AMERICAN SOCIETY FOR MICROBIOLOGY | JMBE Journal of Microbiology & Biology Education

| Research Article

Accessible support at a national scale: the use and value of virtual learning assistants across multiple undergraduate institutions

Christine M. Pribbenow,[1] D'Andrew Harrington,[2] Chinmay P. Rele,[3] Katie M. Sandlin,[3] Wilson Leung,[4] David Lopatto,[5] Laura K. Reed[3]

AUTHOR AFFILIATIONS See affiliation list on p. 8.

ABSTRACT The Genomics Education Partnership (GEP; thegep.org) is a collaboration of more than 260 faculty from over 200 colleges and universities across the continental United States and Puerto Rico, all of whom are engaged in bringing Course-based Undergraduate Research Experiences (CUREs) centered in genomics and bioinformatics to their students. The purpose of the GEP-CURE is to ensure all undergraduate students have access to research experiences in genomics, regardless of the funding and resources available at their institutions. The GEP community provides many resources to facilitate implementation of the genomics curriculum at collaborating institutions, including extensive support for both faculty and undergraduate students. Faculty receive training to implement the curriculum, ongoing professional development, access to updated curriculum, and a community of practitioners. During the COVID-19 pandemic, the GEP developed a virtual learning assistant (LA) program to provide real-time support in GEP activities and research to all students, regardless of their institution, while they were participating in the GEP-CURE. A mixed-methods descriptive study was conducted about this program and draws from quantitative data gathered about the scope and use of the program, as well as the value of the program, as indicated by the undergraduates themselves from their post-course survey responses. Additionally, seven LAs who served in this role between 2021 and 2023 participated in interviews to help the GEP better understand how this resource was used by GEP students, the needs of the students, and to identify the conditions in which this resource could be replicated in other courses.

KEYWORDS learning assistants, course-based undergraduate research experiences, COVID-19 pandemic, undergaduate student support, STEM learning

The Genomics Education Partnership

The Genomics Education Partnership (GEP; thegep.org) was founded in 2006 by S.C.R. Elgin (Washington University in St. Louis). The development of this program was motivated by the need to bring genomics and bioinformatics into the undergraduate curriculum by engaging students in research. The GEP research focuses on using comparative genomics to elucidate how genes and genomes evolve. Due to the limitations of the sequencing technologies and computational algorithms available early in the genomic era, there was a need for substantial human cognitive effort to improve the genome assemblies and to construct gene models by evaluating multiple lines of empirical (RNA-Seq) and computational (sequence alignments and computational gene predictions) evidence. Undergraduate students proved to be an ideal resource for providing that cognitive effort while also providing them with genuine research experiences. The GEP-CURE shows students how to utilize genomic data and comparative evolutionary analyses to better understand the structures and functions

Editor Min-Ken Liao, Furman University, Greenville, South Carolina, USA

Address correspondence to Christine M. Pribbenow, cmpribbenow@wisc.edu.

The authors declare no conflict of interest.

See the funding table on p. 8.

Received 18 September 2024
Accepted 20 January 2025
Published 11 February 2025

of eukaryotic genomes. The students' research projects are then used as the basis of evolutionary genomic studies, originally focused on the genus *Drosophila* (1, 2).

The GEP has grown into a vibrant and collaborative community of hundreds of highly dedicated faculty and enabled thousands of students to participate in genomics research. In 2017, L.K. Reed (The University of Alabama) assumed the role of GEP Program Director. Since then, GEP has additionally focused on recruiting and mentoring faculty at institutions especially well-poised to serve students from historically underrepresented groups in science, technology, engineering, and math (STEM) fields (3) and expanded its research focus into additional groups of organisms (e.g., parasitoid wasps, Puerto Rican parrot).

The standardized curriculum and course

The GEP provides faculty with a supportive community of practice (CoP) and the technical infrastructure to engage students in CUREs (4, 5). GEP-CUREs are designed so that all students can learn the same gene annotation protocol and then apply the protocol to their individual research projects. These manually curated gene models are then used to address scientific questions (e.g., expansion of the *Drosophila* Muller F Element, evolution of the insulin signaling pathway, evolution of venom proteins in parasitoid wasps) posed by a GEP Science Partner (6–11). To facilitate the training of students, the GEP maintains and updates curriculum materials to account for changes in bioinformatics databases and tools. Students are presented with background information both on the scientific aims of the project and on how the data they are analyzing was generated. They are then provided with step-by-step walkthroughs, workflows, and worksheets as part of their training before being assigned their independent projects. The content may be taught as part of an introductory biology course, at an advanced course level, or as independent undergraduate research. The number of students involved and the duration of the course can vary depending on the method of instruction.

The GEP has five core goals: (i) provide undergraduate students with research experiences in genomics and bioinformatics; (ii) establish an inclusive and open community of educators guiding student investigators at a scale that can pursue extensive projects; (iii) model "team science" in a mutually supportive and beneficial collaboration; (iv) publish scientific results with participating faculty and students contributing as co-authors (4–7, 9–12); (v) contribute to the scholarship of teaching and learning by regularly publishing assessment results in the educational literature (1–5, 13, 14).

STEM course support

The use and value of learning assistants (LAs) in undergraduate STEM courses are well-documented and profoundly influential. LAs are defined as "near-peer instructors" and are often undergraduate students who are currently in, or have recently completed, the course and provide opportunities for "peer-peer learning." LAs differ from teaching assistants (TAs) who are typically graduate students who grade homework, run discussion sections, and have other supportive roles and responsibilities within a classroom (15). LAs are primarily available to students in an individual course at one institution where the course enrollment can range from a small number of students (e.g., ~20) to courses with multiple sections and hundreds of students. Prior to the start of the COVID-19 pandemic in 2020, much of the research on LAs was conducted in courses that were completely in person, as opposed to the variety of course modes (e.g., virtual, online, synchronous, asynchronous) more broadly used after 2020.

Extensive research and literature highlight the transformative benefits of LAs/TAs for both undergraduate students and the assistants themselves. When LAs are available to students in large STEM courses, research indicates that students feel a greater sense of belonging in the course (16) and are retained in STEM (17). In a study of three introductory STEM courses, Alzen et al. found that LA support in "any STEM gateway

course [was] associated with a 63% reduction in odds of failure for males and a 55% reduction in odds of failure for females in subsequent STEM gateway courses" (p. 1).

Research also identifies benefits to the LAs/TAs themselves. Breland et al. (18), identified multiple positive outcomes for LAs, such as becoming more reflective learners, and increasing their motivation and self-efficacy. Huvard (19) found a greater sense of STEM identity and an increase in "metacognitive" reflection for those serving as LAs. Serving as a TA produced similar learning outcomes as compared with those who participated as research assistants (20). Others found that LAs acquired pedagogical skills and experienced "transformative learning" by serving in this role (21).

With the COVID-19 pandemic and the move to online and virtual courses, the use of LA support increased at many institutions to ensure student success in STEM courses, both small and large. Research about these experiences suggests that LAs indeed had a positive impact on students. Kahn et al. (22) found that students from many underrepresented groups were negatively impacted by the pandemic and move to online courses, but these negative outcomes were ameliorated by incorporating LAs in courses. Hester et al. (23) found that an instructional team that incorporated LAs as student support indicated increases in self-efficacy and learning for STEM undergraduates as compared with courses without LAs.

While studies about LAs are typically conducted in one course and/or at one institution, the following mixed-methods descriptive study is of an LA program that supports one course/curriculum across multiple institutions. During the COVID-19 pandemic, the GEP developed a real-time support program in which all GEP students were able to virtually access LA support from the early morning until the late evening for 7 days a week through an online Zoom meeting room. The following describes the LA program available to undergraduates enrolled in the 652 courses that implemented the GEP curriculum by 197 faculty at 170 institutions during the period from 2020 to 2023.

METHODS

Description of the GEP virtual LA program

The virtual LA program was established in the summer of 2020 to support GEP faculty and students during their transition to online learning brought about by the COVID-19 pandemic. On average, approximately 14% (91/652) of the courses that utilized GEP materials in 2020–2023 had TAs sponsored by their institutions, so the majority had no extra support for their students. GEP members at both 2- and 4-year institutions were invited to nominate students who had previously used the GEP curriculum and were thought to be positive role models and effective mentors for other students. From these LA nominations, a complementary team of LAs was hired.

Once hired, LAs were provided with ongoing training and weekly meetings to support their role. To provide student support every day of the week, each LA chose 4–8 h during the timeframe of 8 am–10 pm (Central Time) Sunday through Saturday. During the academic year, LAs were typically available to work with students on Zoom for approximately 48 h each week. Besides meeting individually with students and cultivating specialty content areas to support specific GEP research projects, the LAs also created resources and videos, edited curriculum, annotated high priority genes, and completed other tasks to support the overall project and curriculum.

Data collection

Current LAs, all of whom had been in the program for at least 2 years, were invited to participate in this study during the summer of 2023. Participants were current undergraduates, recent graduates of a Bachelor of Science program, or graduate students who had participated in the GEP as undergraduates. All seven consented to an in-person or online interview that was digitally recorded and lasted 25–64 min, with an average length of 45 min. Interviews were transcribed and inductively analyzed based on the semi-structured questions that were asked (24). Interview results were complemented

by quantitative data about program usage, which were collected by the Lead LA and by end-of-course surveys deployed to all students who participated in GEP-related courses each semester.

RESULTS

Use and value of the GEP virtual LA program

In addition to the end-of-course surveys that GEP students may choose to complete, the LAs and students seeking LA assistance contribute to a database about the students who access the LA office hours on Zoom. The following is known about GEP virtual LA usage, based on data from the academic year of 2022–2023:

- Approximately 263 individual students accessed and met with an LA.
- Approximately 18% of the students who accessed this support were enrolled in 2-year institutions. (Students enrolled in 2-year institutions made up 12% of the overall population of GEP students.)
- During September 2023 to June 2024, students spent an average of 39.6 min with an LA during an individual session.

All students who participated in a GEP course were invited to take a survey at the end of the semester in which it was taught. Three academic years of survey data were aggregated to provide an overview of usage by undergraduate students (i.e., 2020–2021, 2021–2022, and 2022–2023). End-of-course survey data indicated that 18% (n = 459) of survey participants had met with an LA; approximately half of that group (52%) sought LA support 2–4 times; 35% used it once; 8% used it weekly; and an additional 5% noted "other." Forty percent (n = 472) of survey participants knew about the LAs but had never used them, of which 74% (n = 323) said they did not need this type of support. Forty-three percent (n = 532) of survey participants were unaware of the LA resource.

Students who met with virtual LAs evaluated the program very positively. When asked to indicate their agreement to a list of statements using a scale from 1 (strongly disagree) to 5 (strongly agree), survey participants agreed that LAs are an important part of the GEP, other courses would benefit from this type of support, and they would recommend the LAs to their peers (see Table 1). Clearly, the perceived benefits of access to virtual LAs from the students' perspectives are profound.

Following end-of-course survey data analyses, interviews were conducted to analyze the nature of the experience from the LA perspective to better understand what about the interaction was most meaningful to both parties.

Initial expectations

When LAs were asked to share their initial expectations of the role, most interviewees did not know what to expect. This was especially the case for interviewees who had not worked as an LA in the past. Those who had been in an LA position before expected it to be similar to study groups or the laboratory sessions they had facilitated for other courses. One interviewee noted, "I expected it to be about the GEP—science, science, science." Quickly however, the LAs quickly found themselves playing more of a supportive role. One LA noted, "it was pretty early when I realized that I would be giving support, and I liked that role." Another shared:

It was almost more important to be a supportive figure to [the student]. They did not feel like they had the safe space to say, "I know I should know this, but I don't." They were able to be vulnerable, complain… they had a safe space.

When this happened, the LA would often share struggles of their own and remind the student that they too had been in a place of not knowing. This response signaled to the student that they would also be able to learn whatever they were struggling with. Once the student got through the emotional and psychological barriers, the LA was able to move into a working relationship with the student.

TABLE 1 Average undergraduate student responses to post-course survey items that evaluate the LA program on a scale from 1 = strongly disagree to 5 = strongly agree; 2020–2023[b]

Survey item	Average	N	Average SD
The virtual LAs are an important part of the GEP and should be continued.	4.44	459	0.85
I think all courses (and students) would benefit from having a nationwide set of virtual LAs.	4.42	459	0.89
I would recommend other students completing the GEP projects to utilize the virtual LAs.	4.38	135[a]	0.92
I felt comfortable asking the virtual LA questions.	4.35	459	0.91
The virtual LA was knowledgeable about the GEP content material.	4.34	459	0.90
A virtual LA was available and responsive when I needed help.	4.32	457	0.88
The virtual GEP LA provided clear and understandable explanations.	4.28	459	0.95
The virtual LA enabled me to successfully complete my GEP project.	4.22	454	0.98
I felt more comfortable asking the virtual LA questions than my instructor.	3.60	459	1.26

[a]Item was removed from student surveys in 2022–2023.
[b]Standard deviation (SD) averaged across the three academic years.

Meeting the needs of students

The theme of addressing emotional and psychological needs emerged from the interviewees when asked to characterize the content of the sessions with students. One LA noted, "three quarters of the students are not coming into the session in a positive space." Other LAs noted, "they are stressed out…students say, 'I don't know what I am doing, I am struggling'" and "The students come in very discouraged and overwhelmed. They can't learn when they are distressed."

As mentioned previously, the LA often empathizes with them and their struggles with the GEP project. They connect with the student and let them know it is "do-able." Since the LAs are close in age and can relate to the students' struggles with gene annotations, the students realize that, despite their current challenges, they will eventually succeed. LAs talked about encouraging both self-efficacy and confidence in the students. One interviewee said, "they need to know they are not stupid, and then they can do it." Reassurance and peer mentoring make the students feel motivated and interested; after this, they are able to discuss science.

LAs document the types of scientific issues and concerns that the students are having after each session. These data show that in most sessions (67%), the LAs are discussing annotation and walking through an individual model with the student. LAs help students with the technical aspects of gene annotations, such as defining splice donor and acceptor sites and their phases, by using both auditory and visual modes (e.g., utilizing the shared screen or white board features in Zoom). One LA noted:

"I get a feel for where they are in the first 5 minutes, ask some questions to see where their 'baseline' is, assess where they are… I scaffold the learning and then give them what they need."

Students are often overwhelmed on how to annotate while attempting to complete the initial walkthrough. LAs help them see the bigger picture and give them tips to break the project down. In general, LAs describe the student as "highly motivated," yet they are struggling to grasp the material taught in the course. Occasionally, they discuss GEP tools and genome browsers, answer general science questions, or any questions related to the students' individual projects.

Besides discussing science, one LA interviewee described helping students gain, "soft skills, like self-advocacy and communicating with their teacher… Also, being willing to be wrong is the best skill they can learn." Another LA noted that they, "[walk the student] through the process as if this is a scientific question. I try to transition them from being a student to a researcher and think 'how do I look at this problem, how do I approach it?'"

An LA shared that "coming into their own as a scientist is the biggest thing [students] get from this." Another LA noted, "with GEP there is no right answer—they are often looking for the right answer and have not realized that this is the scientific process. This is not like a lab. This is often the first time they are doing 'real science.'" If the student comes

in confident but is struggling with a specific detail or challenge, the LAs "nerd out with them" and are excited to problem-solve with their peers.

All LAs identified needs that were consistent with those found by Thompson et al. (25) who developed a taxonomy to identify the topics of discussions between LAs and students. That said, from the LA's perspective, "non course/school-related talk" took up a significant amount of time, as compared to some of the other content-related topics of discussion.

Personal and professional growth of the GEP virtual LAs

The GEP virtual LAs have found this role to be personally and professionally fulfilling. Personally, they appreciate the flexibility to work from wherever they are living and at times that accommodate their schedule and lives as parents and students. Because they do not know who will attend the support session, they have learned how to adjust their styles to meet the needs of students, which has allowed them to grow as individuals. They also recognize when students are struggling and find great fulfillment in helping them understand the science.

Professionally, many noted that being an LA has impacted their career goals and provided them insight into what they both do and do not want to do in their future. Many GEP LAs are currently in graduate programs and want to ultimately be in a faculty position; this experience has provided essential training and teaching experience and has confirmed their love for the field of genomics and bioinformatics. It has also provided them with opportunities to broaden their career goals. Through their extensive knowledge of the GEP curriculum, the LAs have increased in confidence and felt empowered to offer suggestions for improvements, which has enhanced the overall program. Finally, despite mostly working independently of other LAs, their team time and support have helped them to see how their contributions affect others.

GEP virtual LA program is accessible to students

The accessibility of the GEP virtual LA program is one of its greatest benefits. This is realized by both programmatic aspects and the LAs themselves.

Schedule of office hours

LAs are located across the country and provide available meeting times from early in the morning to late at night (e.g., from 8 am to 10 pm or later Central Time). This meets the needs of students who have multiple school, work, and family responsibilities and need help at different hours of the day. It also meets the needs of students based outside the US, whose time zones can sync up with this type of schedule. One interviewee remembers an international student who met with them multiple times on late Friday nights due to the time zone difference and told the LA, "you're the reason I didn't drop out."

Diversity of LAs

The LAs have different expertise in multiple areas of the curriculum (e.g., F-element, pathways, parasitoid wasps), so students can always find someone with expertise in their projects. The LAs also reflect a diversity of ages and experiences, genders, races, and ethnicities, and may be bilingual. Some self-identify as having a disability or being neurodiverse. Because of their special talents and skills, they approach student learning with a variety of methods. Inevitably, there is an LA who will "click" with a particular student. They also serve as positive role models for students to aspire to.

Provides an effective learning space

Students who attend office hours are often uncomfortable admitting to their professors that they are struggling. LAs are intentionally empathic and supportive to the student's needs, and being one-on-one with them allows the student to admit this. The course at

their institution might not have a LA, or the students may not be connecting well with the faculty member or with the LA at their institution. In all cases, the virtual LAs are helpful for students to get individualized support through different teaching methods and explanations.

DISCUSSION

The GEP virtual LA program was invaluable during the pandemic and played a pivotal role for the hundreds of students in a shared GEP course across different institutions. Even when a course LA was available at an institution, the accessible nature of the virtual LAs allowed students to meet with them at a time that was ideal, such as when they were working on their GEP projects. Usage data shows students accessing the Zoom room most often at around 8 pm, followed by 2 pm and 9:30 pm. Higher usage also coincided with assignment deadlines. During these sessions, the virtual LAs provided academic support by using the shared screen and whiteboard tools to help students visualize the scientific problems they were attempting to solve while verbally walking them through it. The LAs also enabled the students to share their vulnerabilities and self-doubt confidentially, which then allowed the students to learn the material.

The LA program is replicable and could serve students in other courses, such as math and physics, or other project-based CUREs by providing cost-effective access to academic support when it may not be accessible at a local scale. Some of the critical conditions needed to run a successful virtual LA program include:

1. LA roles and expectations—Not only do they need to understand the content and the scientific process, the LAs also require the patience and persistence to meet the needs of multiple and diverse types of students.
2. LA support—A successful LA program requires oversight from a faculty member with pedagogical and scientific expertise. For example, the GEP LAs are supported by a lead LA, a graduate student, and the principal investigator of the GEP. They meet weekly to discuss any issues and the overall curriculum.
3. LA resources—Screen sharing is essential for LAs to be able to stay current because each project is different. They also have a Slack channel and use multiple forms of communication, such as a "Notes" page in which they document student questions and progress, so any LA can work with a student when they return for support.
4. LA expertise—The LAs in a program should be able to offer a variety of skills and knowledge related to the curriculum and the various specialties. Together, they should make up a team of diverse talents with the potential to meet individual student needs.
5. Student support—LA support is confidential in that identifiable student information is not shared with their instructor.

Using multiple sources of data, this descriptive study examines the GEP's virtual LA program, which was developed to support undergraduate students during a period of significant challenges. The online and accessible nature of the GEP virtual LA program allowed students from across the 200+ GEP institutions to receive help precisely when it was most needed, fitting seamlessly into their schedules. The program offered essential support to students who were struggling with their GEP coursework and facing psychological stress during the pandemic. Given the broad success of the virtual LAs, the GEP will continue to support the program for the foreseeable future. Virtual LAs are demonstrated to be a highly cost-effective and scalable strategy to support student learning across many institutions. With current online platforms and enhanced tools, this program is easily replicable and adaptable, providing benefits to students in ways that we have yet to measure.

ACKNOWLEDGMENTS

This article is based upon work supported by the National Science Foundation under grant no. 1915544 and National Institute of General Medical Sciences of the National Institutes of Health under award number R25GM130517 to L.K.R. Any opinions, findings, and conclusions or recommendations expressed in this material are solely those of the author(s) and do not necessarily reflect the official views of the National Science Foundation or the National Institutes of Health.

AUTHOR AFFILIATIONS

[1]University of Wisconsin-Madison, Madison, Wisconsin, USA
[2]College of Southern Nevada, Las Vegas, Nevada, USA
[3]The University of Alabama, Tuscaloosa, Alabama, USA
[4]Washington University in St. Louis, St. Louis, Missouri, USA
[5]Grinnell College, Grinnell, Iowa, USA

AUTHOR ORCIDs

Christine M. Pribbenow http://orcid.org/0000-0002-2404-9066
Laura K. Reed http://orcid.org/0000-0002-4381-494X

FUNDING

ETHICS APPROVAL

Both the LA interviews and undergraduate student surveys were covered under approved human subjects research protocols by the Institutional Review Board at The University of Alabama (EX-19-CM-118-R5; e-Protocol #19-06-2428, amendment for interviews approved 19 April 2023). Informed consent was obtained, allowing participants the choice to opt in or out of the individual surveys (undergraduate students) and interviews (LAs).

REFERENCES

1. Shaffer CD, Alvarez C, Bailey C, Barnard D, Bhalla S, Chandrasekaran C, Chandrasekaran V, Chung H-M, Dorer DR, Du C, et al. 2010. The genomics education partnership: successful integration of research into laboratory classes at a diverse group of undergraduate institutions. CBE Life Sci Educ 9:55–69. https://doi.org/10.1187/09-11-0087
2. Elgin SCR, Hauser C, Holzen TM, Jones C, Kleinschmit A, Leatherman J, Genomics Education Partnership. 2017. The GEP: crowd-sourcing big data analysis with undergraduates. Trends Genet 33:81–85. https://doi.org/10.1016/j.tig.2016.11.004
3. Croonquist P, Falkenberg V, Minkovsky N, Sawa A, Skerritt M, Sustacek MK, Diotti R, Aragon AD, Mans T, Sherr GL, Ward C, Hall-Woods M, Goodman AL, Reed LK, Lopatto D. 2023. The genomics education partnership: first findings on genomics research in community colleges. Scholarsh Pract Undergrad Res 6:17–28. https://doi.org/10.18833/spur/6/3/1
4. Lopatto D, Hauser C, Jones CJ, Paetkau D, Chandrasekaran V, Dunbar D, MacKinnon C, Stamm J, Alvarez C, Barnard D, et al. 2014. A central support system can facilitate implementation and sustainability of a classroom-based undergraduate research experience (CURE) in genomics. CBE Life Sci Educ 13:711–723. https://doi.org/10.1187/cbe.13-10-0200
5. Gehrke S, Goodman AL, Ngo L, Reinke C, Sandlin KM, Reed LK. 2024. Virtual engagement in A hybrid community of practice: a descriptive study on the training and integration of new members into the genomics education partnership during COVID-19. J STEM Educ Innov Res:30–41.
6. Slawson EE, Shaffer CD, Malone CD, Leung W, Kellmann E, Shevchek RB, Craig CA, Bloom SM, Bogenpohl J 2nd, Dee J, Morimoto ETA, Myoung J, Nett AS, Ozsolak F, Tittiger ME, Zeug A, Pardue M-L, Buhler J, Mardis ER, Elgin SCR. 2006. Comparison of dot chromosome sequences from *D. melanogaster* and *D. virilis* reveals an enrichment of DNA transposon sequences in heterochromatic domains. Genome Biol 7:R15. https://doi.org/10.1186/gb-2006-7-2-r15
7. Leung W, Shaffer CD, Cordonnier T, Wong J, Itano MS, Slawson Tempel EE, Kellmann E, Desruisseau DM, Cain C, Carrasquillo R, et al. 2010. Evolution of a distinct genomic domain in *Drosophila*: comparative analysis of the dot chromosome in *Drosophila melanogaster* and *Drosophila virilis*. Genetics 185:1519–1534. https://doi.org/10.1534/genetics.110.116129
8. Rele CP, Sandlin KM, Leung W, Reed LK. 2022. Manual annotation of *Drosophila* genes: a genomics education partnership protocol. F1000Res 11:1579. https://doi.org/10.12688/f1000research.126839.3
9. Leung W, Shaffer CD, Reed LK, Smith ST, Barshop W, Dirkes W, Dothager M, Lee P, Wong J, Xiong D, et al. 2015. *Drosophila* muller f elements maintain a distinct set of genomic properties over 40 million years of evolution. G3 (Bethesda) 5:719–740. https://doi.org/10.1534/g3.114.015966
10. Leung W, Shaffer CD, Chen EJ, Quisenberry TJ, Ko K, Braverman JM, Giarla TC, Mortimer NT, Reed LK, Smith ST, et al. 2017. Retrotransposons are the major contributors to the expansion of the *Drosophila ananassae* muller f element. G3 (Bethesda) 7:2439–2460. https://doi.org/10.1534/g3.117.040907
11. Leung W, Torosin N, Cao W, Reed LK, Arrigo C, Elgin SCR, Ellison CE. 2023. Long-read genome assemblies for the study of chromosome expansion: *Drosophila kikkawai*, *Drosophila takahashii*, *Drosophila bipectinata*, and *Drosophila ananassae*. G3 (Bethesda) 13:jkad191. https://doi.org/10.1093/g3journal/jkad191
12. Mo M, LoBello L, Hassan Farah I, Agtang E, Ramos EL, Abdoli R, Santander Diaz L, Helena Schumann Ferreira L, Kokan N, Sadikot T, Sawa A, Arrigo C. 2024. *Drosophila* kikkawai – Sox102F. MicroPubl Biol 2024. https://doi.org/10.17912/micropub.biology.001211

13. Lopatto D, Alvarez C, Barnard D, Chandrasekaran C, Chung H-M, Du C, Eckdahl T, Goodman AL, Hauser C, Jones CJ, et al. 2008. Genomics education partnership. Science 322:684–685. https://doi.org/10.1126/science.1165351
14. Shaffer CD, Alvarez CJ, Bednarski AE, Dunbar D, Goodman AL, Reinke C, Rosenwald AG, Wolyniak MJ, Bailey C, Barnard D, et al. 2014. A course-based research experience: how benefits change with increased investment in instructional time. CBE Life Sci Educ 13:111–130. https://doi.org/10.1187/cbe-13-08-0152
15. Barrasso AP, Spilios KE. 2021. A scoping review of literature assessing the impact of the learning assistant model. IJ STEM Ed 8:12. https://doi.org/10.1186/s40594-020-00267-8
16. Clements TP, Friedman KL, Johnson HJ, Meier CJ, Watkins J, Brockman AJ, Brame CJ. 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 Sci Educ 21:ar26. https://doi.org/10.1187/cbe.21-09-0287
17. Alzen JL, Langdon LS, Otero VK. 2018. A logistic regression investigation of the relationship between the learning assistant model and failure rates in introductory STEM courses. Int J STEM Educ 5:56. https://doi.org/10.1186/s40594-018-0152-1
18. Breland H, Clark CM, Shaked S, Paquette-Smith M. 2023. The benefits of participating in a learning assistant program on the metacognitive awareness and motivation of learning assistants. CBE Life Sci Educ 22:ar30. https://doi.org/10.1187/cbe.22-08-0156
19. Huvard H, Talbot RM, Mason H, Thompson AN, Ferrara M, Wee B. 2020. Science identity and metacognitive development in undergraduate mentor-teachers. IJ STEM Ed 7:3. https://doi.org/10.1186/s40594-020-00231-6
20. Schalk KA, McGinnis JR, Harring JR, Hendrickson A, Smith AC. 2009. The undergraduate teaching assistant experience offers opportunities similar to the undergraduate research experience. J Microbiol Biol Educ 10:32–42. https://doi.org/10.1128/jmbe.v10.97
21. Gong HJ, Kwon J, Brock M. 2022. Experiential learning through a peer learning assistant model in STEM. Educ Res 64:317–333. https://doi.org/10.1080/00131881.2022.2096092
22. Kahn S, Vertesi J, Adriaenssens S, Byeon J, Fixdal M, Godfrey K, Lumbroso J, Wagoner K. 2022. The impact of online STEM teaching and learning during COVID-19 on underrepresented students' self-efficacy and motivation. J Coll Sci Teach 51:6–15. https://doi.org/10.1080/0047231X.2022.12315644
23. Hester SD, Elliott JM, Navis LK, Hidalgo LT, Kim YA, Blowers P, Elfring LK, Lattimore KL, Talanquer V. 2022. Using an instructional team during pandemic remote teaching enhanced student outcomes in a large STEM course. J Coll Sci Teach 51:12–21. https://doi.org/10.1080/0047231X.2022.12290555
24. Bogdan R. 2007. *Qualitative research for education: an introduction to theory and methods*. Boston: Pearson/Allyn and Bacon.
25. Thompson AN, Talbot RM, Doughty L, Huvard H, Le P, Hartley L, Boyer J. 2020. Development and application of the action taxonomy for learning assistants (ATLAs). IJ STEM Ed 7:1. https://doi.org/10.1186/s40594-019-0200-5