PRACTICE

The Genomics Education Partnership: First Findings on Genomics Research in Community Colleges

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Abstract

The Genomics Education Partnership (GEP), a consortium of diverse colleges and universities, provides support for integrating genomics research into undergraduate curricula. To increase research opportunities for underrepresented students, GEP is expanding to more community colleges (CC). Genomics research, requiring only a computer with Internet access, may be particularly accessible for two-year institutions with limited research capacity and significant budget constraints. To understand how GEP supports student research at CCs, the authors analyzed student knowledge and self-reported outcomes. It was found that CC student gains were comparable to non-CC student gains, with improvements in attitudes toward science and thriving in science. The early findings suggest that the GEP model of centralized support with flexible implementation of a course-related undergraduate research experience benefits CC students and may help mitigate barriers to implementing research at CCs.

Keywords: *bioinformatics, community colleges, course-based undergraduate research experiences (CUREs), genomics, undergraduate education*

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Undergraduate research is one of eleven high impact practices shown to increase deep learning among students of all backgrounds (Kuh and Schneider 2008). When undergraduate research opportunities are embedded in the curriculum through course-based undergraduate research experiences (CUREs), participation once limited to a select number of students becomes accessible to all. A well-structured CURE engages students actively in authentic and novel hypothesis-driven work, using collaboration and iteration (Auchincloss et al. 2014). CUREs have been shown to comprise inclusive and equitable teaching and learning practices that result in increased critical thinking skills, higher grades, greater persistence, and greater interest in STEM fields (Corwin et al. 2015; Lopatto et al., 2008; Rodenbusch et al. 2016; Staub et al. 2016). This is especially significant for students of diverse backgrounds who continue to be underrepresented in many STEM disciplines; CUREs can close the achievement gap for many (Awong-Taylor et al. 2016; de Brey et al. 2019; Hensel 2021).

Associate's degree–granting institutions enroll 34 percent of all US undergraduates, including 36 percent of Black or African American, 41 percent of Hispanic or Latino, 34 percent of Asian, 37 percent of Native Hawaiian or other Pacific Islander, and 40 percent of Native American or Alaskan native students (National Center for Education Statistics 2021). Therefore, community colleges (CCs) can be pivotal in efforts to increase diversity, inclusion, equity, and retention in STEM education. CUREs can and should be a critical tool for the efforts of CCs in this area, but there are barriers to implementation. James Hewlett, director of the Community College Undergraduate Initiative, identified the major barrier to offering undergraduate research opportunities at CCs as the lack of an undergraduate research culture. Causes for this include limited financial resources, an incompatible faculty model (e.g., high teaching loads), limited student and faculty preparation, isolation from networks, marginalization from the science research enterprise, and lack of administrative support (Hewlett 2018). In addition to these institutional challenges, nontraditional, underrepresented, and first-generation students attending CCs are likely to have additional responsibilities beyond their studies. For example, 62 percent of full-time students at CCs also are employed during the academic year (Radwin et al. 2018). These challenges to CC culture and student time need to be addressed to fulfill the promise of CUREs for achieving inclusion and equity in STEM education. Fortunately, programs like the Genomics Education Partnership (GEP) can help overcome some of these challenges.

The GEP (Genomics Education Partnership, n.d.), a consortium of over 200 diverse colleges and universities established in 2006, provides a well-established framework for integrating authentic genomics research experiences into undergraduate curricula. The GEP has supported the adoption of effective pedagogical practices (e.g., active learning strategies that emphasize CUREs) through centralized resources and distributed peer-to-peer support, coupled with an effective curriculum on eukaryotic gene structure and workflow to allow students to conduct comparative genomics studies (Lopatto et al. 2014; Shaffer et al. 2010; Shaffer et al. 2014). Results from student research projects have led to three major scientific publications on which the students are coauthors (Leung et al. 2010; Leung et al. 2015; Leung et al. 2017). Through active recruitment since 2015, the GEP presently has 26 CC institutions as members. Undergraduate in silico research opportunities in genomics are especially suitable to associate's degree–granting institutions, as the research is conducted online using publicly available resources (data and tools). These in silico research experiences also are well-suited to nontraditional, underrepresented, and first-generation students due to flexibility of location and time for access to research materials.

The GEP curriculum and research projects are highly adaptable to flexible implementation. This allows CC faculty with high teaching loads to incorporate these experiences into existing programs without the need for creating new courses. GEP-associated faculty may choose to present first-year students with a series of self-guided, active learning modules exploring eukaryotic gene structure and expression while developing familiarity with a genome browser (Laakso et al. 2017). Faculty are encouraged to involve students in the comparative annotation of a previously unstudied region of a *Drosophila* genome in support of ongoing GEP scientific research projects when the course schedule permits. Two current projects focus on the genomes from the genus *Drosophila* to promote better understanding of (a) the evolution of the heterochromatic *Drosophila* F element, and (b) the evolution of genes in the *Drosophila* insulin signaling pathway. For both projects, students must utilize all lines of available evidence (at a minimum, homology to *D. melanogaster*, de novo gene predictions, and RNA-Seq data) to arrive at a best-supported gene model; this often involves several rounds of iteration (Lopatto et al. 2020). A successful student will understand that there is no "right answer," but that they can generate a gene model that they can defend based on available evidence.

Student learning gains after engaging in a GEP project (both knowledge gains as shown by a pre-project and post-project quiz and self-reported gains in science understanding and science skills) have been previously reported by Lopatto and his colleagues (2014). However, that study did not include newly recruited CCs. Here the authors compare student outcomes at CC and non-CC students participating in GEP-supported research opportunities and introductory active learning curriculum. It was hypothesized that CC student outcomes would be comparable to non-CC student gains based on previously published evidence demonstrating that gains are observed regardless of institution type (Shaffer et al. 2014).

Materials and Methods

Faculty Reports

GEP faculty members submit a voluntary report in the fall and spring of each academic year. The questions on the report address a variety of GEP community needs and are updated every year. A subset of questions interrogates the details of all unique implementations of the GEP materials, and the answers to select questions were utilized in this study (see supplemental material). The reports were collected using a Qualtrics survey. During the 2020–2021 academic year, 127 faculty submitted 246 reports describing implementation styles. Among these reports, 17 were from 10 faculty members teaching at community colleges. Of the 246 reports, 239 were included in the analysis. These reports indicated that GEP curriculum was implemented as an independent study or in a course, with the course number and title provided.

To separate the upper-division and lower-division courses at the four-year institutions, a two-step process was used. First, student academic standing reported by the faculty was used to classify the courses, and the course number was used for courses that could not be classified based on enrollment alone. The reports were labeled as "lower-division" if faculty indicated only first-year and second-year student enrollment (*N* = 27). Reports were labeled "upper-division" if they included third-year or fourth-year student enrollment, but no first-year or second-year students (*N* = 131). For reports that indicated mixed enrollment (both lower- and upper-division enrollment, *N* = 63), the course number was analyzed for each report. If the course number was at a 200 or 100 level, the mixed enrollment course was assigned to the lower-division category. As a result, of the 222 reports from four-year colleges, 51 (23 percent) were classified as lower division and 171 (77 percent) received the upper-division classification. To distinguish between required and elective courses, several response options for the question were combined (see supplemental material).

Student Demographics

This report includes data collected in the academic year 2020–2021. The CC student data utilized for this report included 96 cases, which was 39 percent of the student enrollment reported by CC instructors. Seventy percent of the respondents identified as female, and 30 percent as male. Students were invited to report their race or ethnicity by selecting all the categories that applied to them. Of those who chose to identify themselves by one category, the responses were White (35 percent), Black (4.5 percent), Hispanic (9 percent), and Asian (4 percent), and the remainder chose more than one category or chose not to answer (6.5 percent). Student participants also indicated if they were first generation (28 percent) and if they were eligible for a Pell grant (45 percent).

Student Data Measures

Students were asked to complete a voluntary precourse quiz and survey before using GEP materials, and a postcourse quiz and survey afterward (included with supplemental material). After informed consent was obtained for participation in general, students could opt out of any or all questions. All research protocols involving human subjects were reviewed and approved by the Institutional Review Board at the University of Alabama (protocols 18-10-1678 and 19-06-2428). All GEP institutions contributing student data to this study had an established IRB authorization agreement with the University of Alabama. Confidentiality was maintained throughout by using encryption to eliminate identification of individual students. These unidentified responses were aggregated at Washington University in St. Louis and made available for analysis. The sections of the student surveys used for this study are described below. It should be noted that the four assessment instruments (precourse survey, postcourse survey, precourse annotation quiz, and postcourse annotation quiz) were accessed independently so that students could readily opt out of some the assessment tools. The consequence of these student choices was a different sample for each measure. Two of the measures, the self-reported benefits and the thriving items, were on the postcourse survey only.

Results

Curriculum and Implementation

The GEP community has developed an extensive collection of curricular resources freely available to all faculty via the GEP website and CourseSource (BioQUEST 2022; Laakso et al. 2017; Weisstein et al. 2019). GEP members choose and tailor curriculum that best fits the needs of their students and programs. Some modules focusing on the introduction of basic concepts (genes, exons, splicing, genetic code) and tools (the UCSC Genome Browser) are widely used by the GEP members; 70 percent of all faculty reports in 2020–2021 indicated use of these modules. The GEP curriculum spans multiple levels of inquiry, as described by Buck, Bretz, and Towns (2008): from confirmation inquiry (e.g., walk-throughs that provide answers and conclusions, and illustrate the reasoning for arriving at each conclusion); to structured and guided inquiry, where conclusions are not known to students. Faculty often provide additional guided inquiry or practice activities before offering research projects to students.

To understand how GEP members implemented CUREs in their courses, the answers to pertinent questions on the faculty reports for CC implementations and non-CC lower-division and upper-division implementations were compared (Figure 1). Community college implementations were similar to those in the lower-division courses at the four-year institutions (Figure 1A). The largest category for CCs was implementation as a module of a course (59 percent); similarly, 53 percent of lower-division implementations were a module in a course. These were typically introductory genetics or molecular and cell biology courses. In the upper-division implementations, independent study (30 percent) and the entire course (29 percent) were the most common implementation types. Examples of courses in which the entire course relied on the GEP included research and genomics. When comparing the role of the courses or experiences in degree programs, CC and lower-division implementations were primarily in required courses (71 percent and 63 percent of reports respectively), whereas upper-division implementation in required courses comprised only 29 percent of reports (Figure 1B). Most reports for the upper-division courses indicated implementation in elective courses (62 percent; examples included biology research and genomics courses). To estimate how many courses engaged students in research, respondents were asked whether implementation involved claiming research projects. About half of CC and lower-division implementations involved claiming projects, whereas the majority of upper-division implementations did so (Figure 1C). The text comments expanding on details of implementation revealed that using the phrase "claimed projects" underestimated the number of students in courses engaged in doing research. Some faculty reported engaging students in gene annotation without claiming projects; some used annotation as a starting point to generate research proposals (open inquiry); and some planned to submit research project reports in the future but had not completed submission at the time of the faculty report.

Based on the analysis of faculty reports about specific implementations of GEP curriculum, community colleges and lower-division courses at four-year institutions showed similar patterns, distinct from implementations in the upper-division courses.

Genomic Annotation

As of spring 2021, 159 annotation projects, 134 pertinent to the evolution of the *Drosophila* F element and 25 related to the evolution of the *Drosophila* insulin signaling pathway, had been completed by CC students and submitted by GEP faculty affiliated with these institutions to the research project leaders. For quality control, all GEP projects are completed at least twice independently by GEP students (usually from different institutions), and those project submissions are reconciled by experienced GEP students working during the summer with the research project leaders. The 70 F element and seven insulin pathway projects gene models were respectively reconciled.

Annotation Quiz

Students had the option of completing a 20-item quiz on the gene annotation projects. Participating community college students from six institutions completed both the precourse quiz ($N = 43$) and postcourse quiz ($N = 33$) with a difference (postcourse quiz score minus precourse quiz score) of $N = 21$. Students showed a significant increase in scores from precourse (mean = 3.1) to postcourse (mean = 5.5; $t_{(14)} = 2.79$, $p < 0.05$), as shown in Figure 2. Of important note, both CC and non-CC students showed a significant increase in quiz scores from the precourse quiz to the postcourse quiz ($p < 0.001$), and the gains of both the CC and non-CC groups were very similar ($p > 0.7$).

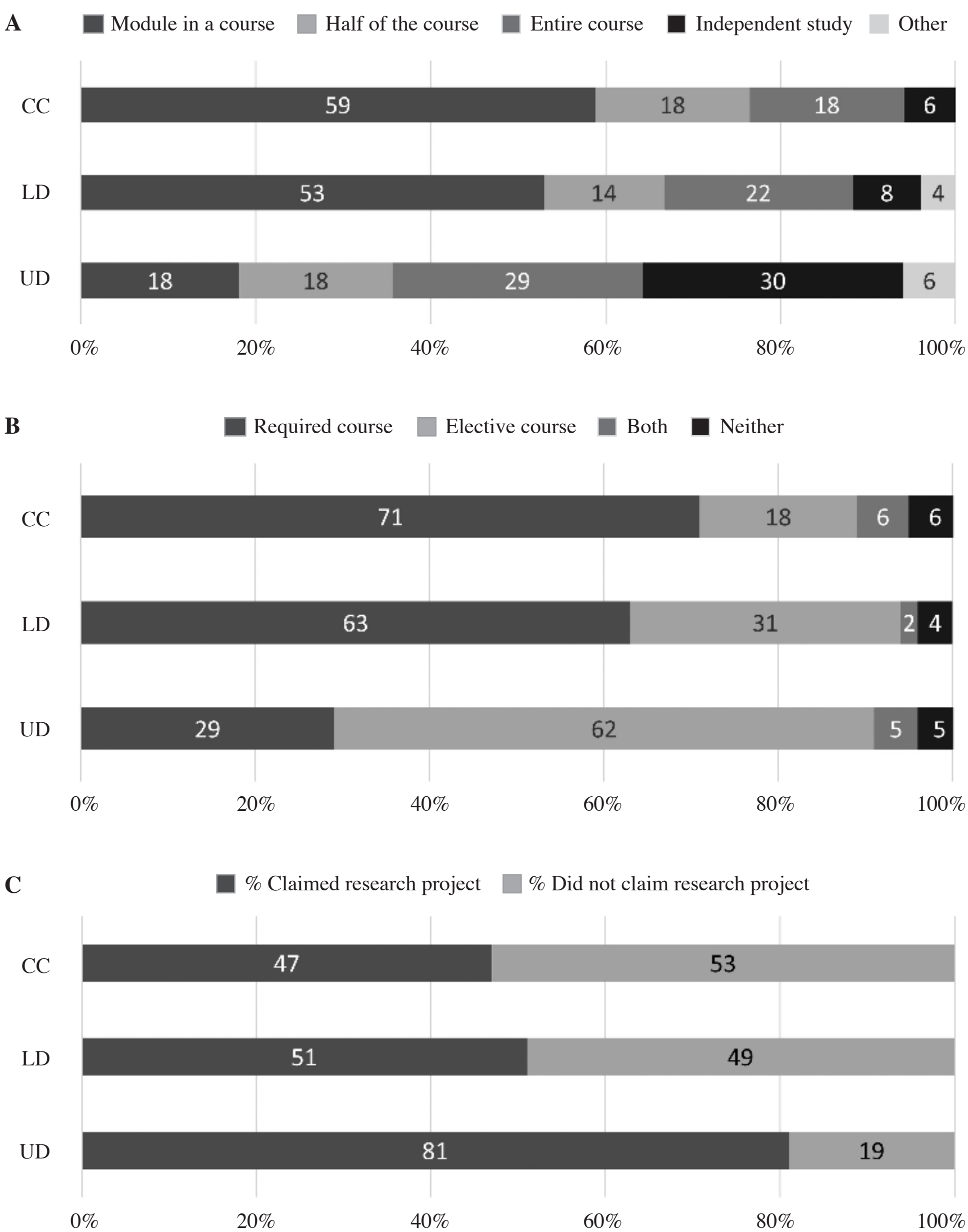
Student Benefits

Students evaluated a series of statements regarding potential learning benefits from their genomics experience as part of the postcourse survey. These items were previously included in a survey of undergraduate research experiences (SURE; Lopatto 2004, 2007). The students evaluated the items on a scale of 1 (little or no gain) to 5 (large gain). The postsurvey self-reported benefits of CC students and other students for the academic year 2020–2021 were compared (Figure 3). The mean evaluations by CC students, shown as light gray circles, are similar to those of the non-CC students, shown as dark gray triangles. Like other genomics students, the CC students rated "Understanding science" (mean = 4.02) and "Understanding that scientific assertions require supporting evidence" (mean = 4.00) highly. "Skill in how to give an effective oral presentation" (mean = 2.70) and "Confidence in my potential to be a teacher of science" (mean = 2.86) had the lowest ratings. A mixed design ANOVA with 20 related items and two groups (CC students versus comparison students from four-year institutions) resulted in no main effect for the groups ($F = 0.9$, $df = 1, 829$, $p > 0.05$). The conclusion was that self-reported learning benefits for CC students were positive and not different from ratings by the comparison students.

Thriving

Recent research on student culture has included discussions of "thriving," a concept of student attitude or morale that suggests the student is happy and positively motivated to succeed. The thriving literature suggests that thriving includes at least five factors, including "engaged learning," "academic determination," "positive perspective," "social connectedness," and "diverse citizenship" (Schreiner 2013). Eleven items were constructed based on common thriving questions but focused on the genomics experience for the postcourse survey. Figure 4 depicts student ratings of the 11 items constructed to reflect thriving. The mean ratings by CC students are shown in light gray, and the mean ratings for comparison non-CC students are shown in dark gray. The overall pattern of responses is similar for each group. The means for the most highly rated item, "I am optimistic about being successful in my future science courses," were identical for the two groups (mean = 4.11). The lowest rated item for both groups was "I enjoyed doing the genomics work and made it a priority for my time and effort," but the mean of the comparison group (mean = 3.6) fell just above the upper boundary of a 95 percent confidence interval for the CC mean. Other ratings for the non-CC group fell within the boundaries of the 95 percent confidence intervals around the CC means (Figure 4). A mixed design analysis of variance (ANOVA) with the 11 items treated as repeated measures for the two groups (CC students versus comparison non-CC students) resulted in no main effect for the groups ($F = 1.03$, $df = 1, 1023$, $p > 0.05$). It was concluded that thriving ratings for CC students were not different from ratings by comparison students, and all were very positive. In addition, the data revealed some preliminary but suggestive evidence that CC students engaged in CURE activities (e.g., submitting a gene annotation project) reported nominally higher scores on the thriving items than CC students who were limited to using the introductory guided inquiry modules (actively learning to use a genome browser) and did not submit research projects (Figure 5). Although the cause of these differences is subject to many interpretations, the result is consistent with the view that research engagement is related to enhanced thriving. CC students appreciated

FIGURE 1. Genomics Education Partnership (GEP) Implementation



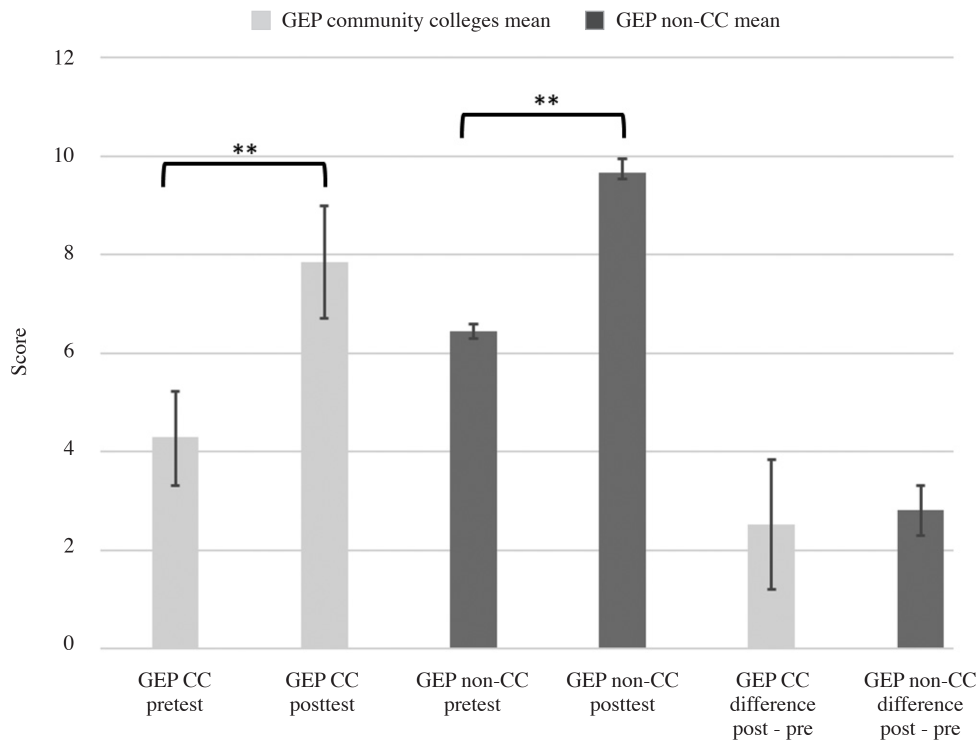
Note: CC, community college; LD, lower division (first- and second-year students); UD, upper division (third- and fourth-year students). The implementation styles for CC students are very similar to those for LD non-CC students. Reported implementations for CC students ($N = 17$), LD courses from other institutions ($N = 51$), and UD courses from other institutions ($N = 171$). 1A shows the implementation style. 1B displays the type of course in which the GEP curriculum was used. 1C shows the percentage of research projects claimed compared to active learning modules without a research project. Total percentages may deviate from 100 percent due to rounding.

the realistic nature of the genomics projects, the opportunity for group work, and the relation to future careers (supplemental table 1).

Discussion

This report includes preliminary but promising data on the effects of implementation of the GEP CURE at CCs. It was hypothesized that CC student outcomes would be comparable to non-CC gains. The rationale was based on previously published evidence demonstrating that outcome gains, although sensitive to time investment on task, instructional time, and iteration, have been observed regardless of institution type (Shaffer et al. 2014). When evaluating knowledge gains, it was found that CC students improved significantly on the knowledge postcourse quiz. Although the baseline score means for the precourse quiz

FIGURE 2. Community College and Non–Community College Student Learning Gains



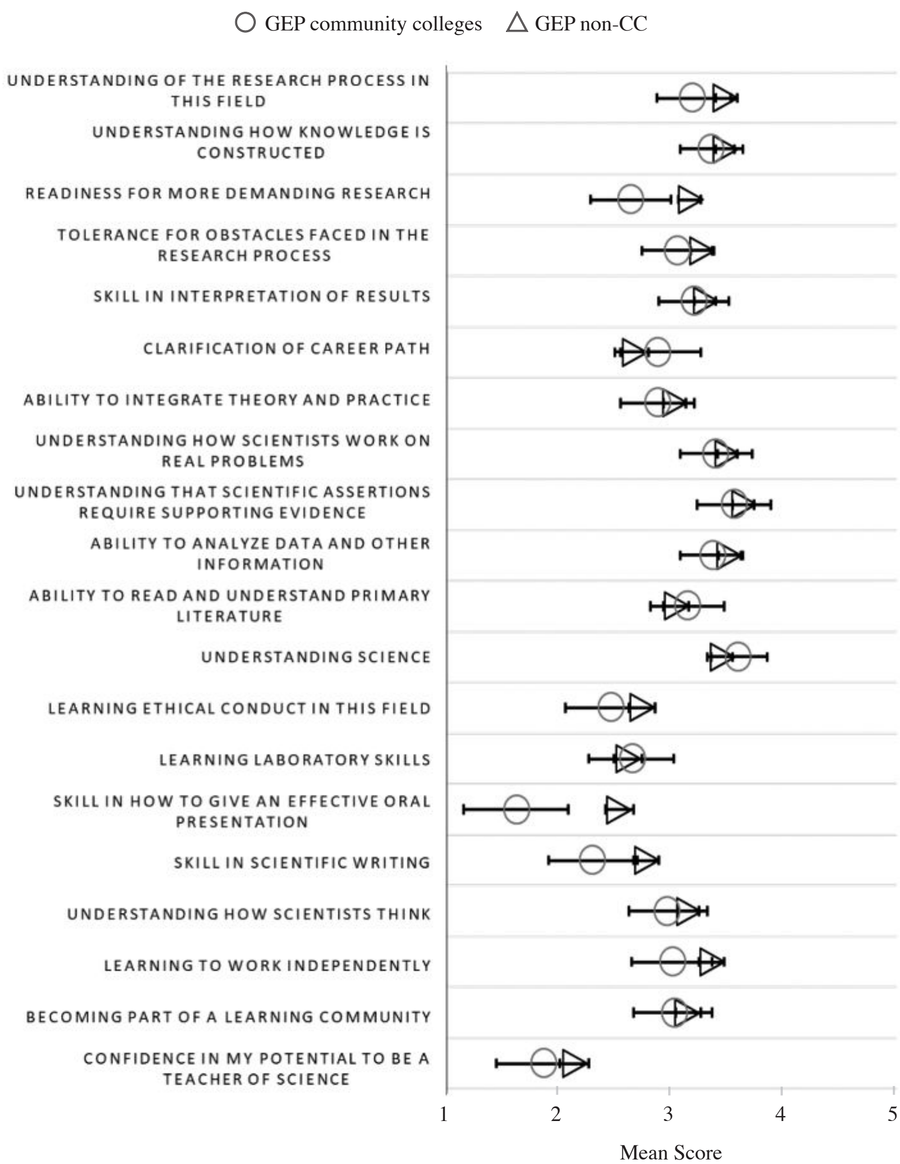
Note: CC, community college; GEP, Genomics Education Partnership. CC and non-CC students show comparable learning gains using the GEP curriculum to students at non-CC. For CC students, precourse quiz $N = 43$, postcourse quiz $N = 33$, difference (postcourse quiz minus precourse quiz) $N = 21$; for students from other institutions, precourse quiz $N = 1294$, postcourse quiz $N = 588$, difference $N = 262$). The error bars show 95 percent confidence intervals around the means. The results for the CC students are very similar to those for non-CC students. Postcourse quiz scores are higher than precourse scores for both groups (** is $p < 0.001$), and the difference in scores (postcourse quiz minus precourse quiz) is similar for both groups ($p > 0.7$).

were higher for non-CC students, the gain in learning due to experiencing the GEP curriculum did not differ between the groups (Figure 2). One limitation of these data is the small sample size (due to low response rate on the postcourse quiz) for the CC group; this observation, although promising, should be interpreted with caution. Additionally, CC student outcomes were assessed based on self-reported gains and on self-reports of the student experience of coping with the uncertainty of an open-ended and authentic genomics research project, utilizing a postcourse survey with both SURE items and 11 items constructed to reflect student thriving while engaged in that work. The analysis demonstrated that CC students' self-reported gains were not significantly different from those reported by non-CC students involved in the GEP projects (Figure 3). Furthermore, CC students' ratings on the thriving items were similar to those of their non-CC counterparts (Figure 4).

The lower scores on the "readiness for more demanding research" and improvement in the "skill in how to give an effective oral presentation" reported by the CC students (Figure 3) may be attributed to limited course offerings at the two-year colleges, where individualized mentored research projects are rare, and opportunities for project presentation in both informal and formal settings are limited. There is an imperative and potential, nevertheless, for improvement of the latter score, especially since oral presentation skills are an important general education competency for all undergraduate students. To achieve this goal, the CC faculty and the GEP may need to be more deliberate in creating opportunities for student project presentations as well as teaching presentation skills to their students.

The flexibility of the GEP curriculum allows for successful adoption at various types of educational institutions (Shaffer et al. 2014). Implementation may include use of active learning modules and genome annotation research projects. However, there are significant differences between CCs and other institutions in possible implementations, mainly due to differences in available courses in which the curriculum can be used. At four-year institutions research projects can be embedded in a wide

FIGURE 3. Student Learning Benefits



Note: CC, community college; GEP, Genomics Education Partnership. GEP students self-report gains for 20 learning benefits. Students at CCs show comparable gains to GEP students at non-CCs. CC students $N = 96$, students from other institutions $N = 758$ (complete data sets). Mean responses are shown; error bars given for the CC means represent 95 percent confidence intervals. For most items, the means are very similar for the two groups of students ($F = 0.9$, $df = 1, 829$, $p = 0.347$).

variety of courses, from introductory- to advanced-level specialized topics courses (e.g., bioinformatics or genomics), whereas adoption at CCs is often limited to introductory biology and second-year-level genetics, in which there can be strict prescriptions for curriculum content for accreditation purposes. A course number for independent research or other experiential learning may be more common at four-year institutions than at CCs. Such a curriculum slot can be very useful for initiating a CURE. Interestingly, this analysis shows that CC and lower-division undergraduate courses have comparable types of implementations, but distinct from upper-division offerings (Figure 1A, 1B, and 1C). The analysis suggests that different types of implementations may impact the CC student experience (Figure 5), with genome annotation research projects resulting in greater gains in measures of thriving than use of the active learning modules alone. Evidence of improved outcomes with the addition of the research project is consistent with previous reports that student gains from GEP curriculum are dependent on student time investment and iteration (Lopatto et al. 2020; Shaffer et al. 2014).

FIGURE 4. Student Thriving Ratings

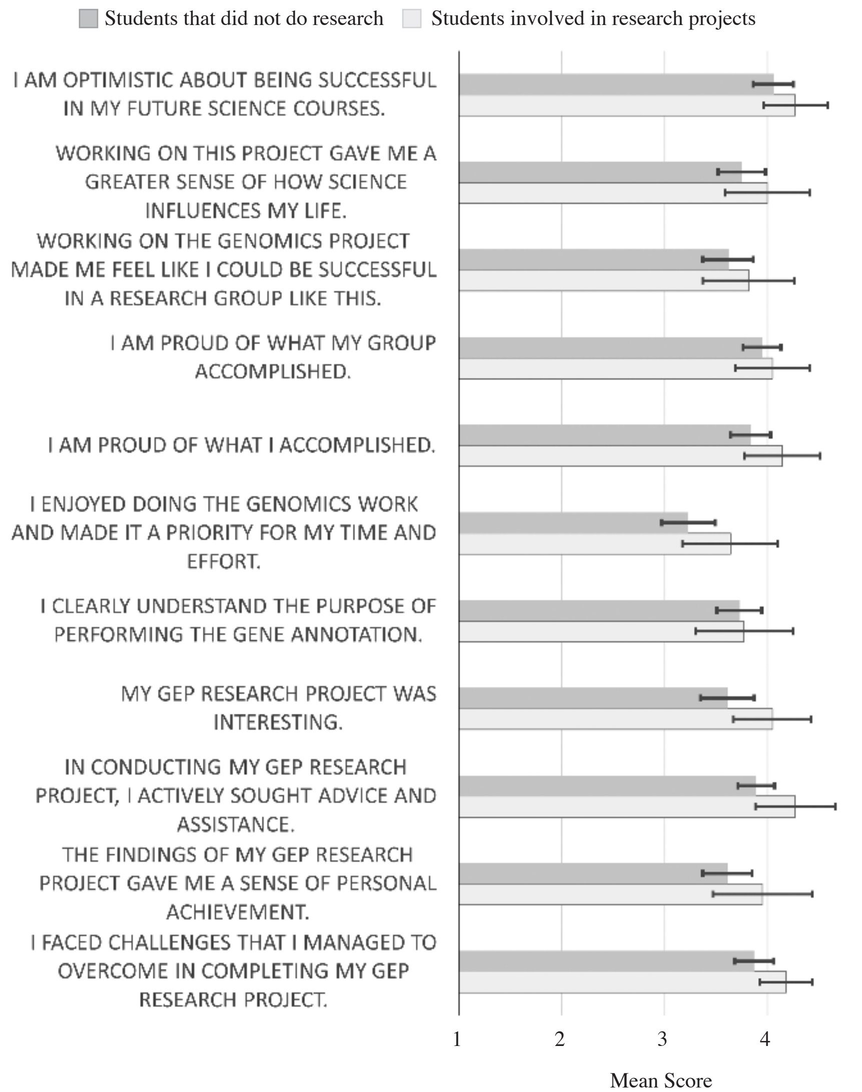
Note: CC, community college; GEP, Genomics Education Partnership. CC and non-CC students show comparable ratings for thriving. Mean scores for 11 items related to thriving from reports by students at CCs and by students at non-CCs. CC students $N = 96$, non-CC students $N = 936$ (complete data sets). The error bars show 95 percent confidence intervals. The results for the CC students are very similar to those for non-CC students ($F = 1.03$, $df = 1, 1023$, $p = 0.3$).

Other bioinformatics and genomics research consortia (such as SEA-PHAGES) are working to scale up CURE participation across institutes of higher learning (Hanauer et al. 2017). Like GEP, these programs have shown benefits for participating students. Hanauer and colleagues also reported student gains after engagement in the SEA-PHAGES research experience regardless of institutional type. This report included eight associate's degree–granting institutions; most of these institutions offered biotechnology programs, which may result in more research capacity and research culture than most CCs. In general, participation of CCs in CURE research partnerships is limited. Understanding how centrally supported CURE organizations can attract and sustain CC participation will be critical as higher education takes aim at increasing equity, inclusion, and retention in STEM. This early analysis suggests that the GEP model, which integrates centralized support with flexible CURE implementation, provides similar benefits for CC and non-CC students.

Data Availability

All supplemental material is available at https://doi.org/10.6084/m9.figshare.21365727.v1

FIGURE 5. Research Project Participation



Note: CC, community college. CC student participation in the research project may produce additional benefits in thriving compared to using only the introductory training as guided inquiry modules. Mean scores for 11 items related to thriving from reports by CC students who participated in the research project (N = 22) and by those CC students who did not participate in the research (N = 74). The error bars show 95 percent confidence intervals around the means. Students participating in the research report nominally higher scores. Although the differences are not large, the direction of the shift is consistently positive.

Institutional Review Board

All research protocols involving human subjects were reviewed and approved by the Institutional Review Board at the University of Alabama (protocols 18-10-1678 and 19-06-2428).

Conflict of Interest

The authors declare that they have no conflicts of interest.

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