the problem that we fail to see where the problem fits in the greater scheme of organic chemistry. But once the problem is solved, going over it again can help fill in any gaps of understanding as well as give a good time to think about where this concept is important. I feel that if the information isn't well organized, it just won't stay in place.

In general, the themes that emerged from the interviews reflect ideas brought out in the leader training class. The interviews provide unequivocal evidence of the abilities of the undergraduate peer leaders to internalize the fundamental principles of Workshop pedagogy and to help students implement these principles. The training class is an essential mechanism for teaching the leaders how to do their jobs; it is a forum for discussing educational theories and practical applications to prepare peer leaders to promote productive student–student and student–problem interaction. The leader is central to the PLTL model; the special flavor of the role of the leader is captured by the following comment from one peer leader:

> I'm the queen of "Why?" If I'm walking around the classroom and they [the students] ask me if their answer is right, I rarely ever say, "Yes," but instead I say, "Does it look good to you?" and "Why?" It's always good to have them explain why they got the answer they got, and it helps to make them more confident in their work.

Conclusions

The goal of the PLTL Workshop was to integrate active and collaborative learning opportunities into an organic chemistry course to promote student learning. The peer-led team learning approach provided a carefully constructed environment in which students interacted and discussed their understanding of organic chemistry and applied that understanding to specific problems. The quantitative analyses demonstrated the positive impact of the Workshop learning environment on student performance, retention, and attitude, whereas the qualitative data yielded insight into the role of the leader and actual activities that contributed to the learning gains. The data are so compelling that PLTL Workshops have now displaced traditional recitations in all four semesters of introductory organic chemistry at the institution in question.

Based on the qualitative data, some of the contributing factors for the improved performance included working in a community of learners, promoting individual reflection and explanation as the students negotiated meaning, and developing a toolkit of general and concept-specific thinking strategies. The peer-led learning environment, in sharp contrast to the typically intimidating and passive experiences in undergraduate science courses (Tobias, 1990), gives students a mechanism for self-expression in a student-centered environment. This self-expression translates into increased sense of autonomy and self-confidence. Moreover, students are engaged in an alternative model for learning how to learn that is transferable to other situations.

The performance analyses indicated that all students, male/female and majority/underrepresented minority, benefited from the PLTL approach. Previous studies showed that group composition (gender and ethnicity) can lead to varying effects for achievement (Cohen, 1982, 1994; Webb, 1982; Webb & Palincsar, 1996). Our results indicate that the PLTL Workshop is a powerful pedagogic approach, improving achievement for a diverse student population.

Clear evidence of the value students place on PLTL is the local dissemination of the instructional model at the institution in question to other courses such as biology, biochemistry, computer science, and physics. Students and, in particular, leaders who were convinced of the utility of their organic chemistry Workshop experience asked instructors in other courses to integrate the pedagogic model into their courses; the students' advocacy for the model serves as striking testimony of the perceived impact of the Workshop. The PLTL instructional approach has also led to similar improvements in performance in general and organic chemistry courses at a wide range of other institutions (Gafney, 2001), and its effect is being explored at the secondary level (Cracolice & Deming, 2001) and in other disciplines.

One implication of this study is the potential impact of the PLTL approach and other student-centered paradigms on the pipeline concern. Previous researchers have discussed the potential waste as talented undergraduates leave the sciences (Seymour & Hewitt, 1997; Tobias, 1990). Whereas this article has demonstrated the impact of the PLTL Workshop on retention and student learning in one key course in chemistry, longitudinal studies need to be conducted to determine the long-term effect of attracting and retaining students in the sciences.

The most important implication concerns the ability of PLTL students and leaders to shift from the familiar instructor-centered to a new student-centered paradigm. Here, the leader-training course is instrumental in equipping the leaders to build teams of reflective, confident learners. Leaders need to wean the students from the instructor-centered paradigm, clearly outline the goals and expectations of a student-centered class, and teach the students how to be productive participants. The training program needs to explore the PLTL model and provide instruction and support about the content, learning theory, and group dynamics. The peer leader serves as a role model and needs to learn to share different ways of thinking and problem-solving strategies while providing individual feedback and support. The leader training activity simultaneously provides a mechanism to help faculty make the shift to a student-centered focus. It is especially powerful because the instructor collaborates with the education specialist to engage the peer leaders in a weekly dialogue about student learning. Finally, the leader training work provides models for the substance and format of TA training programs. Unfortunately, many TA training programs focus primarily on content (Renfrew and Moeller, 1978; Rushin, et al., 1997) with little time devoted to instructional models other than the transmission/demonstration model. This practice probably derives from the lack of a compelling conceptual model, based in pedagogic research. Peer-led team learning can provide one such conceptual model.

The PLTL approach has been implemented successfully with graduate student leaders, although special attention is required to teach them to put aside their growing sense of expert authority. Some graduate students view the PLTL Workshop as an attractive way to meet their teaching obligations and value the opportunity to practice and develop their teaching skills. They like the structured responsibilities and the opportunities for closer working relationships with their students. One graduate leader commented about his experience as a PLTL leader,

> I think it's made me a better teacher. It's made me a lot more compassionate.. . .It's made me understand my students better. It's increased my own communication skills.. . .The leader training class has given me a lot more educational theory than I probably would have ever had otherwise. It's given me an interest for learning more about those kinds of

> things. It's given me, I mean, a resume experience that very few people are going to have.. . .I think it's been a wonderful experience as far as learning what I'm going to be doing in a few years, when I'm trying to get a school that doesn't have Workshops to be doing it.

Graduate students and post-doctoral students alike have volunteered to participate as peer leaders with the goal of implementing nontraditional formats in their future teaching. Many university faculty in the science fields rely on the instructor-centered paradigm because they have had little training or experience with alternative pedagogic approaches. The PLTL model has potentially far-reaching implications as PLTL students, undergraduate peer leaders, and graduate peer leaders move into new phases of their academic careers.

This study demonstrates that undergraduate students can provide a powerful new force in their own education. As institutions consider ways to improve the educational experience, recruiting undergraduates as peer leaders is a financially feasible plan with potential benefits for the students and the leaders. One peer leader reflected on the special opportunities and long-term impact of her Workshop experiences,

> I must say that being a Workshop leader has been an incredible experience for me. I actually never thought. . .that I would have the opportunity to have a leadership role like this so soon in my college career, and I'm really grateful that I have taken advantage of this one. With every Workshop. . .I found myself becoming more aware of the subtleties of how students interact with one another and their designated leader in a group situation. I have become a lot more patient when it comes to explaining concepts and understanding different perspectives on approaches to solving problems—whether they be wrong or right. I'm sure my experience this semester will prove valuable to me in my next two years here and especially in med school where the group problem-based learning technique is being implemented.

While there is both the need and the opportunity to study the effects of peer leadership on the leaders, some preliminary observations are clear. Students have a special regard for the peer leader position; they see it as both honor and opportunity. Among the latter is the chance to benefit from mentoring relationships with course faculty and learning specialists (Jacobi, 1991).

In conclusion, using undergraduate leaders to implement a peer-led team learning model that is built on a social constructivist foundation is a workable mechanism for effecting change in undergraduate science courses. The PLTL format opens new opportunities for student and faculty involvement and enables students to take ownership of their own learning experiences and those of their peers. By organizing the power of the undergraduates to interact productively and to learn from one another, PLTL provides a mechanism for improving the quality and, therefore, the productivity of the educational institution.

The authors thank Tina Collison and Jason Gillmore for evaluating the exams; Nirmala Fernandes and Lynn Ashby for data entry; Gail McElroy, Nancy Niemi, and Ren-yu Zhang for preliminary analyses; and Mark Cracolice and Dawn Rickey for comments on an earlier draft of the manuscript. It is a special pleasure to thank Professor Joseph Dinnocenzo for innumerable hours of stimulating discussion and for his enthusiastic participation in the PLTL model. This work was supported by NSF/DUE awards 9450627 and 9455920.

Notes

[1]Each semester, a small number of graduate students served as Workshop leaders to fulfill their departmental teaching requirement. From 1996 to 1999, 28 of the 140 Workshops were led by graduate students.

[2]These percentages do not incorporate SAT data into the analysis as covariates.

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