Peer instruction in mathematics: a survey of the California State University

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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, peer mentor, collaborative learning

Introduction

Studies have consistently shown the positive impact of peer instruction on student success and equitable outcomes (Alzen et al., 2017; Alzen et al., 2018; Altomare & Moreno-Gongora, 2018; Carbone, 2014; Clements et al., 2022; Frey et al., 2018; Gamlath, 2022; Peregrina-Kretz et al., 2018; Shanbrom et al., 2023; Tucker et al., 2020). The range of studies showing effectiveness demonstrate the versatility of peer instruction as a strategy to support academic achievement. This versatility stems, in part, from the fact that peer instruction can look different depending on local contexts and institutional priorities. 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. This 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 the California State University (CSU) system, a 23-campus system of higher education in the United State, where there is a shared mission but varied implementations, contexts, and institutional priorities. Selected campuses taken together demonstrate the pervasive impact of this practice and can provide examples for a variety of institutions.

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 colloquia 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 Central Tenets of Peer Support), factors that influence implementation (see section Considerations for Implementing Peer Support), and common challenges (see section Identifying Challenges). 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.

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 found 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., Barber et al., 2021; The Campaign for College Opportunity, 2023); potentially revealing even more starkly how community within the learning environment impacts student engagement and success. Peer support has been shown to increase a sense of belonging (Bjorkman, 2019, Clements et al., 2022, Close et al., 2016), motivating broader use of peer instruction as academic staff 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 (The California State University, 2017, n.d.) 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 (Alzen et al., 2017, Dawson et al, 2014, Frey et al., 2018, Shanbrom et al, 2023; Tucker et al., 2020) and helps address/close equity gaps (Alzen et al., 2017, Tucker et al, 2020). Attending to these gaps are especially important in STEM, as many jobs in these fields continue to see lack of diversity (Fry et al., 2021) and particularly in mathematics, given its foundational role in STEM success (Burdman, 2018) and the current active research interest in equity in mathematics (Vithal et al., 2023).

The authors, who represent STEM academic and professional staff across the CSU system, are positioned to share experiences that are relevant nationally and internationally because of the variety of institutional characteristics of our campuses. This variety is balanced by a common mission and vision of equitable student outcomes.

Description of programming

Central Tenets 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. 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.

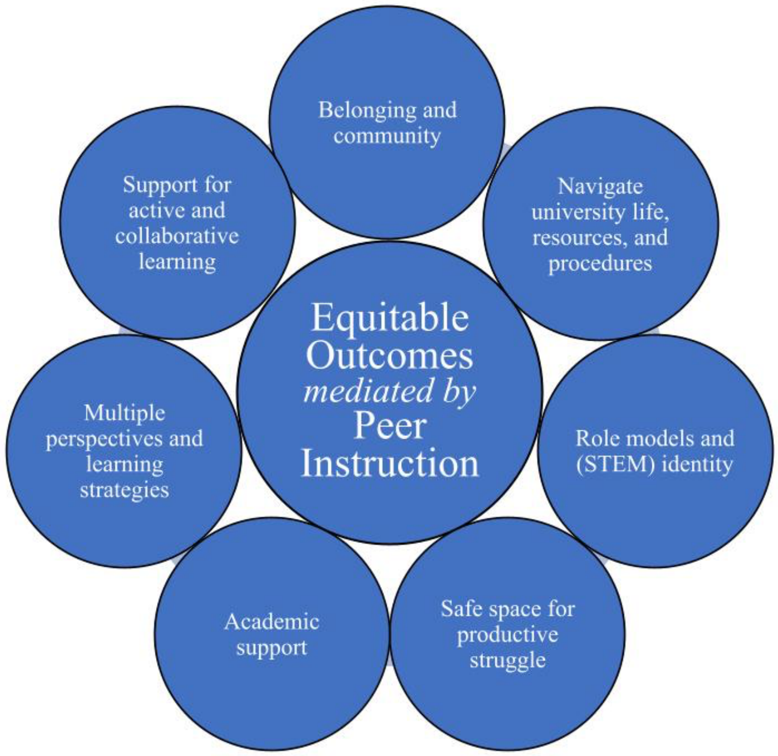

Figure 1: Equitable outcomes mediated by peer instruction.

The primary reason to use peer instruction is that its core characteristics directly contribute to equitable outcomes for participating students. The key tenets emphasized here are supported by educational research (for example, see the extensive bibliography of Arendale (2022)). 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 (Alzen et al., 2017; Alzen et al., 2018; Altomare & Moreno-Gongora, 2018; Clements et al., 2022; Frey et al., 2018; Shanbrom et al., 2023; Tucker et al, 2020)**. 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 (e.g., Mathematical Association of America, 2018; National Council of Teachers of Mathematics, 2014; Richter et al., 2020; Stein et al., 2008)**. Research in education supports the use of multiple perspectives and representations in learning (NCTM stuff here). We see peer learning as an opportunity to provide students with new perspectives and approaches to learning the content. Peer educators having 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 break down and explain terms and concepts in a more accessible way than the course instructor.
3. **Support for active and collaborative learning (e.g., Alzen et al., 2018; Campbell et al., 2019; Hernandez et al., 2021; Wilson & Varma-Nelson, 2016)**. 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 (e.g., Bjorkman, 2019; Clements et al., 2022)**. 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. It is often the diverse group of peer mentors who 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 (e.g., Flores & Estudillo, 2018; Peregrina-Kretz et al., 2018; Yomtov et al., 2017)**. Peer support models include the sharing of learning strategies. Whereas how to learn the subject may not be explicitly addressed in other contexts, the exploration and development of effective learning strategies fundamentally aids in academic success. 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 (e.g., Bjorkman, 2019; Flores & Estudillo, 2018; Yomtov et al., 2017)**. Research supports the idea that students' sense of belonging and shared sense of community positively impacts learning, student persistence, and satisfaction (Carbone, 2014; Kemp et al., 2013). 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 (e.g., Alzen et al., 2017; Alzen et al., 2018)**. 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.

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 (2022) 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.
- **Who coordinates the program (e.g., academic or professional staff) and supervises the peer educators? How are they compensated?** Depending on the size, scale and funding source for the program, the coordinator may be an academic staff 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, 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.
- **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 the peer educator paid, or do they earn course credit?** In most models, tutors are paid; however, especially if the peer educator role is part of a teaching apprenticeship model, they may also be earning credits as compensation.
- **How are instructors involved? What is the linkage between the peer-led/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, 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 through 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 Supplementary 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 the 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 of 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 (Chan & Bauer, 2015; Frey et al., 2018; Shanbrom et al., 2023). Ideally, qualitative measures such as belonging, identity, and community should be included in a comprehensive assessment plan.

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.

We have provided a table in the Appendix at the end of this document to 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 and in different countries.

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 under-utilization 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.

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.

Recommendations

Reflecting on broad discussions, we have the following recommendations to optimize the implementation of peer instruction when multiple models are employed on a single campus.

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**. Similarly 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.

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.

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Appendix

This table includes 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.

	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 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)	Academic staff	Precalculus course coordinator and TA professional development instructor	Tutorial & Supplemental Instruction Coordinator (Full time staff)
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

	Learning Assistants (LAs)	Embedded Supplemental Instruction (SI)	Peer Assisted Learning (PAL)	Precalculus Teaching Assistants (TAs)	Stretch Math Learning Communities
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 the peer educator paid, or do they earn credits?	Paid	Paid	Paid; they also earn credits for the weekly seminar	Paid or course credit	Paid
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
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	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
Is 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 into 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 academic staff analyze student success data from institutional database	Breakout session course evaluations	Student and instructor surveys, statistical attendance and grade data from institutional database