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Abstract

Since its inception in the 1990s, Peer-led Team Learning (PLTL) has evolved into a well-defined and highly effective student-centered and collaborative learning method. It is a pedagogical strategy that employs peer-facilitated workshops to enhance academic achievement and to foster professional development for both student participants and peer facilitators. This paper explores the six critical components of the PLTL philosophy in detail and discusses additional key facets to the pedagogical strategy. In an era marked by a growing number of innovative approaches to instruction and learning, this re-introduction to the PLTL philosophy seeks to clarify and distinguish the approach from other methods, while highlighting how it is uniquely poised to benefit students, program facilitators, and instructors. To support institutions interested in adopting this model, a detailed case study of PLTL implementation in an undergraduate General Chemistry course at Washington University in St. Louis (WashU) is also presented. This details specific, long-standing implementation strategies and explores the unique academic and socio-emotional benefits for both participating students and their peer leaders. The findings strongly suggest that PLTL programs (1) that abide by the six critical components, (2) that are institutionally supported, and (3) that are integrated into the core curriculum lead to improved retention rates, higher test scores, and increased student satisfaction. This paper aims to serve as both a testament to PLTL's lasting impact and a practical guide for its integration into diverse educational settings.

Keywords: Peer-Led Team Learning, PLTL Philosophy, Critical Components of PLTL, PLTL Implementation Guide, PLTL Benefits, Collaborative Learning, PLTL Workshop Facilitation

Introduction

Active and collaborative learning methodologies have garnered significant attention, research, and support in the learning space for several decades and a wide variety of strategies are employed across the world and at every level of education (Barkley, et al., 2005; Smith & MacGregor, 1992). There exists a wide variety of formalized pedagogies which utilize peer-to-peer engagement to achieve improved learning outcomes (Yang, 2023). Taken collectively, a substantial body of literature provides strong evidence that these implementations consistently result in meaningful experiences for students that deepen their understanding of the course content (Frey, 2009; Laal & Ghodsi, 2012; Rutherford, 2014).

Peer-Led Team Learning (PLTL) (https://pltlis.org/) is one such collaborative learning strategy and is now a widely-implemented pedagogical model for science, technology, engineering and mathematics (STEM) courses offered at the post-secondary level (Ahmed & Haji, 2022; Hickman, et al., 2021; Maxwell & Wiles, 2022; Xu, et al., 2018). Since it originated in the 1990s at the City College of New York (Gosser, et al, 1996; Gosser & Roth, 1998; Woodard, et al., 1993), its cornerstone has been the use of embedded Peer-Led Workshops in an undergraduate course (Gosser, et al., 2001; Sarquis, et al., 2001). Students meet in these structured sessions once a week to discuss and engage with each other and the course material. Further, Workshops are facilitated by Peer Leaders (PLs): students specifically selected for the role who undergo formal training to ensure the effectiveness of this learning model for all students in these sessions (Dreyfuss & Gosser, 2006; Varma-Nelson & Gosser, 2005).

The benefits of engagement in PLTL Workshops to students enrolled in the course as well as to students who serve as PLs are widespread and well-researched (Gosser, 2015). These benefits are both academic in nature as well as social and emotional (Labov, et al., 2009; Wilson & Varma-Nelson, 2016). PLTL has served as an effective tool to introduce students to the benefits of peer discussion and peer review in deepening their understanding of STEM relationships and concepts. Moreover, PLTL builds community and promotes belonging, which are critical to students' abilities to persist, adapt, and thrive in challenging courses (Fink, et al., 2020). As such, positive outcomes for Workshop engagement range from elevated test scores to higher retention rates and self-reported satisfaction in a course (Chan & Bauer, 2015; Frey, et al., 2018; Hockings, et al., 2008; Luthi, et al., 2022; Varma-Nelson & Gosser, 2005). Additionally, Workshops provide a formal and structured environment to develop team-based communication skills and opportunities to be exposed to different perspectives and problem-solving strategies (Szteinberg, et al., 2020; Repice, et al., 2016). In this way, both students and PLs are provided with self- and professional-development

opportunities. The learning that occurs in Workshops extends far beyond course content as it also imparts students with the skillset to evolve as successful collaborators and creative thinkers when tackling real-world challenges (Stephenson, et al., 2019). These are skills that are essential to any field, but critical to foster in students following a STEM career path trajectory.

For institutions considering the use of PLTL in one or more of its STEM courses, the authors intend this paper to serve as an informational guide to the PLTL philosophy and a practical reference for its implementation. These are presented in three sections following this introduction. Section I provides detailed explanations for the critical components and other key aspects of the PLTL philosophy, as defined by the PLTL International Society (PLTLIS.org; Gosser et al., 2010). Section II introduces specific implementation strategies of an established General Chemistry PLTL program. These strategies are currently employed at Washington University in St. Louis, where the program has been in operation for more than twenty years. Lastly, Section III visits the unique benefits of PLTL on both the students taking the introductory course as well as the facilitating Peer Leaders.

Section I: The PLTL Philosophy

The PLTLIS identifies six critical components to the PLTL pedagogy (Gosser, et al., 2001). This section identifies those components and explains how their implementation gives rise to the PLTL philosophy. Taken collectively, these are the essential aspects of a successful PLTL program.

The Six Critical Components of the PLTL Workshop Model:

1. The Peer-Led Workshops are integral to the course.
2. Instructors (faculty & teachers) are involved in the selection of materials, training and supervision of Peer Leaders, and they review the progress of Workshops.
3. Peer Leaders are selected, trained and supervised to be skilled in group work as facilitators.
4. Workshop materials are appropriately challenging, directly related to course methods of assessment, and designed for small group work.
5. The Workshops are scheduled and held once a week for two hours, contain six to eight students per group, in space suitable for small-group activities.
6. The Peer-Led Team Learning program is supported by the department and the institution with funds, course status and other support so that the method has the opportunity to be adopted across courses and disciplines.

The PLTLIS lists these critical components to a PLTL program in the order they appear above. To best illustrate how these components work together harmoniously, various components have been grouped together throughout the descriptions below.

Critical Components 1, 2 and 4:
(1) The Peer-Led Workshops are integral to the course;
(2) Instructors (faculty & teachers) are involved in the selection of materials, training and supervision of Peer Leaders, and they review the progress of Workshops;
(4) Workshop materials are appropriately challenging, directly related to course methods of assessment, and designed for small group work.

Workshop materials are designed to be challenging components to a particular unit or module of the course. They must contain a significant degree of application of course material or an appropriate number of "conceptual leaps" to encourage a collaborative effort among students. Discussion allows for a deeper understanding of how key concepts are related and provides students the opportunity to make new connections with the material. This thorough exploration of the material should be aligned with course assessments, and hence, be integral to the course. In order to seamlessly tie the PLTL Workshop materials to the course, instructors are involved in the selection of problems and activities, or author these materials directly.

Robust PLTL problems allow for multiple students to participate in the evolution of the solution. A multi-step, and, whenever possible, multi-concept design prompts students to engage with the course material beyond calculations. Students learn to explain scientific phenomena in their own words, to plot data, and sketch relationships, instrumentation and other phenomena, in addition to calculating parameters of a given system. PLTL problems target relevant complexities that are fundamental to the course content. Problems that explore rare exceptions that may be of interest to only a few who are deeply compelled by the subject, or that investigate remedial concepts to promote the success of students who may be struggling with course material are not appropriate in PLTL workshops. However, both groups of students should be targeted with other course resources in meaningful and worthwhile manners.

There must be a significant level of reward available to students for engaging with such a challenging problem set. This reward system most commonly manifests itself in two forms: (1) translating ideas explored in the PLTL Workshops to questions posed on course

assessments such as quizzes and exams, and (2) participation credit for working collaboratively and productively with fellow course mates in the PLTL Workshops.

(1) Translating ideas explored in the PLTL Workshops to questions posed on course assessments such as quizzes and exams.

If assessments reward full engagement in a PLTL Workshop, students will easily recognize when their efforts in their sessions are being realized. This is accomplished when the assessment prompts students to draw upon the underlying core concepts they reasoned through during the Workshops.

During PLTL Workshops, students are encouraged to break down high-level topics into underlying core concepts, in turn, cultivating their critical thinking skills through analytical approaches from challenging problems posed. By articulating how these core concepts are related to each other, students are better prepared to apply these same approaches to novel problems. In addition, students are prompted to evaluate the reasonableness of their answers, a much-needed skill on course assessments.

When students can recognize that their own understanding of a concept or relationship was fully realized in the context of a PLTL Workshop and then feel successful when their mastery of that concept or relationship is formally assessed, students fully "buy in" to the PLTL philosophy.

(2) Participation credit for working collaboratively and productively with fellow course mates in the PLTL Workshops.

Regular workshop attendance and active participation are expectations of students. Further, students are expected to arrive prepared, being familiar with the appropriate course content. This preparation is critical because the PLTL workshop materials are challenging. Peer discussion is leveraged to its fullest potential when it elevates students' initial sense of understanding and in the application of core concepts.

Many institutions integrate these regular-occurring Workshops into their classroom schedules, making them a mandatory component of the course itself. If PLTL is made a course option, involvement in the Workshops can be successfully incentivized through offerings such as earning additional course credit or credit hours.

Regardless of how the PLTL Workshops are integrated into a course, a thriving PLTL group requires active participation from all its group members throughout the entire term. As a course component, formal assessment of Workshop participation is included in the grading schema of the class. This can involve the PL assessing levels of engagement, peer evaluations of group members or self-evaluations for grading purposes. This type of assessment could also involve a feedback mechanism providing areas of strength as well as

suggested areas of improvement for their role within the academic team. Please see the Section *Other Key Components of the PLTL Philosophy, Attendance and Participation Policies* below for more discussion on this topic.

Critical Component 5: The Workshops are scheduled and held once a week for two hours, contain six to eight students per group, in space suitable for small-group activities.

In order to establish a welcoming, inclusive, and productive work environment that promotes healthy and high-functioning group dynamics, regular meetings with the same group of students and Peer Leader are essential. Students need to feel comfortable with their environment and their fellow students when navigating challenging material. Thus, the PLTL philosophy establishes that groups meet on a weekly basis, for a total of two hours (Gosser, et al, 2001). Both Workshop size and location heavily influence the student experience. PLTL Workshops may consist of small groups of six to eight students (Dreyfuss, 2021). Ideally, groups size would lend itself easily to both large and small group discussions while also ensuring a diverse set of perspectives and experiences among the students. Other factors to consider when grouping students can involve considering identities in an effort to promote diversity and student belonging, such as balancing groups by gender identity. Considerations such as accommodating students' schedule availability may be necessary as well. Given these parameters, students of different academic years, levels of preparation, majors, and college entrance test scores tend to be divided evenly among the groups, and all have the potential to thrive.

Space for small group discussions and activities is optimal. Classroom space with tablet armchairs is not as conducive to group work as tables and chairs. However, for some courses and for some institutions, such as large courses that necessitate a large number of workshops, space may be at a premium. This has been addressed in a number of creative ways including shared spaces (e.g., one campus has used the football stadium to administer a large number of simultaneous workshops). Movable furniture and large displays for group work such as chalkboards, whiteboards, smartboards, are ideal, although poster paper, and small boards that can be passed around are alternative solutions. Flexibility in the physical layout supports the collaborative learning strategies employed during the Workshop.

Critical Components 2 and 3:
(2) Instructors (faculty & teachers) are involved in the selection of materials, training and supervision of Peer Leaders, and they review the progress of Workshops;
(3) Peer Leaders are selected, trained and supervised to be skilled in group work as facilitators.

As discussed above, workshop problems and materials are rigorous and engage students through high-level critical thinking and creative problem solving. This degree of challenge has the potential to initially intimidate students, especially in introductory courses when the PLTL pedagogy is generally employed. PLTL Workshops may be students' first real foray into facilitated structured group learning. The expectation that students engage in a collaborative manner with their fellow students can evoke negative emotions depending on their prior experiences with group-project or group-learning work.

Thus, it is not unreasonable for students to initially feel frustrated with the level of challenge or unsure about the premise of collaborative learning. This is why invested facilitators who have received training and are well prepared to utilize a variety of facilitation strategies are a crucial component to the success of the PLTL Workshops. These student facilitators are tasked with the responsibility of overseeing Workshops by setting group norms, guiding the problem-solving process, anchoring fruitful learning in peer-led discussion, and posing probing questions to help students achieve a deeper understanding of the material together and for themselves.

The selection of PLs cannot be based solely on academic success achieved in the course. PLs must demonstrate an openness to hearing and appreciating multiple perspectives and an understanding that many problems can be approached from multiple angles. "An A+ does not alone a good PL make" is a phrase that is repeated often by the authors of this paper. PLs must be much more than particularly knowledgeable students. They ideally are also compassionate, empathetic, adaptable, engaging, patient, and personable. They also must demonstrate a clear understanding of the PLTL philosophy and a dedication to upholding it in their future Workshops.

While many institutions partner with internal offices, such as a Teaching and Learning Center, an Office for Student Success, or the Undergraduate Education Division of the Dean's or Provost's Office to assist in the application process and selection of new PLs, it is essential that course instructors be integral members of the Selection Committee. The commitment of the course instructor or instructor team to the PLTL pedagogy must be apparent to students pursuing a role in a PLTL program.

At its core, PLTL involves a strong academic team. In the individual Workshops, the team is comprised of a PL and their students. In a broader sense, the full PLTL program is functioning at its highest potential when all team members, including the course instructor(s) and possibly learning specialists, are actively involved in the program goals and learning outcomes of its students. This begins with the selection of highly qualified and dedicated new PLs.

If selected in this way, PLs comprise a truly exceptional cohort of students. But despite their existing skills and prior experiences, PLs need continuous support, guidance, and education in pedagogical strategies in order to fully excel in their facilitator and mentor role. This can be done through coursework where the PLs receive credit hours for their training or by meeting weekly with faculty. This structured support, professional development, and training may be extended to PLs in every semester they engage in this position. PLs may receive pay or other forms of compensation for their time and efforts with the PLTL program, as deemed appropriate by the institution.

In general, the training of PLs addresses two key areas: (1) the pedagogy of facilitation, which includes the importance and implementation of structured, active, collaborative learning as well as (2) the content-specific learning goals of the program. PLs should be exposed to a wide collection of best practices from the current education literature that addresses key knowledge and skills they will need to be successful in their roles including (in no particular order):

- Creating a welcoming and inclusive learning environment
- Establishing group norms and effectively communicating community expectations
- Fostering awareness of identity literacy and cultures
- Promoting emotional intelligence
- Understanding and supporting students with different learning styles and modalities
- Employing interpersonal skills that equip PLs to recognize and navigate various personalities
- Suggesting evidence-based study strategies
- Developing an understanding as to why collaborative learning strategies are effective and how they can be utilized to maximize their positive effects

The PLTL philosophy stipulates that an answer key to the PLTL problem set is not published for either students or PLs (see the Section *Other Key Components of the PLTL Philosophy,*

No Answer Key below for more information on this point). PLs prepare for their upcoming Workshop by working through the materials and the content-specific support should extend far beyond simply checking their answers. PLs need to know where their students are likely to struggle with a particular concept, relationship or problem. To do this, as a team without taking a direct "tutoring approach," they engage with each other and the course instructor(s) to strategize how they will help their students catch their own mistakes or make key connections between challenging ideas.

PLs need to be able to guide students to evaluate the reasonableness of their methodologies and their final answer. Prompting students to articulate their reasoning and providing opportunities to solidify the knowledge they gained are all critical aspects to the PL's role in this student-centered approach. Inviting students to summarize the steps taken to solve a problem or to apply their new knowledge to a different, but related, system are mechanisms the PL employs as they facilitate a full and fruitful problem-solving session.

The complexity of this education and training is often accomplished by a number of key partners. In addition to the vital and integral role that the course instructor(s) play, key partners very often include members with educational backgrounds or expertise such as faculty and staff from Teaching and Learning Centers or similar departments (Dixon, 2012). These individuals can greatly enrich the training aspects that target the pedagogy of facilitation and small group learning.

Other perhaps less obvious key partners in the training of PLs are the PLs themselves. Building strong connections among practitioners is essential to any supportive PLTL community. This occurs on several levels: a connected cohort of new PLs, a mentoring network of experienced PLs and new PLs, and an integrated, thriving learning community that intentionally cultivates these connections.

In the first semesters of service, attention must be given to integrating new PLs into an established community of practice. Particular attention should be paid to affording them opportunities to bond with each other. Learning about and practicing how best to bring their group of learners together as a cohesive academic team forges trust and strong ties among incoming PLs. Sharing their struggles and victories ensures that practitioners feel supported, understood and championed by their fellow facilitators.

Experienced PLs can also play a very important role in the training of new PLs as these more senior PLs can provide mentorship to their incoming counterparts. The transfer of knowledge, wisdom, experience, and advice from these experienced PLs help new PLs gain the confidence and competence to excel in their roles — benefitting the students whom they

guide during Workshops — while also serving to increase camaraderie among fellow facilitators.

These networks and connections forged among the PLs are then further supported by the faculty and staff leading the required training sessions or courses the PLs take as well as by the instructor(s) of the course that is incorporating PLTL. While this can seem like a complex ecosystem, this system creates numerous avenues for PLs to lean on each other and on the faculty and staff supporting the program. This provides PLs opportunities to gain constructive feedback or brainstorm ideas to adapt their facilitation strategies and to navigate difficult circumstances in their Workshops, aiding them as they continuously develop both in their roles as facilitators as well as other areas of their lives. This also provides the instruction team with valuable insight into their students' experience with the course content and their level of mastery of the material.

While it is understandable that establishing these supportive training programs is no small task for any institution new to PLTL to adopt, the payoff is significant. Once these mentoring networks are established, all of the members of the PLTL community tend to feel highly invested and connected to the PLTL philosophy, ultimately allowing a dynamic learning venue that directly benefits the students engaging with the Workshops to flourish.

> *Critical Component 6: The Peer-Led Team Learning program is supported by the department and the institution with funds, course status and other support so that the method has the opportunity to be adopted across courses and disciplines.*

The implementation of a PLTL program is no small feat. To be truly successful, an instructor employing PLTL in their course must be supported from both within their department as well as within their institution. Faculty interested in starting a PLTL program in their course or in their department need to receive support to attend conferences and training sessions to learn about best practices and strategies regarding the PLTL Workshop model, in order to understand the importance of challenging Workshop materials for their students, and methods of education and training for PLs. Ideally, course status and/or compensation for the PLs would be housed outside of the Department so the burden of program logistics would be shared by key campus partners rather than fall directly to the course instructor. This sharing of responsibilities would also aid in the sustainability of both the courses offered to the PLs and funding for the program.

This shared caretaking of the PLTL program outside of the department is also critical for allowing the PLTL philosophy to be employed by multiple disciplines. This creates an

opportunity for instructors to shape their PLTL program to meet the specific needs of their course, while also ensuring that the PLTL philosophy is upheld and that students experience continuity with the pedagogy, regardless of the subject matter studied. When a PLTL program is supported at the institutional level, a larger PLTL community can be established with a shared culture and vision towards learning that benefits the instructors, educational support staff, PLs and students it serves.

Other Key Components of the PLTL Philosophy

Other key components to the practice of PLTL pedagogy (Gosser, et al., 2001) are discussed below. This section will identify those components and explain how their implementation supports the PLTL philosophy.

Choosing Your Facilitation Team

In selecting students to serve as facilitators in a PLTL program, the choice of undergraduate students is strongly encouraged. Graduate students may also be trained as PLs, but there are clear advantages to using undergraduate students in this role. Usually, having recently taken the course they are supporting, they are intimately familiar with the course content, as well as the instructor's policies and classroom culture. Where programs have been well-established, it is helpful to have students who fully participated in PLTL workshops when they were students in the course and thus, students who experienced the PLTL philosophy first-hand. As discussed previously, students who have demonstrated academic success in the class is a consideration, although they do not need to be pursuing a major in the subject area. In fact, having a diverse group of undergraduate PLs pursuing different degrees, and ultimately different careers, in highly visible roles is of significant benefit to current students (Hutton, 2019; Shin, et al., 2016).

Undergraduate students are best-suited to be relatable and empathetic to the students they are facilitating as they are peers. The role of PL is distinctly different from the traditional role of an undergraduate teaching or learning assistant (TA or LA). For a PL, the primary goal is to bring a group of diverse students together as a cohesive and high-functioning academic team. In order to be effective, PLs must invest in each of their students, learning their approaches to problem-solving and their personalities, with an awareness of facial expressions and body language, and adjusting their facilitation strategies accordingly. The forging of such strong personal relationships in a professional context is critical to the development of a welcoming and productive learning environment.

Attendance and Participation Policies

Students are assigned to a specific PLTL group where they are expected to attend regularly and be active members of their group. Once assigned to a PLTL group, the students remain with their Workshop group for the entirety of the term. Healthy group dynamics and academic peer relationships need time to become established and to grow. Viewing these program objectives as long-term goals for each student is essential to a PLTL program's ability to thrive. Of course, there are occasionally circumstances that arise that may result in a roster change. Should an interpersonal conflict arise within a group, faculty and other staff (coordinator, learning specialist) may be called upon to support their PLs as they navigate the issue(s).

To communicate these participation expectations to students, PLTL programs need to provide a transparent attendance policy at the start of the term so that all students may be well aware of program expectations. Expectations for the Workshop sessions must also be stated explicitly. These have often been communicated on course syllabi distributed by the instructor. Such communication is critical as successful Workshops hinge on the regular and consistent engagement of the group.

PLs may be responsible for monitoring attendance and participation for the course instructor during Workshops. While students may not be required to submit their work for participation credit, they are expected to carry out problems and calculations in full and otherwise be diligently utilizing their time in Workshops. As students learn to work collaboratively with their peers, they find that the learning potential of a Workshop increases when each participant balances their personal contributions while respectfully making space for others to contribute their approaches as well.

Faculty Visibility in a PLTL Program

As for their own visibility in the program, faculty are encouraged to take on a more supportive role in the program, such as organizing logistics and engaging in the continued training of PLs. Healthy student development is born from a willingness to make mistakes, challenge ideas, and speak up when clarification is needed. As such, an aim of PLTL is to cultivate a safe space where learners can take these necessary risks without the sense that their performance is being evaluated. While it is important to recognize that the PLTL program would not be successful without faculty involvement, any PLTL organization as a whole should not be perceived as "faculty-facing." After all, the intended purpose is to leverage student connections to foster peer learning. Hence its name. While this indeed may require a significant commitment on the behalf of key players such as instructors and other teaching

team members to develop and oversee such a program, authors from the PLTLIS have suggested that the number of students at office hours have decreased, possibly owing to students' increased grasp of the material from their time in Workshops (Labov, et al., 2009).

Collaborative Learning Strategies

Workshops are facilitated by PLs who are encouraged to utilize collaborative learning strategies as a way to both provide structure to these sessions as well as navigate peer connections to promote group learning. While collaborative learning strategies used by PLs may differ due to the disposition and competencies of students who comprise a group as well as a PL's personal style towards facilitation, strategies often consist of rearranging students into various group sizes to allow for enhanced discussion of the material and the presentation of other students' approaches.

For information on specific collaborative learning strategies, please see Section II: The Implementation of the PLTL Philosophy at Washington University in St. Louis, "*PLTL Workshops and their Facilitation.*"

No Answer Key

Perhaps one of the most surprising key components of the PLTL philosophy, at least for those who are unfamiliar with the pedagogy, is that no answer keys are published for the PLTL Workshop packet. However, it is one of the most important facets to a PLTL program's success (Amar, et al., 2012).

The PLTL Workshop materials are intentionally designed to require a collaborative effort. The problems presented are multi-faceted and push students to process and apply the underlying concepts presented in lecture in novel ways. PLs are also trained to prompt students to communicate their reasoning and justify their responses at every step during the problem-solving process. They are also trained to involve all members of the group in evaluating the reasonableness of a proposed solution.

In this way, students experience what it is like to solve scientific or mathematical problems in a "real-world" manner. Operating without an answer key not only mimics what it is like to solve problems while taking an exam or other class assessment, but mimics what professionals in STEM do throughout their careers. PLTL teaches students to value and actively seek out peer review and peer discussion when navigating complex phenomena. Student motivation to engage in group problem-solving can be negatively affected if they anticipate a published answer key. Emphasizing the importance of the process of problem-

solving over the correctness of a particular answer is one of the most powerful outcomes of a PLTL program. While it can take some time for students to come to trust that a collaboration of fellow students and a skilled facilitator will almost always yield the correct *process*, this is an essential maturation step for any budding scientist, mathematician, or engineer (Gamlath, 2021; Wang, 2012).

It should be noted that the PLTL philosophy does not dismiss productive discussions about PLTL problems outside of Workshops, only the formal publication of an answer key. Students may confirm their thought process with other students in the course or with instructors during office hours or the like.

Section II: The Implementation of the PLTL Philosophy at Washington University in St. Louis

All of these components that comprise the PLTL philosophy have been successfully implemented at a variety of institutions, including two-year colleges, four-year colleges, and doctoral universities, as well as across several disciplines, including math, chemistry, biology, physics, computer science, as well as philosophy, linguistics, and English. How these programs deploy and manage their programs in accordance with the PLTL philosophy depends on many factors including the culture of the institution and the culture of the department or discipline, the students the program serves, and the support and funding available to the program (Fields, 2022; Gafney, 2012; Kampmeier, 2012; Kennedy & Masuda, 2021; Shahid, et al., 2022).

Here the authors present how the General Chemistry PLTL program is managed and supported at Washington University in St. Louis ("WashU"), an R1 research institution and doctoral university (https://circle.wustl.edu/projects/peer-led-team-learning/). As of Fall 2025, there are approximately 8,000 undergraduate students and 8,500 graduate students enrolled. The descriptions below pertaining to an introductory science course provide one illustrative case example of a successful implementation strategy.

PLTL for General Chemistry

In the General Chemistry PLTL program at WashU, course instructors educate primarily first-year students from the College of Arts & Sciences and the School of Engineering. It is the collective goal of the instruction team not only to achieve the learning objectives related to the subject matter, but also to support students as they transition from high school students to university scholars. The course is viewed as a first opportunity for students to be educated to think, analyze, conclude, and communicate like scientists.

Ultimately, the aim is for students to become skilled in learning underlying concepts and applying those concepts in new and creative ways to solve problems in chemistry.

The instructor team's teaching philosophy is explained to students using a "brick-wall-house" analogy. In lecture, students are presented with the key ideas, or the "bricks." Their first objective is to understand these "bricks," including learning terminology, core concepts, and fundamental relationships. Their ultimate objective is to understand how these underlying concepts are related and are used to explain chemical phenomena. This is described as using the "bricks" to build the "walls" and then using the "walls" to build the "houses."

This high level of application of the course material can be extremely challenging to first-year students and requires both active learning and a strong community of scholars to allow students to properly engage with the course material. Thus, in the WashU General Chemistry sequence both a recitation program and a PLTL program have been implemented to assist students in mastering the material presented in lecture, and in learning the value of group discussion, teamwork, and peer review in furthering one's own knowledge.

Students receive three problem sets throughout a unit in the General Chemistry course. The first is the homework set, where they work to master the "bricks." These sets target mastery of key concepts, terms and relationships. Students then proceed to recitation, where the Process-Oriented Guided Inquiry Learning or "POGIL®" pedagogy is employed (https://pogil.org/). Here, students work through a guided inquiry packet written by the course instructors. They work in structured groups of 3-4 students and are facilitated by a trained graduate student or undergraduate teaching assistant. The recitation packet targets relationships between core concepts and prompts students to explain in their own words and justify their reasoning. This is primarily where students are building the "walls." The unit then culminates with the PLTL packet in Workshop, where students encounter the most challenging questions of the unit. For the majority of our students, these questions require a collaborative effort and multiple perspectives to navigate the complexities of the problem. This is the capstone problem set where our students work to bring all of the unit's concepts together to form the "houses."

This analogy not only helps WashU students understand how they are expected to progress throughout a given unit but communicates their responsibility with the course content. For many, this is their first real foray beyond memorization of material. They are expected to think critically and creatively through novel problems presented on course assessments as opposed to relying solely on rote memorization.

Because STEM careers can be at their most fragile in a large, introductory science course, the proper support system for this level of challenge is absolutely critical. The PLTL

program and the skilled facilitation of the trained PLs provide the infrastructure for the encouragement, guidance, and mentorship necessary for the intellectual and academic growth the course instructors target for their students (Cavanagh, 2023; Frey, et al., 2018).

In the following sections, the authors detail the specific key attributes of the General Chemistry PLTL Workshops as well as the preparation courses that all WashU students are required to take in order to serve as PLs.

PLTL Workshops and their Facilitation

WashU believes that Peer-Led Team Learning functions at its fullest potential when Workshops foster an inclusive community of learners in addition to helping students develop the critical and analytical thinking skills they need to be successful in a given course and beyond. As such, PLs typically start their PLTL Workshops with an icebreaker or various team-building exercises to instill and strengthen a sense of community among their students. Often these can take the form of small interactive "games" or "question of the day" share-outs to help students learn more about each other and their interests. PLs are also strongly advised to set clear expectations and develop ground rules during the very first Workshop of the term which lay the foundation for building camaraderie as well as a positive and inclusive group dynamic. Such ground rules may include establishing the expectation that students should treat their peers with respect and kindness regardless of differences in background or understanding of the course content. It is especially important in this particular environment to set the expectation that students listen to each other without interruption, allowing each to contribute equally. By creating this welcoming culture, PLTL encourages students to respect others, build self-confidence, navigate discussions, and develop positive interpersonal relationships.

Following an icebreaker — a group bonding introduction — PLs will proceed with the "warm-up," during which students work with one another to produce a "concept map" of the week's learnings. PLs will often divide their students up into smaller groups, with each smaller group focused on brainstorming a list of principles, diagrams, and equations that pertain to a given key concept. Special emphasis is placed on active recall in which students brainstorm what they can remember about a given key concept without looking at their lecture notes. By conducting active recall, students strengthen their mental connections between ideas presented in lecture as well as reinforce long-term retention of the content (Brown, et al., 2014). After some discussion in small groups, students will be asked to come to the board and present their group's work under each key concept category. Throughout these presentations, the PL asks probing questions to target frequently misunderstood topics

or areas of confusion to help students develop a deeper understanding of the material. Typically, this process takes 10-15 minutes of the two-hour session.

After the "warm-up," PLs will then transition their group into working through the problems in the PLTL packet. At WashU, General Chemistry PLs use several "flagship" collaborative problem-solving strategies referred to as "scribe," "round robin," "small groups," and "pairs." The General Chemistry PLTL packet is designed in a way that encourages PLs to use all of the collaborative learning strategies illustrated below at least once during a given Workshop. The course instructors have previously made suggestions for the appropriate strategy to use based on the content of the question and the nature of the problem-solving process required, but ultimately PLs are given agency to adjust these to the needs of their group.

Scribe: A student is asked to serve as the "scribe." This student will then come to the board and record their peers' suggestions and work on a designated problem. Directing students' focus to a single visual (the board) and away from their individual packet allows them to be more critical and mindful of the problem-solving steps and routes that they collectively choose to take. Often, a scribe problem will even be purposely designed so that there may be multiple methods to get to the right answer. Throughout, the focus is less on the correctness of the final answer but rather on how students may get there. In addition, by being asked to verbalize their process to a peer (the "scribe"), students are being challenged to compose clear and concise explanations, just as they would be asked to do on a formal course assessment such as an exam.

Round Robin: The PL will either nominate one student to start or take volunteers and students will "go around," one-by-one to contribute a step of the problem-solving process for a given problem. In the case that a student is not sure how to proceed and cannot suggest a concrete problem-solving step, they are also encouraged to 1) highlight a given piece of information from the problem stem itself that the group should focus on, 2) contribute an equation that may be helpful or related to a concept that the problem seems to be getting at, or 3) define a concept or ask a question that may be related to the underlying principles of the problem itself. Round robin also offers a valuable opportunity for students to slow down in the problem-solving process and break down a given problem into smaller steps, while being reflective and intentional in pursuing each step. In addition, students build active listening skills by hearing their peers' suggestions ahead of their own and learn to appreciate that there may be multiple valid approaches to answering a given problem, which has further implications as the same is often true in the field when grappling with novel scientific phenomena.

Small Groups (trios or quartets) and Pairs: At WashU, 8–12 students usually comprise a given PLTL group. Thus, "small groups" consist of cohorts between three and four students and "pairs" consist of two students each. Students work for a designated period in these pairings or groups. The PL will then reassemble the larger group and ask each cohort to share their work. This method allows students to interact more personally with one another during the Workshop and is especially valuable for allowing students who are perhaps more reserved within the larger group to voice their ideas directly to a small group or partner.

These key elements of any PLTL Workshop serve to achieve three overarching goals for all General Chemistry students at WashU: 1) to feel a stronger sense of belonging within their PLTL group as well as within their wider community of scholars, 2) a deeper appreciation for the interconnectedness of key ideas, and 3) a greater confidence in their ability to apply key concepts towards novel problems.

Training of Peer Leaders

At WashU, all PLs are required to enroll in two courses housed in the General Studies Department: Seminar for Academic Mentoring (SAM) and Practical Applications of Academic Mentoring (PAAM). While SAM is designed for new PLs, all PLs enroll in PAAM each semester they serve as facilitators in the program. Together, SAM and PAAM supply PLs with both the "hard" and "soft" skills needed to be successful mentors during their time in the PLTL program and beyond.

In SAM, PLs are exposed to the fundamentals of good mentorship and facilitation. This includes engaging in group discussion on how to navigate various scenarios with compassion and professionalism should they arise during a Workshop. SAM also seeks to impart PLs with the psychological principles behind learning so that PLs will understand how to conduct themselves and the group in a way that best enhances students' learning. For example, entire SAM classes have been dedicated to discussions on how mindset can strongly affect learning (Macnamara, 2023; Xu, 2021). The instructors will often present data-driven findings to help the PLs understand the importance of certain mentoring styles, including encouraging their students to adopt a growth mindset. Further, the PLs will use this time to engage with their peers and brainstorm ways in which they can promote a growth mindset among their students during PLTL Workshops. Role play is also often used in this setting to provide opportunities for facilitation practice. Other topics covered in SAM include navigating conflict, using inclusive language, and embracing facilitation methods that are welcoming to students from diverse academic backgrounds.

There are several assignments in SAM that are used to further enhance learning and practical knowledge. These include reading former PLs' reflection essays on approaches to facilitation, advice they have for new PLs, and personal development as a result of their time in the PLTL program. PLs will also have the opportunity to write their own reflection essays throughout SAM, which will ultimately contribute to a final course project — an annual book compiled from all polished reflections (https://circle.wustl.edu/projects/peer-led-team-learning/peer-leader-training-books/). In this way, knowledge, wisdom and best practices are "handed down" from one cohort of PLs to the next as each year, new PLs will read the reflections book created by the PLs the year before (Szteinberg, et al., 2020). Ultimately, the SAM course aims to empower PLs with the resources needed to be successful facilitators as well as build a thriving community of practitioners.

At WashU, PLTL Workshops are held on Saturday, Sunday and Monday evenings. PAAM provides a time for PLs to come together each week to work through the PLTL packet before Workshops are hosted with students that weekend (https://circle.wustl.edu/projects/peer-led-team-learning/practical-applications-of-academic-mentoring-pam/). The instructor will often start with announcements and a brief content review of the week's material. Afterwards, PLs transition into mock PLTL Workshop groups. PLs who have been in the role for one or more years may apply to serve as mentoring PLs. These PLs guide and advise the cohort of new PLs and facilitate their working group(s), just like they would in a Workshop. This allows them to model best practices and prompt new PLs to discuss both key underlying chemistry concepts and facilitation tactics appropriate to specific problems. Other returning PLs who do not serve as mentoring PLs also work in mock PLTL groups with their fellow returning leaders so that all are fully prepared for a successful upcoming Workshop.

This not only serves as a chance for PLs to review the material for themselves but also to engage with the problems from the perspective of a facilitator. This may, for example, entail seeking to understand which aspects of a given problem students may struggle with and how to best provide guidance in such situations. Moreover, PLs use this time and space to think critically about how to best support students' understanding. This may include developing probing questions or planning how to adapt their facilitation strategies to fit the context of a given problem. PLs will also lean on each other's experience, and this sharing of knowledge creates a stimulating and supportive environment that is conducive to mentorship across generations.

Through their required coursework for the PAAM and SAM courses, PLs are routinely provided feedback on their performance as well as opportunities to reflect on their approaches

to facilitation. Over the course of the semester, PLs will engage in two observations of other PLs and submit two "Sharing Best Practices" discussion posts, which are weekly online forums where PLs can both share facilitation strategies that have worked well with their students or situations in which they would like to consult their peers for guidance. Lastly, for a final project, PLs work in teams to design a novel PLTL problem or activity that identifies and targets common areas of confusion with an intent to elucidate gaps in understanding. This project serves as a way that PLs can directly influence and contribute to student learning in PLTL as many projects have inspired future WashU Workshop materials.

An analysis of this required coursework has recently been published, examining feedback mechanisms for peer leader development (Daschbach et al., 2024). The formal feedback provided to PLs as both strengths and possible areas of improvement was tracked over the course of several years. The findings illustrate a clear arc of adaptation and evolution for the PLs throughout their time with the program. For example, what might appear as a suggested area of improvement early in their PL career (e.g., a dominant student was observed to be the main speaker throughout an entire problem) becomes a noted strength by the end of their time with the program (e.g., PL was observed to redirect a dominant student very effectively, allowing others to contribute to the discussion). These analyses provide strong evidence that PLs value the feedback mechanisms deployed in our program and use them as important self-assessment tools to make significant progress in core interpersonal competencies.

Ultimately, SAM and PAAM courses emphasize key principles of academic mentoring with respect to the PLTL philosophy, teaching PLs how to be skilled facilitators for their students. Furthermore, SAM and PAAM are also opportunities in which fellow PLs can collaborate to share or troubleshoot strategies towards facilitation that have worked well for their respective groups, forming camaraderie in the process as well as reinforcing the friendly, welcoming academic environment that they will go on to foster within their own PLTL Workshop groups.

Future work in the General Chemistry PLTL program at WashU will focus on aiding PLs in recognizing these skills they have developed as a result of their efforts and dedication to the role and helping them to communicate these marketable traits on applications, résumés, and CVs (Canales, et al., 2017; Chase, et al., 2020, Gafney & Varma-Nelson, 2007). We have found that some of these competencies are more obvious or more easily articulated than others. Communication and facilitation skills, adaptation, teamwork, confidence and cultivating empathy and compassion are the most common abilities referenced by PLs when prompted for what they believe they gained through their participation with the program.

Specific leadership styles, active listening abilities, emotional intelligence, cultural competency, and identity literacy are often less frequently mentioned because the language is not as familiar to students, yet these are attributes that are highly valued in graduate studies and employment opportunities.

Application and Selection Process

At WashU, where the academic year consists of a fall and spring semester, the application and selection process of new PLs begins in November. The initial step requires all current PLs to review each member of their PLTL group. They evaluate their students based on three sets of criteria: 1) the student's weekly content preparedness, 2) their interactions with their peers, and 3) their engagement with the PLTL philosophy, as described by Daschbach, et al., (2024), considering the benefits of PL involvement in the hiring process. These evaluations help inform our recruitment strategies and form the first set of data used in the selection process.

Recommended students are then recruited via email over the winter break. As the PLTL is an optional program in General Chemistry at WashU, candidates must have completed the program in order to be considered. The PL application includes two personal statements from each candidate and two letters of recommendation. One of these letters must come from a WashU employee (e.g., professor, teaching assistant, mentor, coach, or residential advisor) who can testify to the applicant's interpersonal skills and collaboration abilities that have been observed outside of the PLTL program. The other must come as a formal letter of recommendation from their fall semester PL. The selection process for PLs is quite rigorous and those chosen for the role must exhibit significant achievement in the areas of leadership, scholarship, and service.

Applications are reviewed by the faculty who oversee the program and interview candidates are selected. The interviews are conducted by the program director and a panel of two to four current PLs who are provided with the interviewee's application materials so they can thoroughly review that information prior to the interview. (Note: WashU PLs are paid employees of the university. As employees, they complete required professional training which includes instruction on their obligations regarding confidentiality. After the completion of this training and their subsequent hiring, they are allowed access to the application materials.)

Candidates are questioned about their experience in the course, their PLTL experience, and about their understanding and appreciation for the PLTL philosophy. Their answers to how they found support within their PLTL group and how they helped shape that

encouraging environment should demonstrate their capacity for empathy and compassion. They should also demonstrate enthusiasm for the course material and articulate the positive influence PLTL had on their experience in the course. Moreover, the interview also serves as a first-hand opportunity to gauge the applicants' character, communication skills, and ability to connect with others.

The level of competition for the PL position at WashU is such that of a given General Chemistry class, only approximately 20% of the potential candidates receive an invitation to apply for the position. Of those students, only the top 8-12 candidates will receive offers to serve as PLs. At the time candidates agree to serve as PLs, they sign a contract for the upcoming semester. They agree to enroll in the two required courses: SAM and PAAM. They agree to maintain familiarity with course material and not to provide any unapproved materials (e.g., previous quizzes and exams) to their students. As WashU PLs are paid for their work, thus they agree to abide by both the student and employee codes of conduct and to maintain professional behavior and confidentiality about their student-group members. They are hired in the spring semester to serve as PLs in the upcoming fall term with the expectation that they will continue in the position in the subsequent spring term if it is mutually agreeable. The faculty and staff supporting PLTL programs at WashU are most fortunate that the majority of PLs chose to serve in the role throughout their undergraduate career. This creates avenues of bi-directional mentorship between the approximately twenty returning and ten new PLs.

Program Logistics and Management

At WashU, the Center for Teaching and Learning (CTL) oversees all six PLTL programs: one in the department of Physics, three in the department of Mathematics, and two in the department of Chemistry. The CTL is responsible for formally hiring applicants who are selected and have agreed to serve as leaders, program budgeting, and payroll. The official hiring takes place over the summer such that all documentation is properly filed before the official start of a new academic year. The organization of the PLTL programs also occurs over the breaks preceding a given semester. PLs are polled for their availability and assigned a day/time for their PLTL Workshop.

At WashU, students participating in PLTL have the option to earn an additional credit hour for their participation. Because of the official course status, PLTL Workshops receive assigned classrooms from the University's Registrar's office before the start of term. All classrooms have movable furniture and at least two blackboards or whiteboards to aid in the facilitation of these sessions.

Student participants apply to be a part of a PLTL group throughout the first week of the semester. The application makes our expectations clear that they participate collaboratively with their fellow group members, value the diverse perspectives that exist in their group, and attend at least 9 of the 11 Workshops. PLTL program managers then assign students to a PLTL Workshop in a way that accounts for both their reported availability and balances gender identities throughout the groups. After the second PLTL Workshop meeting, students choose to opt in or out of the one-credit hour option. At WashU, students do not earn an academic letter grade for the PLTL, rather all students receive a passing grade for credit when they successfully complete the program. This credit contributes to the overall hour requirement for graduation but does not count as credit for a major or minor. This system is designed to reward earnest efforts and dedicated time in the PLTL setting without imposing the pressure of an additional academic letter grade on participants. The PLTL philosophy emphasizes collaborative problem-solving and the free exchange of ideas in that process. It would be inappropriate to place an academic reward based on the correctness of answers within these study spaces.

Section III: Benefits of Implementing a PLTL Program

With each PLTL group a student participates in or a new PLTL group a PL facilitates, there is a new cycle of learning and personal growth that takes place. Both the PL and students need to come together over the course of the term as a cohesive team, despite participants entering this space with diverse backgrounds, learning styles, personalities, and communication skills. They are working together not only to expand the boundaries of their conceptual understanding of the course material, but also to develop a sense of who they are and how they can grow holistically as a learner and an individual.

Benefits to Student Participants

Because the PLTL philosophy emphasizes critical thinking as opposed to the correctness of final answers, students learn to evaluate challenging, novel problems as would any professional in a STEM field. Trends demonstrate a continued improvement in academic performance with long-term engagement with a PLTL program, ultimately resulting in student participants earning higher grades (Hockings, et al., 2008; Upmacis, 2021). And while participating in PLTL has been shown to improve students' academic performance, it is worth emphasizing that the students themselves report having increased competence, confidence, a deeper understanding of course content, and improved long-term recall of the material (Gafney & Varma-Nelson, 2007). Moreover, students in PLTL are more likely to

have higher retention rates compared to their non-participating peers (Maxwell & Wiles, 2022). The same study has also shown that PLTL has been particularly effective in improving retention rates of students of marginalized status (i.e., women).

In addition, students have also demonstrated wide-ranging academic benefits from their time in a PLTL program, including in upper-level courses and continued study of the material at more advanced levels. For instance, a study conducted at Pace University found a correlation between PLTL participation and student success in organic chemistry (Upmacis, 2021). Students with PLTL experience outperformed their peers by as much as 10% in the course. The study stated that a primary driving force to this improvement was likely due to "greater interactions between instructors, PLs, and undergraduate students," which they thought could be attributed to students' prior exposure to PLTL. It is true that positive learning interactions not only enhance students' understanding of the material but also foster a stronger subject interest and sense of community within a discipline.

Along with learning benefits, student participants in a PLTL program reap the far-reaching impacts of collaborative group learning, often in ways that continue to influence their development in other aspects of their lives such as in their future careers (Chase, et al., 2020). PLTL provides an opportunity for students to understand how their personalities, their problem-solving approaches, and their leadership styles intertwine with those of their fellow student group members. They must adapt to come together as a high-functioning academic team. This involves several factors such as:

- learning to listen, value, and incorporate diverse perspectives in their group, such as giving space to others while also being a full participant themselves;
- appreciating that complex problems often have multiple valid approaches to the correct solution;
- communicating in a number of ways including through the written word, mathematical equations and relationships, sketches, and quantitative plots;
- using conflict resolution skills when a disagreement arises during the problem-solving process;
- establishing connections in a professional context with their fellow group members to celebrate achievements and provide support in times of stress.

Offering multifaceted benefits to its participants in areas of academic achievement as well as personal and professional development, PLTL represents a unique holistic learning opportunity. By fostering critical thinking, collaboration, and communication skills, PLTL

equips students with tools to tackle complex problems and adapt to diverse perspectives. Its emphasis on community building and mutual support not only enhances students' understanding and retention of course material but also prepares them for success in advanced studies and their future careers. In these ways, PLTL serves as a transformative learning model that empowers students to excel both within and beyond the classroom.

Benefits to Peer Leaders

At its core, the role of a PL is to facilitate. Their job is to seed and help guide fruitful discussions about key concepts and actively encourage their students to articulate their reasoning throughout the Workshop. This gives PLs a formal venue to hone core interpersonal competencies such as cultural awareness, empathy and compassion, reliability and dependability, resilience and adaptation, active listening abilities, and the ability to form meaningful and supportive personal connections with their students in a professional manner.

These abilities, skills, and competencies are all highly valued by graduate programs and employers alike. They are marketable qualities and characteristics that do not often have formal opportunities to be developed in an academic setting (Chase, et al., 2023). PLs who serve in the role for multiple years have the time and space to find and develop their leadership style. Moreover, each new PLTL group presents a unique opportunity to explore how a PL can effectively motivate, inspire, guide, and nurture their students.

Any PL's primary goal is to bring a group of students with diverse backgrounds, learning styles, personalities, and communication skills together as a cohesive academic team. They must gain their students' trust. They must be very limber with the course material, and thus, capable of approaching a single topic from multiple angles and perspectives. They must be prepared to challenge students with a strong grasp of the course material and ready to empathize, comfort and support students who are struggling with the concepts. This wide range of abilities, competencies, and expectations that are required of a successful PL not only serve their students in an immediate sense, but also greatly benefit PLs, making them highly competitive and desirable applicants across a variety of career paths (Canales, et al, 2017; Chase, et al., 2020; Gafney & Varma-Nelson, 2007).

Conclusions

Over the course of the last 35 years, PLTL has emerged as a novel solution with direct and wide-ranging benefits to students, facilitators, and faculty. When an institution of higher learning embraces the PLTL philosophy and incorporates all its tenets into its classrooms and its culture, it is an incredibly powerful and impactful pedagogical tool. It can transform

traditional modalities of instruction into arenas where students and instructors are active partners. It blends both challenge and support so that students may grow their intellectual capabilities without feeling overwhelmed or discouraged. It provides a platform for student PLs to hone leadership, communication, and mentorship skills in a formalized and professional setting.

The critical components of the PLTL philosophy have been formally published for over three decades. However, the authors hope that the illustrative descriptions of these components provided here bring further clarity of how these foundational principles weave together to give rise to this unique collaborative learning method. Taken collectively, these critical components distinguish the PLTL approach from other cooperative and collaborative strategies, making it uniquely effective in post-secondary STEM courses. Its successes can be measured in terms of both immediate outcomes and long-term benefits for students, PLs, staff, instructors, and administrators.

PLTL has been adopted across many institutions worldwide, providing a wealth of examples as to how the PLTL philosophy can be embodied. Here, the authors provide one grounded example of how the PLTL philosophy is applied to an undergraduate level chemistry course at Washington University in St. Louis. It is our hope that institutions seeking to enhance student learning through collaborative methods will find this manuscript to be both a testament to PLTL's enduring impact as well as a practical resource for adopting Peer-Led Team Learning.

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