

PRIMUS



Problems, Resources, and Issues in Mathematics Undergraduate **Studies**

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/upri20

Peer Instruction in Mathematics: A Survey of the **California State University**

Julie Glass, Su Karl, Bori Mazzag, Loriann Negri, Mary E. Pilgrim, Corey Shanbrom & Arianna Thobaben

To cite this article: Julie Glass, Su Karl, Bori Mazzag, Loriann Negri, Mary E. Pilgrim, Corey Shanbrom & Arianna Thobaben (13 Feb 2025): Peer Instruction in Mathematics: A Survey of the California State University, PRIMUS, DOI: 10.1080/10511970.2025.2456847

To link to this article: <u>https://doi.org/10.1080/10511970.2025.2456847</u>



Published online: 13 Feb 2025.



Submit your article to this journal 🗗



View related articles



View Crossmark data 🗹



Check for updates

Peer Instruction in Mathematics: A Survey of the California State University

Julie Glass, Su Karl, Bori Mazzag, Loriann Negri, Mary E. Pilgrim ^(D), Corey Shanbrom, and Arianna Thobaben

ABSTRACT

This report describes the current landscape of peer instruction models for mathematics, and its diversity, commonalities, and efficacy across California State University (CSU) campuses. While models differ in their placement, organization, and level of support, they share similar goals and values: increasing a sense of belonging in students, improving their academic self-sufficiency and confidence, creating an academic and social community of learners, and improving course-level outcomes and retention. Here we identify and synthesize shared themes, factors that influence implementation, and common challenges. Based on our investigation, we share recommendations for universities, departments, and other relevant stakeholders for sustainably implementing and coordinating peer instruction within their institutions.

KEYWORDS

Peer instruction; equitable outcomes; academic support; sense of belonging; near-peer mentor; collaborative learning; peer educator

1. INTRODUCTION

Peer instruction has consistently shown to have a positive impact on student success and equitable outcomes [1–3,10,12,17,18,27,29,34]. The range of studies substantiating effectiveness demonstrates the versatility of peer instruction as a strategy to support academic achievement. In this paper, we define the term "peer instruction" broadly, using it for all models of instruction that use peers or near-peers interacting with students to support their academic success. The versatility of peer instruction stems, in part, from the fact that peer instruction can look different depending on local contexts and institutional priorities. Our definition allows us to consider the broad range of studies, reflecting the variety of structures deemed peer instruction in the literature. We examine the use of peer instruction in mathematics in the California State University (CSU) system, the largest public university system in the United States. The 23-campus system shares a mission with varied implementations, contexts, and institutional priorities, making the CSU system an ideal case study to explore this important educational tool. Selected CSU campuses,

CONTACT Corey Shanbrom corey.shanbrom@csus.edu Department of Mathematics and Statistics, California State University, Sacramento, 6000 J St., Sacramento, CA 95819, USA.

2 😉 J. GLASS ET AL.

taken together, demonstrate the pervasive impact of this practice and provide examples and recommendations that can be applied to a variety of higher educational institutions.

1.1. The California State University System

The CSU system is the largest and most diverse public four-year university system within the United States. Its campuses vary greatly in enrollment (from 1,000 to 40,000 students), selectivity, student demographics, and academic focus. The variety of campuses represented by the authors allows for an authoritative look at the use of peer instruction that is relevant and practical for institutions globally. Recognizing that most campuses were using peer instruction in some fashion, we organized a systemwide online colloquium series at the height of Covid-19, during Spring 2021, to share practices and outcomes. As a result, we hosted 22 presentations on peer instruction over the course of a month. One of the most striking outcomes of the colloquium series was that despite the substantial consistency in goals and values as well as barriers faced, there was significant diversity of implementation strategies. Examining our common goals yet varied practices, we were able to identify shared themes (see Section 2.1), factors that influence implementation (see Section 2.2), and common challenges (see Section 2.4). We synthesize these themes, factors, and challenges to develop recommendations for universities, departments, and other relevant stakeholders to identify how they might implement a peer instruction model that best fits their circumstances.

1.2. Impetus for Peer Instruction

Two national and global imperatives, the Covid-19 pandemic and the movement for social justice and anti-racism, help to reveal the value, relevance, versatility, and broad use of peer instruction. Covid-19 had substantial impacts on how education was offered to students. With the pivot to online learning, we saw firsthand in our own programs that students were struggling to navigate both the new course structure and the stress and trauma associated with living in a global pandemic. During and after the Covid-19 pandemic, equity gaps grew or, at best, remained unchanged (e.g., Refs [6,33]); potentially revealing even more starkly how a community within the learning environment impacts student engagement and success. Peer support has been shown to increase a sense of belonging [7,12,13], motivating broader use of peer instruction as faculty searched for ways to support students and build community in virtual classrooms. This extended use and versatility of peer instruction became evident to the authors through the Spring 2021 colloquium series.

Questions about how and whether higher education serves all students equitably are paramount in our reckoning for social justice where equity of educational outcomes is at the forefront. For example, in the CSU, multiple system-level initiatives and mandates [31,32] targeted improved student outcomes and reductions in equity gaps (e.g., gaps in performance between racially and ethnically underrepresented

students and their White counterparts) in course grades, retention and graduation rates. There is evidence that peer instruction is an equitable practice that improves outcomes [1,14,17,29,34] and helps address/close equity gaps [1,34]. Attending to these gaps is especially important in STEM, as many jobs in these fields continue to see a lack of diversity [16]. This is particularly pressing in mathematics, given its foundational role in STEM success [8] and the current active research interest in equity in mathematics [35].

1.3. The Impact of Peer Instruction in Mathematics

The use of peer support has been shown to be effective in a variety of lower division mathematics courses, ranging from developmental mathematics through the calculus sequence [14,29,34]. However, there are additional reasons why the mathematics classroom is especially suitable for peer instruction. For example, math curriculum models tend to fit peer instruction well, with an emphasis on problem-solving and opportunities for coordination among multiple course sections. The natural sequencing of mathematics courses also brings multiple benefits, such as improving the facility with material foundational for success in future courses, and the possibility of cohorting students through multiple sequential courses with peer support. In addition, within the context of the national movement away from remediation in mathematics, peer educators have the opportunity to assist with any underdeveloped prerequisite content that is neither covered in the parent course nor offered as a standalone remedial class. And for practitioners looking to start or sustain a peer instruction program, the position of mathematics as a foundation for future success makes a compelling case to administrators and funding bodies alike; peer instruction in mathematics is particularly worth investing in.

Moreover, at many institutions nationwide, and within the California State University System, it is common for all first-year students to enroll in a course that fulfills a mathematical degree requirement (in the CSU this is a General Education Area B4: Math/Quantitative Reasoning.) Student placement in this first-year curriculum often results in significant external pressure and attention on the departments offering these courses as student success is closely measured and required for progression toward degree [26,22,5]. These courses and departments shoulder the burden, and embrace the opportunity, for providing a foundation of success for these first-time college students. Many mathematics departments are early adopters of active learning and group work, approaches which lend themselves to building essential skills for success such as collaboration, teamwork, and productive struggle [21,24]. For these reasons, the mathematics classroom is the ideal place to reach these students, introduce them to the university learning community, and provide a foundation on which they can build their academic identity and sense of belonging. Implementing embedded peer support in these classes allow students to develop the practice of learning in community, merging social/emotional learning with academic success.

1.4. Positionality

The authors are uniquely positioned to make recommendations to practitioners for several reasons. First, we represent five CSU campuses (and the peer programs they house) which differ in important ways. Our campuses vary significantly in size (from less than 8,000 students to more than 37,000 students), geography (urban, suburban, and rural, from Southern, Central, and Northern California), culture, student profile, selectivity, and academic programming. As demonstrated in Table 1, the peer programs we work with are also extremely diverse with regard to the considerations of Section 2.2. This variety is complemented by a shared mission and vision focused on achieving equitable student outcomes.

Second, as individuals we represent a variety of academic and professional backgrounds. We hold PhDs in Mathematics and Mathematics Education and Master's degrees in Education and English. We currently serve as faculty (in Mathematics departments), staff (directing Learning Centers and coordinating programs), and administrators (in Colleges of Science). This diversity in roles enriches our understanding of peer instruction from multiple vantage points, including its practical implementation in classrooms and its impact on institutional policies and student outcomes. We possess a collective 94 years of experience working in peer instruction (and many more in mathematics classrooms), years which include reading literature and participating in conferences and professional networks in addition to running our own peer programs. We offer a well-rounded understanding of both the theoretical and practical aspects of peer instruction.

Third, the authors organized and participated in a colloquium series in Spring 2021 for the CSU Math Council, a consortium representing all Departments of Mathematics and Statistics in the California State University System. This series of talks focused on peer instruction models in use across and outside the CSU system, hosting 22 presenters over four weeks, including faculty, department chairs, and learning center directors from nine CSU campuses. The speakers and attendees were all passionate advocates for peer instruction, and the findings in this paper are informed by these presentations and conversations as well as the literature and our own experiences. In fact, an early goal of this paper was to disseminate many of the ideas shared in the colloquium series.

2. DESCRIPTION OF PROGRAMMING

2.1. Central Goals of Peer Support: Equitable Outcomes in Focus

Many universities have established the use of peer support, both within and outside the classroom, as an academic support mechanism that can impact students throughout their degree pathway and create a sense of community that builds belonging, confidence and scholarship as a social endeavor. Initially, university peer support was often limited to college access programs that targeted populations that were historically underserved and/or identified as likely to need such support based on demographic and/or socioeconomic class. As publicly funded university systems have opened their doors to more students with greater variations in background and preparation, peer support has moved from being limited to specific populations, to serving all students, especially in entry-level and gateway courses.

Although the specifics of different kinds of peer instruction models may vary, there are some underlying values central to peer support. These values were common to all the programs represented in our colloquium series, and are also ubiquitous in the literature. In Figure 1, we illustrate themes across peer instruction in the CSU system. In particular, we present themes as supporting equitable outcomes for students through peer instruction.

The primary reason to use peer instruction is that its core characteristics directly contribute to equitable outcomes for participating students. The key goals emphasized here are supported by educational research (for example, see the extensive bibliography of Arendale [4]). The online/hybrid environment during the pandemic particularly highlighted the need for having inclusive academic spaces, for peer role models, and for community and academic-identity formation. All of these important aspects of college success are supported by peer instruction:

- 1. Academic support ([1–3,12,17,29,34]). A common goal of all peer programs is to increase student success and retention by reducing academic barriers and increasing student access to support and to the academic community.
- 2. **Multiple perspectives and strategies** ([23,25,28,30]). Research in education supports the use of multiple perspectives and representations in learning. We see peer instruction as an opportunity to provide students with new perspectives and approaches to learning the content. Peer educators who have taken the class previously and are further along in their degree can share helpful strategies and tips that have contributed to their success. They are often able to provide alternate or additional explanations which complement those of the course instructor.
- 3. **Support for active and collaborative learning** ([2,9,19,36]). Peer support allows for more group work and hands-on learning with guidance from a peer. This type of active and collaborative learning is considered an equitable pedagogical practice. When students are actively engaged in the learning process and able to practice and talk about the content with others, they are more likely to understand it.
- 4. Role models and STEM identity ([7,12]). Students are more successful when they have peer mentors/role models who they can identify with and trust with their learning process. When students form positive relationships with one another, they are more likely to engage with the content, seek support, and feel more connected to the discipline as well as the university. A diverse group of peer mentors can provide much-needed role models corresponding to students' identity, contributing to greater and more equitable student retention, particularly in STEM.
- 5. **Navigate university life, resources, and procedures** ([15,27,37]). The exploration and development of effective learning strategies fundamentally aids in

6 🔄 J. GLASS ET AL.



Figure 1. Equitable outcomes mediated by peer instruction.

academic success. Discussion of such strategies is included in peer instruction models, and may not be explicitly addressed in other contexts. Students learn from each other how to manage their time, to take notes or to study effectively for an exam. Other types of institutional knowledge (available resources, location of certain offices, etc.) are also shared in peer-to-peer settings. Such support may be particularly helpful in the online setting where peer instructors can help navigate class structure and learning management systems.

- 6. Belonging and sense of community ([7,15,37]). Research supports the idea that students' sense of belonging and shared sense of community positively impacts learning, student persistence, and satisfaction [10,20]. Peer support fosters a sense of belonging and facilitates the formation of study groups and informal and formal learning communities.
- 7. Safe space for productive struggle ([1,2]). Students are generally more comfortable asking questions and making mistakes in front of a peer than their instructor. Because there is less of a power dynamic and less at stake when asking for help from a peer, peer instruction provides safe places to make mistakes and ask questions.

The literature cited in this section both informs and supports our Recommendations. Research demonstrates that peer instruction can help achieve the outcomes listed above, but when multiple models are employed on a single campus new challenges are introduced. Our recommendations are intended to help administrators and staff mitigate these challenges.

2.2. Considerations for Implementing Peer Support

The approaches to achieve the goal of equitable learning outcomes through peer support can vary widely. This section describes a list of questions that we considered for understanding our respective peer instruction programs. These questions provide context for how decisions are made at various levels (university, department, program), leading to diverse programming. Departmental and campus conditions (in terms of funding and personnel availability, programming goals, etc.) vary significantly, giving rise to a wide variety of implementation forms. The framework in Gamlath [18] considered such factors via stratification into external, institutional, and individual levels. Because the range of conditions can be so different, we found the following questions to be useful in guiding the specific structures and approaches to use:

- What student population is served? Often a particular subset of students is identified as the target audience of the program, e.g., first-year students, first-generation students, or students with a particular level of math preparation.
- What are the primary (non-grade) outcomes sought? These may include retention, sense of belonging, developing learning skills, or creating a safe academic space for students. Many of the details and the specific aims depend on who offers peer instruction (a program or a learning center), evaluation capacity, and the context of other programming offered to students.
- What is the pedagogical model employed? There are a variety of models, from Supplemental Instruction (where peer educators develop and teach independent sections) to Learning Assistants (who help the instructors in the classroom). Different approaches have different strengths and different complexities in implementation. The specific type of pedagogy involved may depend on a number of factors, such as the extent of instructor involvement or the level of training offered to students.
- How is the program funded? Funding can come from the university and may be a stable budget line. In other cases, funding may be a transient part of a grant-supported program. Often, successful programs rely both on an institutional base budget as well as one-time funding or additional grant support. Peer educators are paid, and the bulk of program costs is typically student salaries.
- Who coordinates the program and supervises the peer educators? How are coordinators compensated? Depending on the size, scale and funding source for the program, the coordinator may be a faculty member or a professional staff member. In larger programs, typically those offered through learning centers, there may be different staff members coordinating the peer instruction and training and supervising the peer educators. The compensation can vary widely here too, from teaching credits to salary, and part-time to full-time positions.
- How are peer educators trained? The extent and type of peer educator training and development highly depends on departmental budgetary constraints, prioritization of training, the pedagogical knowledge and experience of the supervisor,

8 😉 J. GLASS ET AL.

and the complexity of the peer instruction program. Some programs adopt and/or adapt training materials produced by programs such as The International Center for Supplemental Instruction and the Learning Assistant Alliance. Some programs also offer credit-bearing courses as part of the pedagogical training for peer educators.

- Do instructors/supervisors require training? For peer instruction models in which peer educators participate in the class, instructors may also participate in training and professional development in order to most effectively leverage their peer support in the classroom. Some programs encourage or require supervisor training or certification.
- Who creates the instructional content (e.g., peer educator or course instructor)? In some models, peer educators are highly trained not only in the content but also in pedagogical practices and are able to create instructional content. Other peer educators, such as peer tutors, may serve a very different role, and do not create instructional content, but focus on supporting students based on standard course materials.
- Is there a dedicated physical space for peer educators to meet with students? Peer educators may offer office hours or review sessions outside of class time. Having a specific student-centered meeting space that is centrally located can increase access to support, contribute to social-emotional growth and build a STEM student community.
- How are instructors involved? What is the linkage between the peerled/supported course and parent course? Depending on the model of peer instruction used, course instructors may only have loose, sporadic contact with tutors (e.g., with drop-in tutors employed by the learning center) or they may have a close working relationship with embedded peer tutors or learning assistants who attend class on a regular basis. A high degree of instructor involvement can positively impact the peer educators' own development, how many students utilize peer support, and it can help align learning in the classroom and outside it. However, peer instruction models that require a high level of instructor involvement tend to cost more and be more complex to coordinate.
- Where is the program housed (e.g., department or learning center)? The program's home impacts the student population served, the level of instructor involvement, the program's visibility, and often the financial aspects of the program as well as the training of the peer instructors.
- Are the peer educators embedded in the classroom? If so, what is their role? How is their work linked to that of the instructor? In some models, peer educators are embedded in the class and work with students as part of the regular instruction. This may range from simply attending class and acting as a model student to helping with group work to leading in-class activities independently. Other models of peer instruction do not involve peer educators in the classroom.
- How much autonomy do peer educators have? Drop-in tutors and Supplemental Instruction (SI) leaders can work quite independently from instructors. This can have positive effects, such as different ways of explaining the material, and

exposing students to multiple approaches. However, there is also a danger of peer instruction not aligning well with the course content. In other models, such as embedded peer tutors who attend class, peer instructors might have much less autonomy in designing activities or content.

- Is the program voluntary for students? Several models are opt-in models, such as drop-in tutoring or the classical SI model. This opting-in typically requires a higher level of motivation and engagement from students. However, opt-in models may not reach as broad of an audience as opt-out models (e.g., embedded tutors or learning assistants attending a class). Because of the design and implementation complexities of the various models, there is no conclusive evidence that either opt-in or opt-out models are always more effective.
- How is data collected? How is the efficacy of the program assessed? Evaluation of peer instruction can be difficult due to the myriad factors impacting student participation and success. Assessment of opt-in programs can be complicated by "selection bias" especially when course grades are used as a measure of success [11,17,29]. Data may include number of visits and participants. Ideally, qualitative measures such as belonging, identity, and community should be included in a comprehensive assessment plan.

2.3. Examples of Programs

Part of the difficulty in presenting a common narrative about peer instruction is the variety of terms, each with its local context, used to describe programming. Peer learning is a general term referring to students supporting students in an educational environment. Some commonly used names for peer support programs are the following: Tutoring, Embedded Tutoring, Embedded Peer Support, Supplemental Instruction, Modified Supplemental Instruction (MSI), Learning Assistant Program (LAP), and Peer Assisted Learning (PAL). While the language used can have local meanings, those meanings may not translate as intended outside of that institution, which may lead to some confusion. Thus, it may help to compare some specific examples of models broadly used within the CSU.

In Table 1, we provide a snapshot of some peer instruction models in the CSU. The table is not meant to be an all-encompassing view, rather, it is an illustrative sample based on the authors' personal knowledge and connections, as well as the aforementioned colloquium presentations. There are a variety of structural differences between the local conditions, so even the models listed may work quite differently at different universities.

The steps required to create a new peer instruction program often depend on the program model, and choosing which model to adopt (or adapt) is likely the first big decision to be made. Some programs belong to national or international networks possessing a wealth of resources for getting started, such as the Learning Assistant (https://learningassistantalliance.org/) or Supplemental Instruction

	Learning Assistants (LAs)	Embedded Supplemental Instruction (SI)	Peer Assisted Learning (PAL)	Precalculus Teaching Assistants (TAs)	Stretch Math Learning Communities
Sample CSU campus	East Bay: large, urban	Humboldt: small, rural	Sacramento: large, urban	San Diego: large, urban	Sonoma: small, suburban
What student population is served?	All first-year STEM pathway courses + gateway STEM courses in the sciences	Students in introductory general education mathematics courses (typically first-year students)	Students in selected Math, Stat, Bio, Phys, and Chem courses with low pass rates	Students enrolled in Precalculus	First-year students enrolled in specific math courses
What are the primary (non-grade) outcomes sought?	Belonging, community, and building student confidence	Community and sense of belonging, introduction to the university. Review content and help students learn how to learn	Community and sense of belonging	Building community among the students they are helping through group collaboration	Community and sense of belonging, acclimating to university, review of content and helping students learn how to learn
What is the pedagogical model employed?	Embedded peers with outside support	Peer educators lead collaborative review activities in the core classroom for all students enrolled in the course	Peer-led team learning	TAs lead small course breakout sections using group learning	Peer educators lead collaborative activities for all students enrolled in the course
How is the program funded?	Campus funds	Campus funds	Campus, student government, and federal grant funds	Department funds	Student government funds
Who coordinates the program and supervises the peer educators?	Full-time staff who direct the STEM Lab with instructor support	Supplemental Instruction Coordinator (Full-time staff)	Faculty with professional staff support	Precalculus course coordinator and TA professional development instructor	Tutorial & Supplemental Instruction Coordinator (Full-time staff)

Table 1. Characteristics of some representative programs on the authors' CSU campuses. Most campuses have multiple programs and the table is not comprehensive, rather it is meant to provide evidence of the richness and variety of existing programs.

(continued).

Table 1. Continued.

	Learning Assistants (LAs)	Embedded Supplemental Instruction (SI)	Peer Assisted Learning (PAL)	Precalculus Teaching Assistants (TAs)	Stretch Math Learning Communities
How are peer educators trained? Do instructors require training?	Preterm training with weekly professional development throughout the year. Pedagogy workshop series for first-semester LAs. Instructors are encouraged to attend	SI Leaders attend pre-semester training, a bi-weekly SI program training; bi-weekly Embedded Math SI Leader meeting. Instructors do not require training	PAL Facilitators attend pre-semester training and a weekly seminar. Instructors do not require training	TAs meet regularly with the course coordinator and course instructors	Robust preterm training and on-going weekly staff meetings throughout the year. Instructors do not require training
Who creates the instructional content?	Common resources are available and are created by current and past instructors and peer educators	Peer educator with support from the SI Coordinator and in collaboration with instructors	Instructors	Course coordinator and course instructors	Peer educator with support from the SI Coordinator and collaboration with instructors
Is there a dedicated physical space for peer educators to meet with students?	LAs hold open hours in the STEM LAB for drop-in help and collaboration.	Embedded SI Leaders hold office hours or "study session" hours in the Learning Center tutoring lab.	Yes, PAL Facilitators hold office hours in the PALace office complex.	Yes, TAs hold office hours in the tutoring left.	Yes, Mentors hold office hours and tutor in the Learning and Academic Resource Center.
How are instructors involved? What is the linkage between the peer-led/supported course and parent course?	LAs attend the parent class and communicate regularly with the instructor	SI Leaders attend the parent course and share lesson plan ideas with the instructor before implementation	PAL Facilitators attend lecture and participate according to instructor preference	TAs attend lecture and meet regularly with course coordinator and course instructors	The Learning Community Mentor attends the parent class and communicates regularly with the instructor
Where is the program housed?	College of Science	Learning Center	College of Natural Sciences and Mathematics	Mathematics & Statistics Department	Learning & Academic Resource Center

(continued).

Tab	le 1	. (on	tin	ued	
-----	------	-----	----	-----	-----	--

	Learning Assistants (LAs)	Embedded Supplemental Instruction (SI)	Peer Assisted Learning (PAL)	Precalculus Teaching Assistants (TAs)	Stretch Math Learning Communities
Is the peer educator embedded in the classroom? If so, what is their role?	Yes; LAs attend the parent class and assist the instructor in active-learning strategies	Yes; peer educators attend the core class twice per week. One day they attend lecture, the other day they lead a review activity, share campus resources, study strategies, etc.	Yes; PAL Facilitators attend lecture, participating according to instructor preference	No	Minimally; they attend the parent class and observe, may participate in some group activities
How much autonomy do peer educators have?	They can create icebreakers and activities at the guidance of the instructor	They have autonomy in creating the lesson plan for their review activity and holding tutoring hours in the Learning Center	They must follow the worksheets written by course instructors	They must follow worksheets/activities provided by course coordinators and course instructors	They have autonomy to create the session plans and design activities based on observation of the parent class curriculum
ls the program voluntary for students?	Partially. Embedded support is provided in class and therefore is not voluntary. Out of class drop-in tutoring hours are voluntary	No. The SI Leader is embedded in the class	Yes	No. TA-led breakout sections are part of the Precalculus course, and students are required to register for a breakout section	No. Students are enrolled in the Learning Community when they register for the stretch math class
How is data collected? How is the efficacy of the program assessed?	Student surveys, LA surveys, and instructors and graduate TA feedback. Student and LA success data is tracked	Student surveys and instructor feedback. Student success data is collected but analysis is forthcoming	Mathematics and Statistics faculty analyze student success data from institutional database	Breakout session course evaluations	Student and instructor surveys, statistical attendance and grade data from institutional database

(https://info.umkc.edu/si/) models; it is sometimes possible to import these models wholesale. Other programs are more unique to their campuses and require considerably more customization to get started, followed by regular revision.

For example, the Peer Assisted Learning (PAL) program at Sacramento State was conceived by a single faculty member who acted on inspiration from a conference on student engagement in 2009. She took the Peer Led Team Learning (PLTL) model as the core pedagogical structure but quickly incorporated a number of ideas from other sources, including an undergraduate research component inspired by another conference, and a tiered student leadership structure based on her experiences as a student bus driver in her college years. Logistically, starting this program required both writing grant applications and convincing a number of colleagues and administrators to buy in; instructor support proved to be absolutely critical. The PAL program was born in 2011 with the award of an NSF-STEP grant, after two unsuccessful prior submissions. The first PAL sections were held in 2012 supporting an introductory Chemical Calculations course with low pass rates that was acting as a gatekeeper course for STEM majors. The program was partly institutionalized in 2016 by presenting compelling data showing effectiveness in student success, combined with an argument that by getting students through these courses faster the program was saving the university as much money as it cost to operate. Federal and internal grants, student government support, and donors have allowed the program to grow and keep up with increasing costs.

2.4. Identifying Challenges

The richness of peer instruction programming across the CSU grew out of a need and desire to support students across affinity groups, academic standing, majors, and student preferences. While the variety of programming offers many opportunities for students, the current framework also presents challenges. These challenges are summarized here to provide context for the Recommendations section of our paper.

Specifically, there is often confusion for instructors and students in understanding the available resources and support structures. This can lead to an underutilization of the support if instructors do not recommend, or students do not seek, peer support. Students may also become accustomed to a specific type of peer instruction and may have difficulty adjusting to multiple different types of programming. Instructor buy-in is harder to enlist when support structures are complicated and instructors may teach courses with different types of peer support.

The variety of programming and lack of centralization also makes it difficult for the administration to oversee and manage programs and understand their strengths. When programs are structured differently, data collection and assessment become cumbersome, and in some cases, it may be difficult to compare the outcomes of different programs. Recruitment, training, compensation, and supervision of peer tutors may also vary, leading to greater burdens and a duplication of efforts. 14 😉 J. GLASS ET AL.

Funding can be quite inconsistent, and change year-to-year, or may not reflect changing needs. Some programs, particularly those offered by learning centers, may be more likely to have consistent base funding that comes from the university budget; however, this base funding is often not sufficient in meeting needs. Smaller programs, particularly those administered by departments, often start as a result of grant funding or special initiatives. In the CSU, they often meet niche needs and have requirements (e.g., special equipment or software) that are difficult to address centrally through learning centers.

3. RECOMMENDATIONS

Based on our collective position as peer education professionals, broad discussions with other peer education leaders within and outside the CSU, and the literature cited throughout this paper, we provide the following recommendations to optimize the implementation of peer instruction when multiple models are employed on a single campus. These recommendations are the primary research claims of this paper, which are synthesized through the Central Goals above.

- 1. Establish a Coordinating Committee to improve campus oversight and management of peer instruction. The Coordinating Committee should consist of representatives of all campus programs that provide peer academic support, have a committee structure and charge that includes annual reporting requirements.
- 2. Allocate centralized funding for peer instruction as a campus line-item. The distribution of these funds should be done in a manner that reflects the values and impact of each program as reflected by the work of the Coordinating Committee. Programmatic assessment should be integral to peer instruction programs from the beginning. Inconsistent funding was viewed as one of the greatest challenges at the CSU in offering consistent, high-quality peer instruction.
- 3. Direct individuals and departments interested in developing peer instruction programs to the Coordinating Committee in order to best leverage existing programming. By discussing grant applications and existing peer programming, campuses can leverage the structures that already exist and can move forward in ways that reduce duplication of effort and can streamline the peer instruction landscape in the long run.
- 4. Establish a peer instruction student employment portal where individuals interested in providing academic support can find a listing of all such positions on campus. We note that such portals can help all students but particularly transfer students who are qualified to serve as peer tutors but may not have the institutional knowledge to find the opportunities.
- 5. Establish a portal for receiving academic support. Similar to the previous recommendation, students who seek help (particularly first-year students) often

find it challenging to find all relevant information about peer instruction because of the variety of programming available.

- 6. Establish a consistent protocol for evaluation and assessment of peer support programs, including uniform data collection. Assessment of peer instruction is often challenging because program goals and structures vary widely. This makes comparisons between the effectiveness of programs difficult.
- 7. Integrate academic departments into the peer instruction structure from the beginning and acknowledge the importance of broad instructor engagement. Instructors directly work with students in the classroom and can be the greatest ally of peer instruction programs. However, instructors may not be aware of available resources, or, if not consulted, may not embrace programs that require regular communication and coordination. Greater collaboration between academic programs and those offering peer instruction can improve student participation and outcomes.

4. CONCLUSION

As our paper illustrates, many versions of peer instruction have been developed and successfully implemented. Our survey of the CSU system presents examples that reflect unique institutional features alongside the common goals of student success and equity. The recommendations and considerations described in this paper can inspire and guide the development and modification of programs, aligned with specific institutional values, priorities, and settings. While implementations may differ, each example shares an emphasis on the value of peers for creating community aligned with academic success and combating the perception that learning and community are separate endeavors.

ACKNOWLEDGEMENTS

The authors are grateful to the participants of the Spring 2021 CSU Math Council Colloquium series for sharing their experiences and expertise, inspiring this paper. We would also like to thank Jennifer Lundmark for sharing a detailed history of the CSUS PAL program.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

ORCID

Mary E. Pilgrim D http://orcid.org/0000-0002-9178-4052

REFERENCES

 Alzen, J. L., L. Langdon, and V. K. Otero. 2017. The learning assistant model and DFW rates in introductory physics courses. *Conference Proceedings of the Physics Education Research Conference*. https://www.per-central.org/items/perc/4741.pdf. 16 🕒 J. GLASS ET AL.

- [2] Alzen, J. L., L. S. Langdon, and V. K. Otero. 2018. A logistic regression investigation of the relationship between the learning assistant model and failure rates in introductory STEM courses. *International Journal of STEM Education*. 5(56): 1–12. doi:10.1186/s40594-018-0152-1.
- [3] Altomare, T. K., and A. N. Moreno-Gongora. 2018. The role and impact of Supplemental Instruction in accelerated developmental math courses. *Journal of College Academic Support Programs*. 1(1): 19–24. doi:10.36896/1.1fa2.
- [4] Arendale, D. R. (Ed.). 2022. Postsecondary peer cooperative learning programs: Annotated bibliography. [Unpublished manuscript]. Department of Curriculum and Instruction, University of Minnesota. https://z.umn.edu/peerbib.
- [5] Ayele, A. D., Z. Carson, and C. Tameze. 2023. An efficacy study of ALEKS-based placement in entry-level college math courses. *PRIMUS*. 33(4): 414–430. doi:10.1080/10511970.2022. 2073623.
- [6] Barber, P. H., C. Shapiro, M. S. Jacobs, L. Avilez, K. I. Brenner, C. Cabral, M. Cebreros, E. Cosentino, C. Cross, M. L. Gonzalez, K. T. Lumada, and M. Levis-Fitzgerald. 2021. Disparities in remote learning faced by first-generation and underrepresented minority students during COVID-19: Insights and opportunities from a remote research experience. *Journal of Microbiology and Biology Education*. 22(1): 10–1128. doi:10.1128/jmbe.v22i1.2457.
- Bjorkman, K. 2019. The identities of undergraduate mathematics peer tutors within the figured world of a mathematics learning center. [Doctoral Dissertation. University of California San Diego]. https://escholarship.org/content/qt8gt0r4ff/qt8gt0r4ff_noSplash_42cb80993c 183f8a08770a117c417e2a.pdf.
- [8] Burdman, P. 2018. The mathematics of opportunity: Rethinking the role of math in educational equity, just equations. https://justequations.org/resource/the-mathematics-of-opport unity-rethinking-the-role-of-math-in-educational-equity.
- [9] Campbell, J. M., J. L. Malcos, and J. M. Bortiatynski. 2019. Growing a learning assistant program. *Journal of College Science Teaching*. 48(3): 66–73. https://www.jstor.org/stable/2690 1284.
- [10] Carbone, A. 2014. A peer-assisted teaching scheme to improve units with critically low student satisfaction: opportunities and challenges. *Higher Education Research & Development*. 33(3): 425–439. doi:10.1080/07294360.2013.841644.
- [11] Chan, J. Y. K., and C. F. Bauer. 2015. Effect of peer-led team learning (PLTL) on student achievement, attitude, and self-concept in college general chemistry in randomized and quasi experimental designs. *Journal of Research in Science Teaching*. 52(3): 319–346. doi:10.1002/tea.21197.
- [12] Clements, T. P., K. L. Friedman, H. J. Johnson, C. J. Meier, J. Watkins, A. J. Brockman, and C. J. Brame. 2022. "It made me feel like a bigger part of the STEM community": Incorporation of learning assistants enhances students' sense of belonging in a large introductory biology course. CBE—Life Sciences Education. 21(2): 1–13. doi:10.1187/cbe.21-09-0287.
- [13] Close, E. W., J. Conn, and H. G. Close. 2016. Becoming physics people: Development of integrated physics identity through the learning assistant experience. *Physical Review Physics Education Research*. 12(1): 1–18. doi:10.1103/PhysRevPhysEducRes.12.010109.
- [14] Dawson, P., J. van der Meer, J. Skalicky, and K. Cowley. 2014. On the effectiveness of supplemental instruction: A systematic review of supplemental instruction and peer-assisted study sessions literature between 2001 and 2010. *Review of Educational Research*. 84(4): 609–639. doi:10.3102/0034654314540007.
- [15] Flores, G., and A. G. Estudillo. 2018. Effects of a peer-to-peer mentoring program: Supporting first-year college students' academic and social integration on campus. *Journal of Human Services: Training, Research, and Practice.* 3(2): 3. https://scholarworks.sfasu.edu/ jhstrp/vol3/iss2/3.

- [16] Fry, R., B. Kennedy, and C. Funk. 2021. STEM jobs see uneven progress in increasing gender, racial and ethnic diversity. Pew Research Center. 1: 28. https://www.jstor.org/stable/pdf/ resrep57656.pdf.
- [17] Frey, R., A. Fink, M. J. Cahill, M. A. McDaniel, and E. D. Solomon. 2018. Peer-led team learning in general chemistry I: Interactions with identity, academic preparation, and a course-based intervention. *Journal of Chemical Education*. 95(12): 2103–2113. doi:10.1021/acs.jchemed.8b00375.
- [18] Gamlath, S. 2022. Peer learning and the undergraduate journey: A framework for student success. *Higher Education Research & Development*. 41(3): 699–713. doi:10.1080/07294360.2021.1877625.
- [19] Hernandez, D., G. Jacomino, U. Swamy, K. Donis, and S. L. Eddy. 2021. Measuring supports from learning assistants that promote engagement in active learning: Evaluating a novel social support instrument. *International Journal of STEM Education*. 8(1): 1–17. doi:10.1186/s40594-021-00286-z.
- [20] Kemp, M. W., T. J. Molloy, M. Pajic, and E. Chapman. 2013. Peer relationships and the biomedical doctorate: A key component of the contemporary learning environment. *Journal of Higher Education Policy and Management*. 35(4): 370–385. doi:10.1080/1360080X.2013.812055.
- [21] Lucas, A. 2009. Using peer instruction and I-clickers to enhance student participation in Calculus. PRIMUS. 19(3): 219–231. doi:10.1080/10511970701643970.
- [22] Madison, B. L., C. S. Linde, B. R. Decker, E. M. Rigsby, S. W. Dingman, and C. E. Stegman. 2015. A study of placement and grade prediction in first college mathematics courses. *PRIMUS*. 25(2): 131–157. doi:10.1080/10511970.2014.921653.
- [23] Mathematical Association of America (MAA). 2018. *MAA instructional practices guide*. https://maa.org/resource/instructional-practices-guide/.
- [24] Miller, R. L., E. Santana-Vega, and M. S. Terrell. 2006. Can good questions and peer discussion improve calculus instruction? *PRIMUS*. 16(3): 193–203. doi:10.1080/1051197060898 4146.
- [25] National Council of Teachers of Mathematics (NCTM). 2014. *Principles to Actions: Ensuring Mathematical Success for all*. Reston, VA: NCTM.
- [26] Norman, K. W., A. G. Medhanie, M. A. Harwell, E. Anderson, and T. R. Post. 2011. High school mathematics curricula, university mathematics placement. *PRIMUS*. 21(5): 434–455. doi:10.1080/10511970903261902.
- [27] Peregrina-Kretz, D., T. Seifert, C. Arnold, and J. Burrow. 2018. Finding their way in postsecondary education: the power of peers as connectors, coaches, co-constructors and copycats. *Higher Education Research & Development*. 37(5): 1076–1090. doi:10.1080/07294360. 2018.1471050.
- [28] Richter, T., H. Münchow, and J. Abendroth. 2020. The role of validation in integrating multiple perspectives. In P. Van Meter, A. List, D. Lombardi, and P. Kendeou (Eds.), *Handbook of Learning from Multiple Representations and Perspectives*, pp. 259–275. New York: Routledge. doi:10.4324/9780429443961-18.
- [29] Shanbrom, C., M. Norris, C. Esgana, M. Krauel, V. Pigno, and J. Lundmark. 2023. Assessing student success in a peer assisted learning program using propensity score matching. *Journal of College Science Teaching*. 52(7): 129–136. doi:10.1080/0047231X.2023.12315888.
- [30] Stein, M. K., R. A. Engle, M. S. Smith, and E. K. Hughes. 2008. Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning*. 10(4): 313–340. doi:10.1080/10986060802229675.
- [31] The California State University. 2017. *Executive Order (EO)* 1110. https://calstate.policystat. com/policy/6656541/latest/.
- [32] The California State University. n.d. *Graduation initiative 2025*. https://www.calstate.edu/ csu-system/why-the-csu-matters/graduation-initiative-2025/Pages/default.aspx.

18 🕒 J. GLASS ET AL.

- [33] The Campaign for College Opportunity. 2023. A rising tide in graduation rates at the California State University (CSU), a persistent divide in racial equity. https://collegecampaign.org/ wp-content/uploads/2023/08/080223-Rising-Tide-Persistent-Divide-GI2025-FINAL-com p.pdf.
- [34] Tucker, K., G. Sharp, S. Qingmin, T. Scinta, and S. Thanki. 2020. Fostering historically underserved students' success: An embedded peer support model that merges non-cognitive principles with proven academic support practices. *The Review of Higher Education*. 43(3): 861–885. doi:10.1353/rhe.2020.0010.
- [35] Vithal, R., K. Brodie, and R. Subbaye. 2023. Equity in mathematics education. *ZDM–Mathematics Education*. 56: 1–12. doi:10.1007/s11858-023-01504-4.
- [36] Wilson, S. B., and P. Varma-Nelson. 2016. Small groups, significant impact: A review of peer-led team learning research with implications for STEM education researchers and faculty. *Journal of Chemical Education*. 93(10): 1686–1702. doi:10.1021/acs.jchemed.5b00862.
- [37] Yomtov, D., S. W. Plunkett, R. Efrat, and A. G. Marin. 2017. Can peer mentors improve first-year experiences of university students? *Journal of College Student Retention: Research, Theory & Practice*. 19(1): 25–44. doi:10.1177/1521025115611398.

BIOGRAPHICAL SKETCHES

Julie Glass holds a PhD in Mathematics from UC Santa Cruz. After serving many years in the Department of Mathematics, she is now Associate Dean for Student Equity and Success in the College of Science at California State University, East Bay.

Su Karl holds an M.S.Ed. in School Counseling from Long Island University. She is Cal Poly Humboldt's Learning Center Director in Arcata, CA.

Bori Mazzag earned her PhD in Applied Mathematics in 2002 from UC Davis, then, after a postdoctoral position at the College of William and Mary and the University of Utah, she joined the Cal Poly Humboldt (then Humboldt State University) Mathematics faculty in 2005. She currently serves as the Associate Dean of Academic Affairs in the College of Natural Resources and Sciences at Cal Poly Humboldt.

Loriann Negri holds a M.A. in English, Rhetoric and Composition from Cal State Sonoma. She currently directs the Learning and Academic Resource Center and the Center for Community Engagement at her alma mater, Sonoma State University.

Mary E. Pilgrim holds an MS in Mathematics and Ph.D. in Mathematics Education from Colorado State University. She is Associate Professor of Mathematics Education in the Department of Mathematics and Statistics at San Diego State University and is the Math Graduate TA professional development provider. Her research area is in undergraduate mathematics education, focusing on mathematics graduate teaching assistant professional development for teaching, with a focus on active, equitable, and inclusive practices. In addition, she studies the uptake and sustainability of related change efforts at the department level. She has two NSF grants supporting her work (Award Nos 2013590, 2013563, and 2013422; Award Nos 1953713 and 1953753).

Corey Shanbrom holds a PhD in Mathematics from UC Santa Cruz. He is currently Professor of Mathematics and Director of Peer Assisted Learning at California State University, Sacramento.

Arianna Thobaben holds an M.A.Ed. and MS Credential. She coordinates the Supplemental Instruction program at Cal Poly Humboldt where she is also a teacher educator in the School of Education.