An inclusive Research Education Community (iREC): Impact of the SEA-PHAGES program on research outcomes and student learning

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Engaging undergraduate students in scientific research promises substantial benefits, but it is not accessible to all students and is rarely implemented early in college education, when it will have the greatest impact. An inclusive Research Education Community (iREC) provides a centralized scientific and administrative infrastructure enabling engagement of large numbers of students at different types of institutions. The Science Education Alliance–Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) is an iREC that promotes engagement and continued involvement in science among beginning undergraduate students. The SEA-PHAGES students show strong gains correlated with persistence relative to those in traditional laboratory courses regardless of academic, ethnic, gender, and socioeconomic profiles. This persistent involvement in science is reflected in key measures, including project ownership, scientific community values, science identity, and scientific networking.

bacteriophage | genomics | science education | evolution | assessment

Engaging undergraduates in scientific research is educationally advantageous, regardless of the students' career aspirations (1–3). Several well-established models, each with benefits and challenges (4), provide this engagement. In apprentice-based research experiences (AREs), students, typically in their later college years, perform research under the direct supervision of an experienced mentor. An ARE can provide a high level of training, but the opportunities are constrained by laboratory space and supervisory capacity, imposing high-stakes selection for a relatively small number of students (5). Course-based research experiences (CREs) represent a second model; in this case, students conduct research as a class. In comparison with AREs, well-designed CREs can engage more students earlier in the curriculum (6), which is expected to have higher impact (7, 8). However, developing authentic research activities suitable for a CRE is challenging. A drawback of both models is that they largely exclude the 40% of US undergraduate students who attend 2-y colleges or 4-y colleges with limited research infrastructures (9).

A third model is the inclusive Research Education Community (iREC), in which a common scientific problem is addressed by students at multiple institutions that are supported by a centralized scientific and programmatic structure. Because of the centralized support, the iREC presents three advantages over other models. (*i*) The iREC is inclusive, because it is designed for students with few prerequisites, thus emphasizing the exploration of a student's potential rather than selection based on past accomplishments. (*ii*) The iREC presents students at all types of institutions with the opportunity to participate in authentic research, including at schools with little or no investigator-driven research. (*iii*) The iREC encourages growth, because the programmatic costs per student decrease as more students participate.

The centralized scientific and programmatic structure of the iREC encourages the development of a collaborative community, in which the students interact with one another both within the same institution and across institutions. The sense of community is strengthened in several ways: all of the schools pursue the same scientific problem, instructors from different institutions regularly come together in training workshops and faculty meetings, and students and faculty are presented with opportunities to share their findings with one another [e.g., the Science Education Alliance–Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) annual symposium]. In these ways, the student's cognitive experience mirrors that of an experienced researcher, and the social community aspects of scientific practice are apparent. Because iRECs require robust centralized programmatic structures that support the study of suitable research topics (10), iRECs are rare (5). Examples include the Genomics Education Partnership (11, 12), Small World Initiative (13, 14), and the SEA-PHAGES program (15).

The special characteristics of the iREC make it a particularly strong candidate for enhancing science education early in a student's career, with the long-term outcome of enhancing engagement and student persistence in the sciences. The iREC educational

Significance

The Science Education Alliance–Phage Hunters Advancing Genomics and Evolutionary Science program is an inclusive Research Education Community with centralized programmatic and scientific support, in which broad student engagement in authentic science is linked to increased accessibility to research experiences for students; increased persistence of these students in science, technology, engineering, and mathematics; and increased scientific productivity for students and faculty alike.

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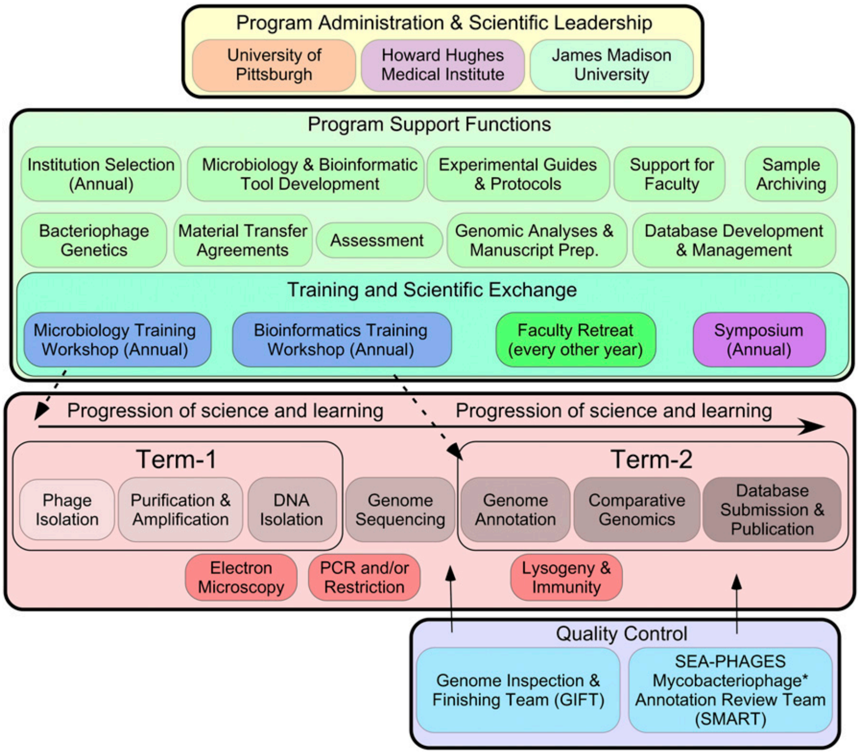

Fig. 1. Organization and structure of the SEA-PHAGES program. The SEA-PHAGES program administrators (yellow box) oversee support components critical to program implementation (green box). Typical two-term course structure (red box) includes phage isolation through comparative genomics; additional characterization includes EM, PCR/restriction analysis, and lysogeny assays (red ovals). Sequence and annotation quality control is shared with SEA-PHAGES faculty teams (purple box).

approach, fully implemented in the SEA-PHAGES program, provides a testing ground to explore the outcomes of this approach in terms of scientific productivity, student engagement, and student persistence in science, technology, engineering, and mathematics (STEM). Here, we report the combined impacts of research productivity and student persistence of the SEA-PHAGES program. The synergy between research authenticity and student engagement suggests that the iREC model could play a transformative role in science education.

Results

SEA-PHAGES Program Infrastructure. The SEA-PHAGES program seeks to understand viral diversity and evolution taught as a two-term laboratory course research experience. The first term is focused on bacteriophage isolation, purification, and DNA purification, and the second term focuses on genome annotation and bioinformatic analyses of the isolated phages (Fig. 1). Because the phage population is vast, dynamic, old, and consequently, enormously diverse (16, 17), the probability that a student will isolate a phage with a new genome or with previously unidentified genes is high (18, 19). When coupled with the technical simplicity of phage isolation, rapid and cheap sequencing capabilities, and powerful bioinformatic tools, SEA-PHAGES presents an accessible and discovery-rich research experience.

Programmatic support and scientific support are critical for success of an iREC. The SEA-PHAGES program elements include the development and publication of detailed experimental protocols, two 1-wk faculty training workshops in (*i*) phage discovery and (*ii*) bioinformatics, curated databases of students' results, archiving of collected bacteriophages, continuous system-wide assessment,

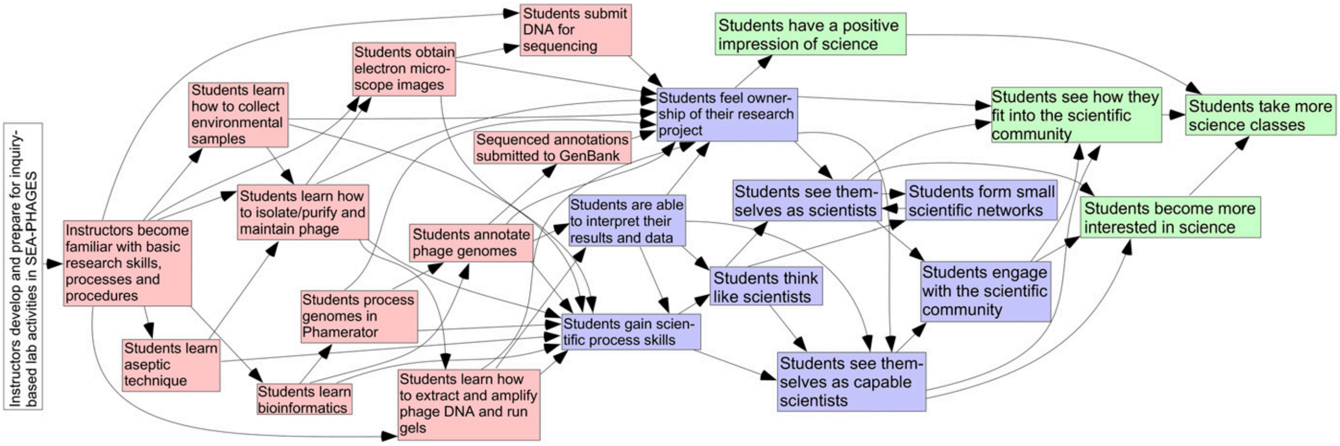

Fig. 2. The SEA-PHAGES systems-level model. Systems-level SEA-PHAGES activities (white box) with short-, medium-, and long-term outcomes (red, blue, and green boxes, respectively). *SI Appendix*, Fig. S1 shows the entire model.

scientific exchange in online forums, and an annual symposium. All of the SEA-PHAGES faculty meet in a biennial faculty retreat, and faculty also participate in advanced genome annotation workshops. In addition, Science Education Alliance faculty teams contribute to quality control of both sequence data and genome annotation (Fig. 1). Two databases facilitate coordination of the scientific and programmatic data (phagesdb.org and https://seaphages.org, respectively).

Because of the potential complexity of SEA-PHAGES, we used systems-level methods (20, 21) to construct a detailed pathway map (Fig. 2 and *SI Appendix*, Fig. S1) that relates program activities to short-, medium- and long-term outcomes in SEA-PHAGES. The full model (*SI Appendix*, Fig. S1) captures all of the program elements and how they connect to outcomes, and a modest subset illustrates the pathways linking course design with student persistence (Fig. 2). This model is helpful for facilitating program development, designing additional iRECs, and providing a framework for assessment strategies.

SEA-PHAGES Program Scale and Costs. The initial investment in iREC administrative and programmatic structure facilitates program growth. The SEA-PHAGES program has grown by addition of 7–25 institutions each year, and over its 9-y development, it now includes over 100 institutions (Fig. 3*A* and *SI Appendix*, Table S1), spanning R1 universities to community colleges (Fig. 3*B* and *SI Appendix*, Table S1). The 104 schools joining in the first 8 y showed a strong propensity to continue for multiple years in the program, and the probabilities for remaining after 3, 4, or 5 y are 97, 89, and 87%, respectively; continuation rates are not significantly different for schools joining in different years. The massively parallel approach enabled inclusion of over 4,000 students in academic year 2016–2017 (16,300 total over 9 y) (Fig. 3*A*), 80% of whom were in their first or second year of study. Although scalability of undergraduate research programs often presents substantial challenges (1), an iREC promotes cost efficiencies, because the program administration expenditures are nearly independent of the number of students involved; thus, as the

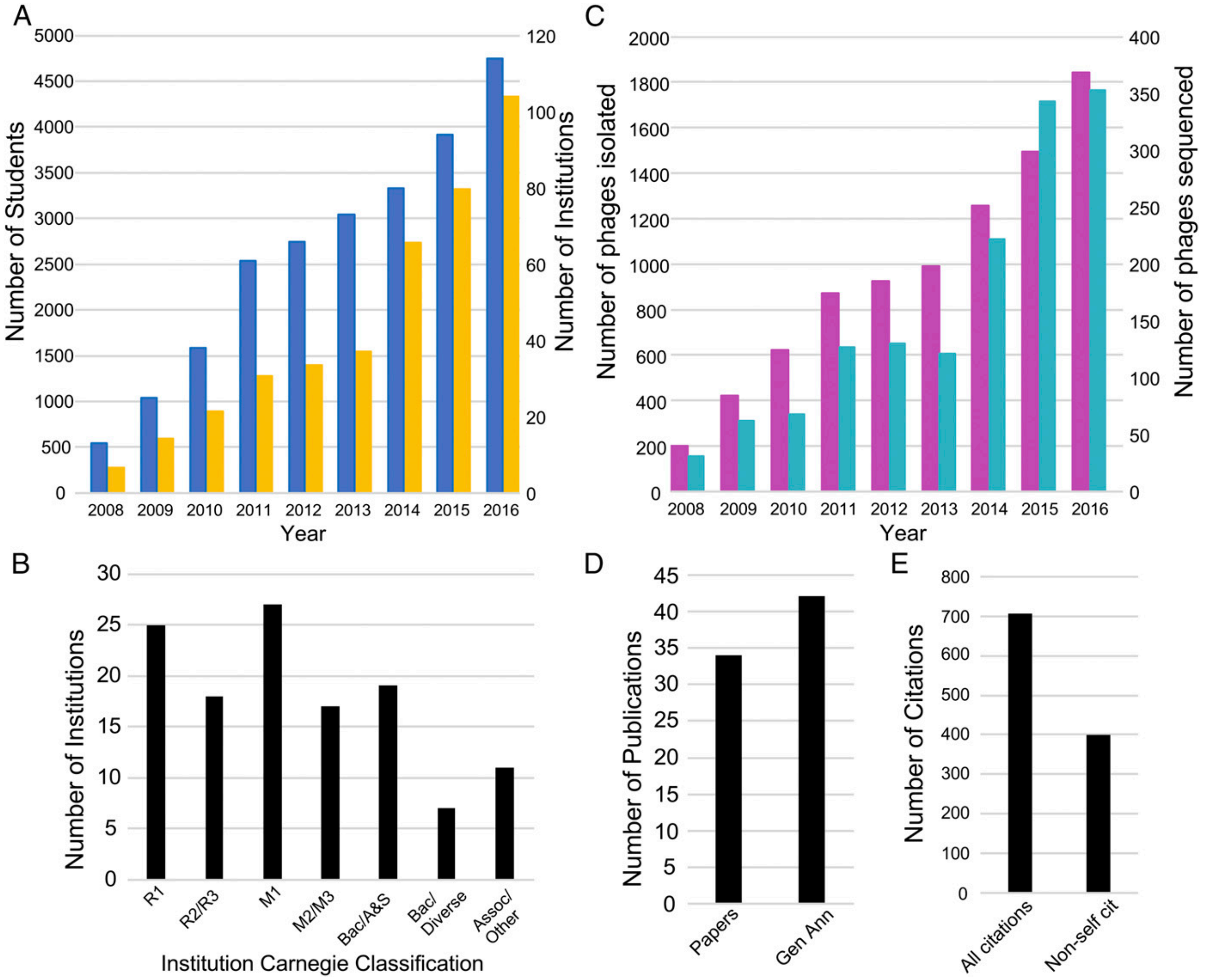

Fig. 3. Program participants and research productivity from the SEA-PHAGES program. (*A*) Numbers of SEA-PHAGES institutions and students (blue and yellow bars, respectively) participating by academic year (fall semester). (*B*) Carnegie Classifications of SEA-PHAGES participating institutions. Assoc/Other, associate's colleges, and others; Bac/A&S, baccalaureate colleges—arts & sciences; Bac/Diverse, baccalaureate colleges—diverse fields; M1–M3, larger, medium, and smaller master's colleges and universities, respectively; R1–R3, doctoral universities with highest, higher, and moderate research activity, respectively. (*C*) Numbers of phages isolated and genomes sequenced (pink and aqua, respectively) by academic year. (*D*) Numbers of peer-reviewed SEA-PHAGES publications as *Genome Announcements* (Gen Ann) and other peer-reviewed papers (Papers) (*SI Appendix*, Table S2). (*E*) Citations of SEA-PHAGES papers, showing all citations and nonself-citations.

number of participating institutions increases, the cost per student decreases. For the SEA-PHAGES program, the current administrative costs per student (~$500, encompassing all of the support items in Fig. 1) are 33% lower than 2 y previously, and additional program growth will extend the cost-effectiveness. The low per student cost enables the iREC to be delivered to large numbers of students early in their undergraduate careers, thus encouraging students to explore science in a relatively low-risk "gateway" experience. The iREC can introduce the student to research at a better time and at a much lower cost than the more traditional ARE. For those students who find research to be something that they want to explore further, the iREC can provide a stepping stone to subsequent AREs and should facilitate a more productive research experience. We note that the instructional and material costs at SEA-PHAGES participating institutions are greater than for traditional laboratories but are commensurate with other CREs.

SEA-PHAGES Research Productivity. The authenticity of the research conducted in an iREC is critically important, not only for addressing scientific questions but because it also influences the cognitive experiences of student participants (22, 23). In the SEA-PHAGES program, research productivity is reflected in the numbers of phages isolated (~10,000 in total) (Fig. 3*C*) and sequenced (~1,400) (Fig. 3*C*), representing substantial proportions of the total numbers of all phages isolated and sequenced to date (24, 25). These findings are reported in over 70 peer-reviewed publications (Fig. 3 *D* and *E* and *SI Appendix*, Table S2) (including 40 short *Genome Announcement* papers), many with student and SEA-PHAGES faculty coauthors. The availability of archived and sequenced phages for experimental manipulation by the scientific community at large provides a valuable resource for gaining insights into bacteriophage biology (24, 25). This research productivity compares favorably with that of one to two NIH R01 grants (26, 27).

Impact of SEA-PHAGES on Student Intention to Persist in STEM. A key iREC educational goal is for students to share the experience of the professional research scientist, including the thrill of discovery, collaboration within a community, and advancing scientific knowledge relevant to the broader community. These psychosocial elements are strongly linked to educational persistence (28–31) and benefit all students, regardless of their intended area of study. Using the psychometric Persistence in the Sciences (PITS) assessment tool (28), we compared 2,850 students taking either SEA-PHAGES or nonresearch traditional laboratory courses at a total of 67 institutions. PITS encompasses five survey components: project ownership (with content and emotion categories), self-efficacy, science identity, scientific community values, and networking, each measuring psychological components that correlate strongly with a student's intention to continue in science (22, 28). We also collected information on academic performance, socioeconomic status, and other demographics (*SI Appendix*).

To separate the influence of the type of course taken from other variables, including the possibility of student self-selection of

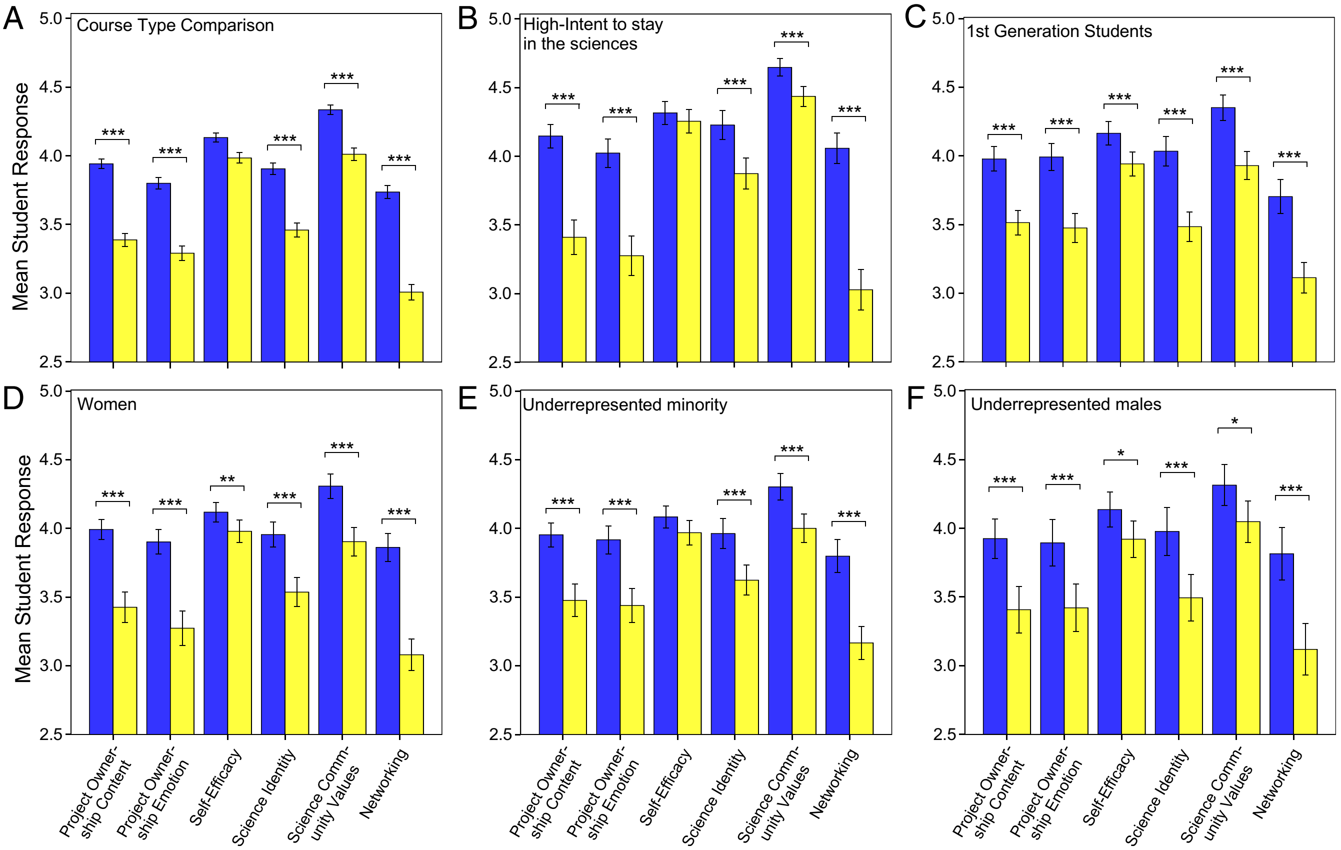

Fig. 4. Comparison of intent to persist in the sciences for students taking SEA-PHAGES and traditional laboratory courses. The PITS survey responses comparing SEA-PHAGES and nonresearch laboratory courses (blue and yellow bars, respectively). (*A*) Propensity score matching balanced all variables, except for course type. (*B*–*F*) Equally sized randomly chosen subsets of students were selected and compared using multivariate ANOVA (MANOVA) (all $P < 0.0001$) and ANOVA, with significant differences indicated. Groups analyzed are those reporting a high (scoring five on a five-point scale) intent to stay in the sciences (*B*), first generation students (*C*), women (*D*), underrepresented minorities (*E*), and underrepresented minority males (*F*). The PITS survey rating scales are from one (strongly disagree) to five (strongly agree) for all measures except for scientific community values, which had a one (not like me at all) to six (very much like me) scale. All scales had full descriptors for each of the levels on the scale. *$P < 0.05$; **$P < 0.01$; ***$P < 0.0001$.

SEA-PHAGES or traditional laboratories, we used propensity score matching (32) (Fig. 4*A*). We observed large and significant differences in five of six categories (all except self-efficacy, which assesses students' confidence in their abilities to function as scientists) (Fig. 4*A*), reflecting substantial gains by SEA-PHAGES students. Of the measures used, self-efficacy is the one most closely related to the primary goals of the typical nonresearch traditional laboratory, which are to develop confidence in laboratory procedures and skills. The overall pattern of the PITS measures shows significant increases in multiple aspects of the research experience (project ownership, science identity, science community values, and networking) but little difference in student confidence in laboratory procedures and skills (i.e., self-efficacy). Because the experiments in SEA-PHAGES have greater uncertainty and are directed by the necessities of authentic science, it is reassuring that we did not observe a reduction in self-efficacy compared with traditional laboratories. SEA-PHAGES and traditional laboratories both encourage student development of procedural confidence, but SEA-PHAGES adds an authentic research experience that promotes continued engagement in science.

Because students were not randomly assigned at all 67 institutions, it is plausible that the SEA-PHAGES courses could be disproportionately populated with students interested in pursuing science. To test this, we compared students declaring the highest possible intent to stay in science and observed similarly strong gains by SEA-PHAGES students (Fig. 4*B*). The surprisingly low scores—correlating with poor persistence (28)—from students with high intent to study science who are taking traditional nonresearch laboratory courses resonate with national concerns about science education (9). A simple interpretation is that students keen on pursuing science interests were discouraged by their experiences in traditional laboratory courses.

iREC Inclusion Promotes Broad Student Success. To examine the inclusive nature of the iREC, we compared student cohorts known to have poor science persistence early in college careers (33, 34), particularly first generation college students (Fig. 4*C*), women (Fig. 4*D*), underrepresented minorities (Fig. 4*E*), and underrepresented men (Fig. 4*F*). The broadly shared gains by SEA-PHAGES students strongly support the conclusion that the iREC model provides authentic research experiences (Fig. 4 *C–E*) to all students with similar advantages. We also find that student responses are similar for different types of institutions (Fig. 5*A*)—with small additional project ownership gains at community colleges relative to other schools—and we hypothesize that the supportive iREC programmatic structure (Fig. 1) facilitates success at institutions, such as community colleges, that typically do not have robust investigator-driven research activity. Students with different socioeconomic backgrounds (Fig. 5*B*), academic performance (Fig. 5*C*), gender (Fig. 5*D*), and ethnicity (Fig. 5*E*) also score similarly, reinforcing the inclusive nature of the iREC as exemplified by the SEA-PHAGES program. Finally, to confirm that students reliably self-report their intention to persist in the sciences, we measured the average numbers of science courses taken by subsets of students in each of the three subsequent terms after their introductory laboratory course (Fig. 5*F*). The SEA-PHAGES students enrolled in a consistently higher number of science courses than students taking traditional laboratory courses (Fig. 5*F*).

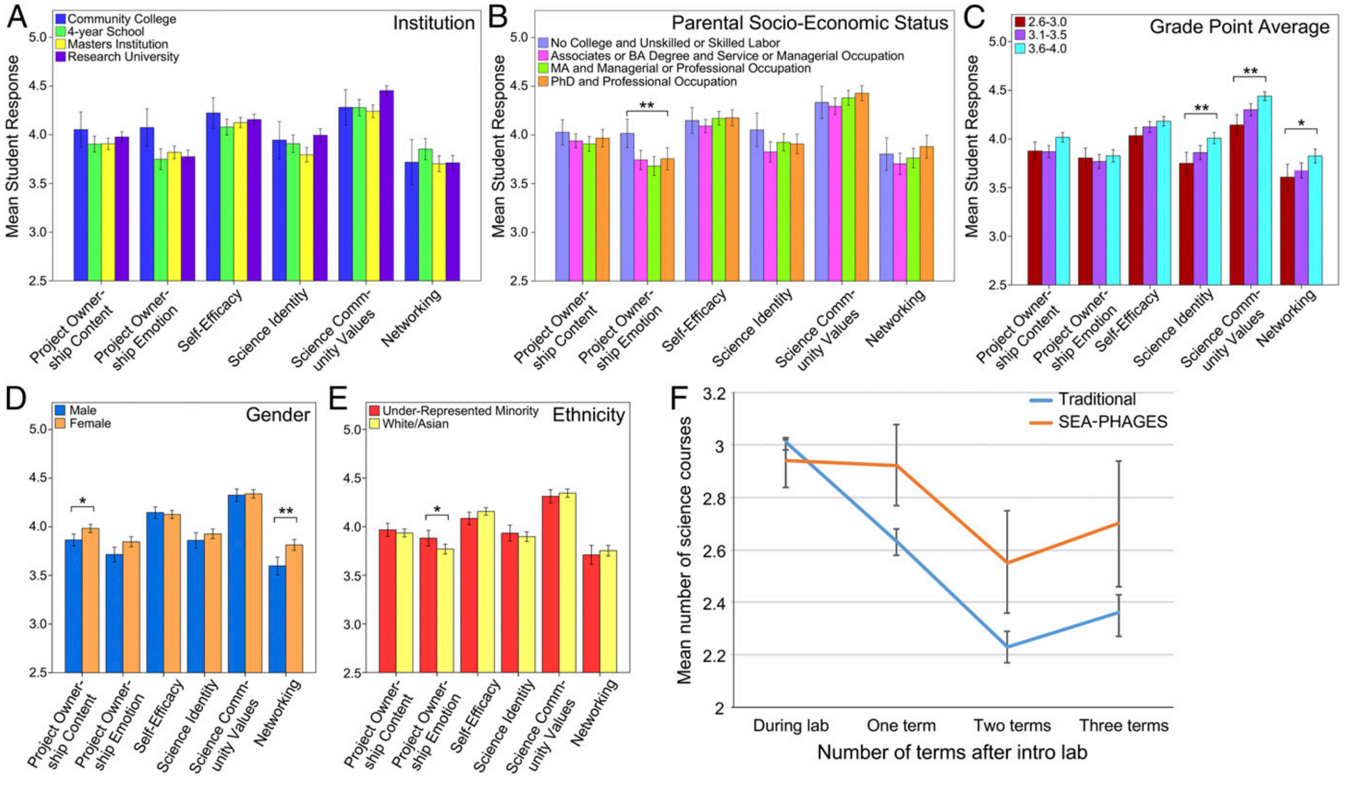

Fig. 5. Comparisons of student subgroups taking the SEA-PHAGES courses on their intent to persist in the sciences. The PITS survey responses for equally sized randomly chosen subsets of students were selected and compared. Groups differed by institutions (*A*), socioeconomic status (*B*), grade point average (*C*), gender (*D*), or ethnicity (*E*). Multivariate ANOVA (MANOVA) showed only small differences for some groups (institution type, $P < 0.049$; grade point average, $P < 0.04$; gender, $P < 0.001$). Significant differences using univariate analyses (ANOVA) are shown. The PITS survey rating scales are from one (strongly disagree) to five (strongly agree) for all measures except for scientific community values, which had a one (not like me at all) to six (very much like me) scale. All scales had full descriptors for each of the levels on the scale. $^*P < 0.05$; $^{**}P < 0.01$. (*F*) Average number of science courses taken by students experiencing SEA-PHAGES (red) or a nonresearch laboratory course (blue) in three subsequent terms; 95% confidence intervals are shown.

Discussion

We have described here the iREC model for promoting student persistence in STEM education. The iREC, as illustrated by SEA-PHAGES, focuses on scientific discovery within a community accessible by early career undergraduate students and a centralized administrative structure that supports a broad range of institutions. Furthermore, it enables student development regardless of demographic or academic background. We propose that the iREC concept could have a transformative impact on science education when expanded to include additional research topics. We encourage research institutions to design and implement additional iREC programs. We emphasize that the authenticity of iREC research topics is important, not only for promoting student engagement through project ownership but also for program sustainability and acquiring financial support.

Several important questions arise regarding SEA-PHAGES program implementation and iREC development in general. For example, the SEA-PHAGES program spans experimental approaches, including microbiology, molecular biology, imaging, and computational biology, and the contributions of each of these elements to student persistence are unresolved. Furthermore, as yet, we know little of how the iREC experience influences students' choices in enrolling for other STEM courses and laboratories or in pursuing other research experiences. We also do not know how the SEA-PHAGES experience influences student career choices after graduation. Because early career students succeed in SEA-PHAGES, regardless of background or experience, we predict that the benefit of experiencing the process of discovery—vs. the unfortunately too frequent imposition of exercises for which the "right" answers are already known—will be broadly accrued by all students, including those who sample science via this iREC but who choose to pursue nonscience careers. Layering iREC experiences through different levels of the undergraduate curriculum could multiply their impacts.

Although the initial costs of establishing an iREC administrative structure can be substantial, they can be considerably less so if built on an extant independently funded research program. After it is operational, the program structure can support rapid expansion of the numbers of institutions and student participants, thereby substantially reducing the costs/student. Defining the SEA-PHAGES programmatic structure (Fig. 1), analyzing the relationships among its component elements (Fig. 2), and documenting the research and educational outcomes (Figs. 3–5) provide a path for future iREC development. Widespread use of this model has the potential to drive a major transformation of undergraduate science education.

Materials and Methods

The pathway model was constructed using previously described approaches (20), and detailed methods are described in *SI Appendix*. Program assessment used the PITS survey tool and comprised five existing survey tools covering project ownership, self-efficacy, science identity, scientific community values, and networking, all of which measure different psychological components of a research experience and have individually been used in a range of investigations of educational programs. Before usage in this data collection process, the PITS survey was evaluated for its dimensionality, validity, and internal consistency (28). The tool underwent psychometric evaluation and has been validated for usage in the assessment of research experiences. Details of the survey cohorts, data, and statistical analyses are described in detail in *SI Appendix*. This study was approved and supervised by the Institutional Review Board of the Indiana University of Pennsylvania (14-302) and the University of Pittsburgh Institutional Review Board (PRO14100567 and PRO15030412).

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1. Gentile J, Brenner K, Stephens A (2017) *Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities* (National Academies, Washington, DC).
2. Lopatto D (2004) Survey of undergraduate research experiences (SURE): First findings. *Cell Biol Educ* 3:270–277.
3. Lopatto D (2007) Undergraduate research experiences support science career decisions and active learning. *CBE Life Sci Educ* 6:297–306.
4. Brewer C, Smith D, eds (2011) *Vision and Change in Undergraduate Biology Education: A Call to Action* (American Association for the Advancement of Science, Washington, DC).
5. Wei CA, Woodin T (2011) Undergraduate research experiences in biology: Alternatives to the apprenticeship model. *CBE Life Sci Educ* 10:123–131.
6. Bangera G, Brownell SE (2014) Course-based undergraduate research experiences can make scientific research more inclusive. *CBE Life Sci Educ* 13:602–606.
7. Spell RM, Guinan JA, Miller KR, Beck CW (2014) Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. *CBE Life Sci Educ* 13:102–110.
8. Linn MC, Palmer E, Baranger A, Gerard E, Stone E (2015) Education. Undergraduate research experiences: Impacts and opportunities. *Science* 347:1261757.
9. President's Council of Advisors on Science and Technology (2012) Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Available at https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf. Accessed April 7, 2015.
10. Lopatto 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.
11. Shaffer CD, 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.
12. Elgin SCR, et al.; Genomics Education Partnership (2017) The GEP: Crowd-sourcing big data analysis with undergraduates. *Trends Genet* 33:81–85.
13. Caruso JP, Israel N, Rowland K, Lovelace MJ, Saunders MJ (2016) Citizen science: The small world initiative improved lecture grades and California critical thinking skills test scores of nonscience major students at Florida Atlantic University. *J Microbiol Biol Educ* 17:156–162.
14. Davis E, et al. (2017) Antibiotic discovery throughout the small world initiative: A molecular strategy to identify biosynthetic gene clusters involved in antagonistic activity. *MicrobiologyOpen* 6.
15. Jordan TC, et al. (2014) A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. *MBio* 5:e01051–e13.
16. Hendrix RW, Smith MC, Burns RN, Ford ME, Hatfull GF (1999) Evolutionary relationships among diverse bacteriophages and prophages: All the world's a phage. *Proc Natl Acad Sci USA* 96:2192–2197.
17. Rohwer F, Youle M, Maughan H, Hisakawa N (2014) *Life in Our Phage World: A Centenial Field Guide to the Earth's Most Diverse Inhabitants* (Wholon, San Diego).
18. Hanauer DI, et al. (2006) Inquiry learning. Teaching scientific inquiry. *Science* 314: 1880–1881.
19. Hatfull GF, et al. (2006) Exploring the mycobacteriophage metaproteome: Phage genomics as an educational platform. *PLoS Genet* 2:e92.
20. Corwin LA, Graham MJ, Dolan EL (2015) Modeling course-based undergraduate research experiences: An agenda for future research and evaluation. *CBE Life Sci Educ* 14:es1.
21. Urban JB, Trochim W (2009) The role of evaluation in research practice integration working toward the "golden spike." *Am J Eval* 30:538–553.
22. Hanauer DI, Hatfull G (2015) Measuring networking as an outcome variable in undergraduate research experiences. *CBE Life Sci Educ* 14:ar38.
23. Brownell SE, et al. (2015) A high-enrollment course-based undergraduate research experience improves student conceptions of scientific thinking and ability to interpret data. *CBE Life Sci Educ* 14:ar21.
24. Pope WH, et al.; Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science; Phage Hunters Integrating Research and Education; Mycobacterial Genetics Course (2015) Whole genome comparison of a large collection of mycobacteriophages reveals a continuum of phage genetic diversity. *eLife* 4:e06416.
25. Dedrick RM, et al. (2017) Prophage-mediated defence against viral attack and viral counter-defence. *Nat Microbiol* 2:16251.
26. Berg J (2011) Productivity metrics and peer review scores *NIGMS Feedback Loop Blog*. Available at https://loop.nigms.nih.gov/2011/06/productivity-metrics-and-peer-review-scores/. Accessed September 14, 2016.
27. Jacob BA, Lefgren L (2011) The impact of research grant funding on scientific productivity. *J Public Econ* 95:1168–1177.
28. Hanauer DI, Graham MJ, Hatfull GF (2016) A measure of college student persistence in the sciences (PITS). *CBE Life Sci Educ* 15:ar54.
29. Robnett RD, Chemers MM, Zurbriggen EL (2015) Longtidinal associations among undergraduates' research experiences, sefl-efficacy, and identity. *J Res Sci Teach* 52:847–867.
30. Estrada M, Woodcock A, Hernandez PR, Schultz PW (2011) Toward a model of social influence that explains minority student integration into the scientific community. *J Educ Psychol* 103:206–222.
31. Graham MJ, Frederick J, Byars-Winston A, Hunter AB, Handelsman J (2013) Science education. Increasing persistence of college students in STEM. *Science* 341:1455–1456.
32. Austin PC (2011) An introduction to propensity score methods for reducing the effects of confounding in observational studies. *Multivariate Behav Res* 46:399–424.
33. Asai DJ, Bauerle C (2016) From HHMI: Doubling down on diversity. *CBE Life Sci Educ* 15:fe6.
34. Huang G, Taddese N, Walter E, Peng SS (2000) *Entry and Persistence of Women and Minorities in College Science and Engineering Education* (US Department of Education, National Center for Education Statistics, Washington, DC).

Supplementary Information

An Inclusive Research-Education Community (iREC): Impact of the SEA-PHAGES Program on Research Outcomes and Student Learning

Appendix

Materials and Methods

Pathway model methodology

We developed a highly detailed pathway model of the SEA-PHAGES program to ground our measure development and evaluation planning efforts. Using methods from the Systems Evaluation Protocol (SEP), we developed an initial logic model and then a more complex pathway model through a series of iterative revisions. To inform the pathway model, we conducted unstructured individual interviews by web conference with 1) a small team of SEA-PHAGES evaluators (through iterative review) and 2) three key SEA-PHAGES program leaders (during final model revision stages). In these interviews, evaluators would review an existing model draft with the stakeholder, before encouraging the stakeholder to identify content holes, jumps in logic, and inconsistencies in the model based on their personal program expertise. To supplement stakeholders' unstructured reviews of the models, we also used questions on program scope, stakeholder groups, model content holes, pathways from activities to outcomes, key outcomes, and overarching model themes to collect information from the model reviewers during interviews. These interview sessions were conducted until all content was represented in the model. These sessions aimed to create a realistic representation of full SEA-PHAGES program through model reviews by stakeholders with different knowledge bases.

Between sessions, a program modeler analyzed qualitative data from each session and input changes to the model using evaluationnetway.com (the SEPs partner website for modeling building and evaluation planning). The program modeler also conduced revisions between review sessions to clean the model and identify content areas needing further review.

The output of this full process is a highly complex model that captures the program knowledge of several stakeholders to connect activities, short-term outcomes, mid-term outcomes, and long-term outcomes for the SEA-PHAGES program. The model scope included program administration, instructor training, class implementation, and student outcomes.

Specifically, the model identified the following theme progression for the SEA-PHAGES program:

1) Institutional preparation and application to the SEA-PHAGES program

(e.g. “Instructors negotiate parameters of the potential class and advocate for the program with the department”)

2) Instructor training and preparation

(e.g. “New instructors participate in bioinformatics activities at an *in silico* workshop”)

3) Student and instructor contribution of science knowledge via class research

(e.g. “Students upload phage genomes to SEA-PHAGES database”)

4) Development of differentiated curriculum for class

(e.g. “Instructors allow for variation in students’ experiences and in the pace of work”)

5) Instructor and student collaboration leads to recognition of each others talents

(e.g. “Instructors see students as talented and capable”)

6) Post-class growth

(e.g. “Students make informed decisions about their future pursuit of STEM”)

7) Long term student and institutional commitment to science

(e.g. “Increased retention of participating students in biology and other STEM classes, and in STEM majors”)

See Figure S1 for the full pathway model. Numbers on activities and outcomes on the full model correspond to numbers from the themes above.

The final model was used to inform measure development (e.g. PITS), develop evaluation plans, and connect and contextualize findings.

Institutional continuation in SEA-PHAGES

In order to analyze the degree of continued school membership in the SEA-PHAGES program, a survival analysis was conducted on the first eight cohorts of schools in the program (n=104). Overall, there was a survival rate of 84.6% of schools continuing in the SEA-PHAGES community. A Mantel-Cox log-rank test of equality of survival distributions for the different cohorts did not show any significant differences between cohorts [Chi-Square (7)=4.22, p=.75]. The probability of staying in the program for 3, 4 and 5 years was calculated. The probability of staying in the program for 3 years was 0.97, for 4 years 0.89 and for 5 years 0.87.

Publications from the PHIRE and SEA-PHAGES programs

Publications from the PHIRE and SEA-PHAGES programs were collated, with numbers of citations obtained using Google Scholar in February 2017. The numbers of non-self citations were obtained for each paper by deducting the number of citations of that paper that included the senior author. The numbers of papers published was considered equivalent to 1-2 NIH R01 grants, although the publication rates for R01 grants varies enormously. In addition, the data presented in the papers varies from those that exclusively include work by SEA-PHAGES students (as is common in the Genome Announcement papers), to those that include additional work outside of the SEA-PHAGES labs but are dependent on the phage isolation and characterization within SEA-PHAGES labs. The publications can be considered as an offset of the program administrative costs, although these costs include both direct program support and some ongoing research support. The estimate of research productivity as offsetting 40% of the administrative costs is a reasonable but likely imprecise estimate.

PITS survey collection and analysis

The *Persistence in the Sciences* (PITS) survey is a tool for assessing the outcomes of undergraduate, course-based research experiences (*24*). The PITS survey was comprised from five existing survey tools covering project ownership, self-efficacy, science identity, scientific community values and networking, all of which measure different psychological components of a research experience and have individually been used in a range of investigations of educational programs. Prior to usage in this data collection process, the PITS survey was evaluated for its dimensionality, validity and internal consistency (*24*). The tool underwent psychometric evaluation and has been validated for usage in the assessment of research experiences (*24*).

Sample specification

The PITS survey data was collected during the Fall 2016 semester. Data was collected from courses in the SEA-PHAGES program and from a range of traditional introductory laboratory courses at schools associated with the SEA-PHAGES program. In all, data were collected from 67 different schools across the US. The aim was to create a data set which would allow appropriate comparisons to be made between the two types of educational experience and to evaluate the relative value of the SEA-PHAGES program as an educational approach. The outcome of this effort was a data set consisting of 2,850 participants with 1,587 from the SEA-PHAGES program and 1,263 from traditional laboratories. Of the SEA-PHAGES students, 88% were taking the phage discovery semester, and 12% were taking the bioinformatic semester. Participation rates were similar for students in the two types of courses, 52.2% and 51.0% for SEA-PHAGES and traditional labs respectively. The size of the data set, it's diversity across different demographics of relevance and the greater than 50% participation rates for both groups allows comparisons to be made between samples, and adds validity to the current analysis. Table S3 presents the demographic data and institution type for students of the complete dataset.

Comparison of propensity score matched-groups of students in SEA-PHAGES and traditional labs

To evaluate the effect of the SEA-PHAGES education program on the outcomes of the psychological measures of research experiences, a propensity score group matching approach was employed comparing SEA-PHAGES students to students who studied in a traditional lab. A traditional lab was defined as an introductory laboratory course whose main emphasis in the curriculum consists of teaching students a series of specific laboratory procedures without relating these to a data collection process or a current on-going research project. A random sample of 400 students was elicited from the full data set of the SEA-PHAGES program (n=1554) and from a comparison sample consisting of 11 different traditional lab courses at 8 institutions (n=1297). To preserve the integrity of the sample, all the traditional labs chosen for the comparison came from institutions that also have SEA-PHAGES courses. Table S4 presents the comparison of the two groups on the covariate variables of gender, grade point average, education level of parents, profession of parents and ethnicity (differentiated into White/Asian and Under Represented Minorities, URM). As can be seen in Table S4, there are differences in the two populations with significant x^2 statistics for gender, GPA, ethnicity and parents' occupation and with parents' educational level nearly significant at the 0.05 level.

To take these differences into account, two matching procedures were utilized: propensity score matching and nearest neighbor matching. In addition, an unmatched t-test was conducted. All three analytical procedures were performed on all of the PITS variables (Project Ownership Content, Project Ownership Emotion, Self-Efficacy, Science Identity, Scientific Community Values and Networking). The propensity score matching technique utilized here compared the outcome for each student in the SEA-PHAGES group with the average outcomes of students deemed similar using propensity scores from the traditional group. The nearest-neighbor matching technique matches each subject from the SEA-PHAGES group with the subject that has the nearest propensity score from the traditional lab. To check the outcomes of the propensity score matching technique a balance density plot of propensity scores for matched and unmatched samples was generated. To evaluate the quality of the propensity score matching, standardized differences and variance ratios were generated for the matched groups. For each of the covariates standardized differences were close to 0 (+/- 0.06) and variance ratios were close to 1 (+/- 0.15) suggesting appropriate matching had occurred.

Table S5 presents the results of these analyses. As can be seen in Table S5, the unmatched t-test find all variables significantly different between the two groups. However, for both propensity score matching techniques, self-efficacy is not significantly different between the groups. All other PITS variables are significantly different with the SEA-PHAGES program exhibiting increased ratings. Specifically, the SEA-PHAGES program increases Project Ownership Content responses by 11% (0.56 points); Project Ownership Emotion by 10% (0.5 points); Science Identity by 9% (0.43 points); Scientific Community Values by 7% (0.37 points) and Networking by 14% (0.71 points) over the matched traditional lab students. The results of both matching techniques produced similar results.

Comparison of the impact of SEA-PHAGES and traditional laboratory courses for students with a high intent to stay in the sciences.

To evaluate the outcomes of the SEA-PHAGES course on students with a high declared intent to stay in the sciences, a one-way, multivariate analysis of variance (MANOVA) was performed with course type (SEA-PHAGES/traditional lab) as an independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on students who have already declared a high intent to stay in the sciences. A high-intent participant was operationally defined as a student who gave a “Strongly Agree” rating (5 on a 5 point scale) to the statement “I intend to complete a science related degree”. A random sample of 400 high-intent students consisting of two equal groups of 200 defined by course (SEA-PHAGES/traditional lab) was elicited from the full data set of the both programs (SEA-PHAGES, n=1554; traditional lab, n=1297). Table S6 presents the demographic data of the sample.

A one-way MANOVA with course type (SEA-PHAGES/traditional lab) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 200 high-intent participants for each group were extracted from the SEA-PHAGES and traditional lab multi-section samples. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 67:1, well above the threshold level of 20:1. To test the assumption of multicollinearity, Pearson correlations were performed for all dependent variables. As can be seen in Table S7 the assumption of multicollinearity is not violated as variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 81.5 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S8 presents the descriptive statistics for the two groups. As can be seen in Table S8, high-intent students from the SEA-PHAGES courses had higher or slightly higher ratings for all PITS variables. The one-way MANOVA revealed a significant main effect for course type, with Pillai's Trace = 0.31, F(6, 393) = 28.89, p <0.0001. Table S9 presents the results of the follow-up univariate ANOVA tests. Statistically significant results were found for courses type on all of the PITS variables except Self-Efficacy (Project Ownership Content, F (1, 398) = 90.37, p<0.0001, Project Ownership Emotion F (1, 398) = 69.86, p<0.0001, Science Identity F (1, 398) = 19.99, p<0.0001, Scientific Community Values F (1, 398) = 12.31, p<0.001 and Networking, F (1, 398) = 121.36, p<0.0001. Consideration of the partial eta^2 shows that networking (0.23) project ownership content (0.19) and Project Ownership Emotion (0.15) with large effect sizes and high levels of power. Overall the results suggest that there are significant differences between high-intent students in the SEA-PHAGES and traditional lab courses with SEA-PHAGES students generating higher ratings on the PITS survey.

Comparison of impact on 1st Generation students in SEA-PHAGES and traditional laboratory courses

To evaluate the outcomes of the SEA-PHAGES course on 1st generation college students, a one-way, multivariate analysis of variance (MANOVA) was performed with course type (SEA-PHAGES/traditional lab) as the independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on students who are the first in their family to go to college (1st generation). A random sample of 548 students consisting of two equal groups defined by course (SEA-PHAGES, n=272/traditional Lab, n=276) was elicited from the full data set of the both programs (SEA-PHAGES, n=1554; traditional lab, n=1297). Table S10 presents the demographic data of the sample.

A one-way MANOVA with course type (SEA-PHAGES/traditional lab) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 270 first generation students for each group were extracted from the SEA-PHAGES and traditional lab multi-section samples.

The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 93:1 well above the threshold level of 20:1. To test the assumption of multicollinearity, Pearson correlations were performed for all dependent variables. As can be seen in Table S11 the assumption of multicollinearity is not violated as variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 56.76 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S12 presents the descriptive statistics for the two groups. As can be seen in Table S12, 1st generations students from the SEA-PHAGES courses had higher ratings for all PITS variables. The one-way MANOVA reveals a significant main effect for course type, Pillai's Trace = 0.15, F(6, 541) = 16.04 , p <0.0001. Table S13 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for courses type on all the PITS variables (Project Ownership Content, F (1, 546) = 52.56, p<0.0001, Project Ownership Emotion F (1, 546) = 49.59, p<0.0001, Self-Efficacy F(1, 546)=12.42, p<,0001, Science Identity F (1, 546) = 51,69, p<0.0001, Scientific Community Values F (1, 546) = 32.48, p<0.001 and Networking, F (1, 546) = 48.48, p<0.0001. Consideration of the partial eta^2 shows moderate effect sizes and high levels of power throughout. Overall the results suggest that there were significant differences between 1st generation college going students in the SEA-PHAGES and traditional lab courses with SEA-PHAGES students having higher ratings.

Comparison of impact on women in SEA-PHAGES and traditional laboratory courses

To evaluate the outcomes of the SEA-PHAGES course on female students, a one-way, multivariate analysis of variance (MANOVA) was performed with course type (SEA-PHAGES/traditional lab) as the independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on women students. A random sample of 480 students consisting of two equal groups defined by course (SEA-PHAGES, n=240/traditional lab, n=240) was elicited from the full data set for both programs (SEA-PHAGES, n=1554; traditional lab, n=1297). Table S14 presents the demographic data of the sample.

A one-way MANOVA with course type (SEA-PHAGES/traditional lab) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 240 female participants for each group were extracted from the SEA-PHAGES and traditional lab multi-section samples. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 80:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S15 the assumption of multicollinearity is not violated as variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 135.09 and had a p value of 0.0001. Accordingly, the Pillai’s Trace statistic will be reported as the multivariate test of difference.

Table S16 presents the descriptive statistics for the two groups. As can be seen in Table S16, female students from the SEA-PHAGES courses had higher ratings for all PITS variables. The one-way MANOVA revealed a significant main effect for course type, Pillai’s Trace = .22, F(6, 468) = 22.16 , p <0.0001. Table S17 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for course type on all the PITS variables (Project Ownership Content, F (1, 473) = 72.18, p<0.0001, Project Ownership Emotion F (1, 473) = 64.15, p<0.0001, Self-Efficacy F(1, 473)=6.56, p<0.01, Science Identity F (1, 473) = 35.54, p<0.0001, Scientific Community Values F (1, 473) = 33.75, p<0.0001 and Networking, F (1, 473) = 101.9, p<0.0001. Consideration of the partial eta^2 shows moderate effect sizes for project ownership content, project ownership emotion and networking and high levels of power throughout. Overall the results suggest that there were significant differences between female college going students in the SEA-PHAGES and traditional lab courses with SEA-PHAGES students having higher ratings.

Comparison of impact on under-represented minority students in SEA-PHAGES and traditional laboratory courses

To evaluate the outcomes of the SEA-PHAGES course on under-represented minority students, a one-way, multivariate analysis of variance (MANOVA) was performed with course type (SEA-PHAGES/traditional lab) as independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on under-represented minority students. A random sample of 465 students consisting of 2 equal groups defined by course (SEA-PHAGES, n=233/traditional lab, n=232) was elicited from the full data set of both programs (SEA-PHAGES, n=1554; traditional lab, n=1297). Table S18 presents the demographic data of the sample.

A one-way MANOVA with course type (SEA-PHAGES/traditional lab) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 233 under-represented minority participants for each group were extracted from the SEA-PHAGES and traditional lab multi-section samples. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 77:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S19 the assumption of multicollinearity is not violated as variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 135.57 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S20 presents the descriptive statistics for the two groups. As can be seen in Table S20, under-represented minority students from the SEA-PHAGES courses had higher ratings for all PITS variables than students in traditional lab courses. The one-way MANOVA revealed a significant main effect for course type, Pillai's Trace = .14, F(6, 458) = 12.38 , $p < 0.0001$. Table S21 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for courses type on all the PITS variables except Self-Efficacy (Project Ownership Content, F (1, 463) = 41.71, $p<0.0001$, Project Ownership Emotion F (1, 463) = 35.29,

$p<0.0001$, Self-Efficacy $F(1, 463)=3.8$, $p<0.052$, Science Identity $F(1, 463) = 19.36$, $p<0.0001$, Scientific Community Values $F(1, 463) = 17.85$, $p<0.0001$ and Networking, $F(1, 463) = 54.96$, $p<0.0001$. Consideration of the partial eta^2 shows small effect sizes for project ownership content, project ownership emotion and networking and high levels of power for all variables except self-efficacy. Overall the results suggest that there were significant differences between under-represented minority college going students in the SEA-PHAGES and traditional lab courses with SEA-PHAGES students having higher ratings.

Comparison of impact on under-represented minority male students in SEA-PHAGES and traditional laboratory courses

To evaluate the outcomes of the SEA-PHAGES course on under-represented minority male students, a one-way, multivariate analysis of variance (MANOVA) was performed with course type (SEA-PHAGES/traditional lab) as independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on under-represented minority male students. A random sample of 236 students consisting of 2 equal groups defined by course (SEA-PHAGES, n=120/traditional lab, n=116) was elicited from the full data set of the both programs (SEA-PHAGES, n=1554; traditional lab, n=1297). Table S22 presents the demographic data of the sample.

A one-way MANOVA with course type (SEA-PHAGES/traditional lab) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 120 under-represented minority male participants for each group were extracted from the SEA-PHAGES and traditional lab multi-section samples. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 39:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S23 the assumption of multicollinearity is not violated as variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 70.31 and had a p value of .0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S24 presents the descriptive statistics for the two groups. As can be seen in Table S24, under-represented minority male students from the SEA-PHAGES courses had higher ratings for all PITS variables than did the students in the traditional lab courses. The one-way MANOVA revealed a significant main effect for course type, Pillai's Trace = 0.13, F(6, 222) = 5.45 , p <0.0001. Table S25 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for course type on all the PITS variables (Project Ownership Content, F (1, 227) = 22.24, p<0.0001, Project Ownership Emotion F (1, 227) = 15.72, p<0.0001, Self-Efficacy F(1, 227)=5.79, p<0.017, Science Identity F (1, 227) = 16.12, p<0.0001, Scientific Community Values F (1, 227) = 6.43, p<0.012 and Networking, F (1, 227) = 27.39, p<0.0001. Consideration of the partial eta^2 shows small effect sizes for project ownership content, project ownership emotion and networking and high levels of power for all variables except self-efficacy and scientific community values. Overall the results suggest that there were significant differences between under-represented minority male college going students in the SEA-PHAGES and traditional lab courses with SEA-PHAGES students having higher ratings.

Comparison of Gender in the SEA-PHAGES program

To evaluate whether the SEA-PHAGES course has a different impact depending on gender, a one-way, multivariate analysis of variance (MANOVA) was performed with gender as the independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect depending on gender, a variable which in past literature has been considered to be important in when examining student persistence. A random sample of 800 students consisting of two equal groups defined by gender (male/female) was elicited from the full data set of the SEA-PHAGES program (n=1554). Table S26 presents the demographic data of the sample.

A one-way MANOVA with gender (male/female) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 400 participants for each group (male/female) were extracted from the SEA-PHAGES multi-section sample. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 67:1, well above the threshold level of 20:1. To test the assumption of multicollinearity, Pearson correlations were performed for all dependent variables. As can be seen in Table S27 the assumption of multicollinearity is not violated as all variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box’s M test of equality of covariance matrices. The Box’s M value was 55.65

and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S28 presents the descriptive statistics for the two groups. As can be seen in Table S28, female participants seem to have slightly higher ratings for all PITS variables except for self-efficacy. The one-way MANOVA revealed a significant main effect for Gender, Pillai's Trace = 0.028, F(6, 793) = 3.74, p <0.001. Table S29 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for Gender on the variables of Project Ownership Content, F (1, 798) = 2.15, p<0.03, and Networking, F (1, 798) = 7.46, p<0.006. Consideration of the observed power and partial eta^2 shows networking (.79) and project ownership content (0.57) with moderate to low levels of power. Very small effect sizes were found for both significant variables: networking (0.01) and project ownership content (0.006). Overall the results suggest that while there were significant differences between genders in the SEA-PHAGES sample, these differences were very small. For both the variables in which there were differences, these resulted from higher ratings from the female participants. It seems that women do slightly better than men in the SEA-PHAGES course but this difference is negligible.

Comparison of Ethnicity in the SEA-PHAGES program

To evaluate the outcomes of the SEA-PHAGES course on different ethnicities (Under-represented minorities/ White and Asian), a one-way, multivariate analysis of variance (MANOVA) was performed with ethnicity as the independent variable and Project Ownership Content, Project Ownership Emotion, Self-Efficacy, Science Identity, Scientific Community Values and Networking as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on different ethnicities, a variable which in past literature was seen to be important in exploring student persistence. To explore this question, the participants in the SEA-PHAGES program were arranged into two groupings of ethnicities. All White and Asian students were defined as one group; African

American, Black, Latino, Hispanic, Native Alaskans, and Pacific Islanders were defined as a second group termed Under-represented Minority students. A random sample of 800 students consisting of two equal groups (n=400) defined by ethnicity was elicited from the full data set of the SEA-PHAGES program (n=1554). Table S30 presents the demographic data of the sample.

A one-way MANOVA with ethnicity (URM/White-Asian) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 400 participants for each group (URM/White-Asian) were extracted from the SEA-PHAGES multi-section sample. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 133:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S31 the assumption of multicollinearity is not violated as all variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 53.32 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S32 presents the descriptive statistics for the two groups. As can be seen in Table S32, mean ratings between the two groups seem very similar. The results of the one-way MANOVA confirm this observation and do not find a significant main effect for ethnicity, Pillai's Trace =

0.011, F(6, 793) = 1.51, p <0.17. Although no significant multivariate results were found, univariate tests were still conducted to explore potential relationships between ethnicity and the individual measures. Table S33 presents the results of this analysis. Only the variable of Project Ownership Emotion F(1, 798)=4.74, p<0.03 was significantly different. Consideration of the partial eta squared for Project Ownership Emotion (0.006) was very small with low power (0.56) suggesting that this potential difference is negligible. Accordingly, it was concluded that within the SEA-PHAGES program there were no significant differences between students from different ethnicities.

Comparison of Socio-Economic Status in the SEA-PHAGES program

To evaluate the outcomes of the SEA-PHAGES course on different socio-economic statuses, a one-way, multivariate analysis of variance (MANOVA) was performed with socio-economic status as the independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on different socio-economic groupings, a variable which in past literature was seen to be important in exploring student persistence. To explore this question, four groups integrating different parent educational levels and parent occupation were constructed. A comparative analysis of the frequencies of occurrence for different levels of parent education and parent occupation indicated that four groupings of participants representing different levels of socio-economic status were present within the data set. The four groupings were: Parents with no college education working in unskilled or skilled labor; Parents with an Associate of BA degree and working in a service or managerial position; Parents an MA and working in a managerial or professional occupation; and parents with a PhD and working in a professional occupation. A random sample of 400 students consisting of 4 equal groups (n=100) defined by socio-economic status was elicited from the full data set of the SEA-PHAGES program (n=1554). Table S34 presents the demographic data of the sample.

A one-way MANOVA with 4 levels of socio-economic status as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, 4 random equal groups of 100 participants for each group were extracted from the SEA-PHAGES multi-section sample. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 67:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S35 the assumption of multicollinearity is not violated as all variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 218.6 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S36 presents the descriptive statistics for the two groups. As can be seen in Table S36, the lowest socio-economic group seems to consistently have higher ratings for the PITS variables. However the results of the one-way MANOVA do not confirm this observation and do not find a significant main effect for socio-economic status, Pillai's Trace = 0.067, F(18, 1179) = 1.51, $p < 0.08$. Although no significant multivariate results were found, univariate tests were still conducted to explore potential relationships between the socio-economic status groupings and the individual measures. Table S37 presents the results of this analysis. Only the variable of

Project Ownership Emotion F(3, 396)=5.22, p<0.002 was significantly different. The partial eta squared for Project Ownership Emotion (0.038) was small with high power (0.93). To follow-up on this analysis a Tukey HSD post hoc test was conducted with the result that the lowest socio-economic status group (Parents with no college education working in unskilled or skilled labor) was significantly different from the 3rd SES group (Parents an MA and working in a managerial or professional occupation) at the .005 significance level and from the highest SES group (PhD and working in a professional occupation) at the 0.003. In both cases the lowest SES group had significantly higher Project Ownership Emotion ratings than the other groups. Overall, the analyses presented here do not present significant differences between the different socio-economic status groups in the SEA-PHAGES groups.

Comparison of students with different Grade Point Averages in the SEA-PHAGES program

To evaluate the outcomes of the SEA-PHAGES course on GPA (grade point average), a one-way, multivariate analysis of variance (MANOVA) was performed with GPA as independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on GPA. Since there were very few participants who had GPAs below 2.5 or above 4, the analysis was conducted on the three central groups consisting of students with a GPA from 2.6 to 3; from 3.1 to 3.5; and from 3.6 to 4. A random sample of 600 students consisting of 3 equal groups of 200 defined by level of GPA was elicited from the full data set of the SEA-PHAGES program (n=1554). Table S38 presents the demographic data of the sample.

A one-way MANOVA with GPA (2.6-3/3.1-3.5/3.6-4) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 200 participants for each group were extracted from the SEA-PHAGES multi-section sample. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 100:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S39 the assumption of multicollinearity is not violated as all variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 90.14 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S40 presents the descriptive statistics for the two groups. As can be seen in Table S40 participants with the highest GPA level (3.5-4) seem to have slightly higher ratings for all PITS variables when compared with the other two groups. The one-way MANOVA revealed a significant main effect for GPA, Pillai's Trace = 0.048, F(12, 1186) = 2.42, p <0.004. Table S41 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for GPA on the variables of Science Identity, F (2, 597) = 6.43, p<0.002, Scientific Community Values F (2, 597) = 6.21, p<0.002 and Networking, F (2, 597) = 3.46, p<0.03. Consideration of the observed power and partial eta^2 shows that science identity (.9), scientific community values (.89) and networking (.65) have high to moderate levels of power. Very small effect sizes were found for the significant variables: science identity (0.02), scientific community values (0.02) and networking (0.01). To further explore the source of the differences post-hoc group comparisons were calculated. Since the variables of Science Identity and Scientific Community Values violated the homogeneity of variances assumptions, Dunnett T3 post hoc tests were conducted. The results situate the source of difference in both Science Identity and Scientific Community Values to be between the high GPA group (3.6-4) and the low GPA group (2.5-3). These differences were significant at the 0.002 level and in the direction of higher GPA leading to higher levels of these variables. Tukey HSD post hoc tests were conducted for the Networking variable but no significant group differences were identified. Overall the results suggest that while there were significant differences between GPA levels in the SEA-PHAGES sample that these differences were very small.

Institution Type Comparison in the SEA-PHAGES program

To evaluate the outcomes of the SEA-PHAGES course on different categories of institution a one-way, multivariate analysis of variance (MANOVA) was performed with Institution Type as independent variable and the six PITS variables as dependent measures. This analysis was designed to evaluate the question of whether the SEA-PHAGES program has a differential effect on different types of institution. In this analysis, the four types of institution (Community College, Four-Year School, Master's Granting Institution and Research University) were used as the groupings. A random sample of 400 students consisting of 4 equal groups of 100 defined by type of institution was elicited from the full data set of the SEA-PHAGES program (n=1554). Table S42 presents the demographic data of the sample.

A one-way MANOVA with Institution type (Community College, Four-Year School, Master's Granting Institution and Research University) as the independent variable and project ownership content, project ownership emotion, self-efficacy, science identity, scientific community values and networking as dependent variables was calculated. To ensure independence of measures, random equal samples of 100 participants for each group were extracted from the SEA-PHAGES multi-section sample. The assumption of linearity was checked using scatter plots for all dependent variables. No curvilinear relationships were observed, indicating that the assumption of linearity had not been violated. The ratio of participant to dependent variable was 67:1 well above the threshold level of 20:1. To test the assumption of multicollinearity Pearson correlations were performed for all dependent variables. As can be seen in Table S43 the assumption of multicollinearity is not violated as all variables are correlated with each other in a moderate range scale. The emergent pattern of correlations suggests that a MANOVA is an appropriate approach for this data set. Both the assumptions of multivariate normality and homogeneity of variance were violated in this data set. However, the sample has equal group sizes and the MANOVA is quite robust against violations of this type with this sample size and equality of groups. Homogeneity of variance was tested using the Box's M test of equality of covariance matrices. The Box's M value was 121.97 and had a p value of 0.0001. Accordingly, the Pillai's Trace statistic will be reported as the multivariate test of difference.

Table S44 presents the descriptive statistics for the groups. As can be seen in Table S44, the participants from the Community College have higher ratings for their positive emotions (Project Ownership Emotion) than other groups and the participants from the Research University have higher ratings for the variables of Science Identity and Scientific Community Values when compared with the other groups. The one-way MANOVA revealed a significant main effect for Institution type, Pillai's Trace = .107, F(18, 999) = 2.06, p <0.006. Table S45 presents the results of the follow-up univariate ANOVAs. Statistically significant results were found for Institution Type on the variables of Project Ownership Emotion, F (3, 336) = 3.84, p<0.01, and Scientific Community Values F (3, 336) = 3.22, p<0.02. Consideration of the observed power and partial eta^2 shows that Project Ownership Emotion (0.82) and scientific community values (0.74) with moderate levels of power. Small effect sizes were found for the significant variables: Project Ownership Emotion (0.033) and scientific community values (0.028). To further explore the source of the differences post-hoc group comparisons were calculated. Tukey HSD tests were calculated for the two significant variables. The results situate the significant difference between Community College participants and the Master's Institution for Project Ownership Emotion at the 0.01 level of significance and between the Research University and the Master's Institution for Scientific Community Values at the 0.02 level of significance. In both cases, the Master's Institution had significantly lower ratings on these two variables. Overall the results suggest that while there were significant differences between the institutions with the Master's Institution having lower ratings on two variables, these differences were small and may not suggest a substantial difference in performance on the different measures.

Persistence analysis for one SEA-PHAGES institution

Students' data were analyzed from one institution offering both the SEA-PHAGES program and an introductory non-research laboratory course. This institution's traditional lab course included standard skills instruction as well as inquiry modules of student-designed experiments (answers were unknown by the student but known by the lab developer, thus "traditional" not "authentic research"). Sociodemographic data for 4,195 undergraduate students taking the non-research laboratory course from fall 2012 through Fall 2015 was obtained from an administrative database. During this time, the number of SEA-PHAGES students per term rose from eighteen to ninety-five as multiple sections were added, while almost one thousand students took the requisite-equivalent traditional laboratory course each term. In total 3,975 students taking the traditional lab and 220 taking the SEA-PHAGES lab were included in demographic and academic analyses.

Sociodemographic and prior academic record. When enrolling, students provided the institution with demographic information including gender, race, ethnicity, citizenship status, date of birth, and high school identification. Gender was represented with an indicator variable with female as the reference group. Race was coded with an indicator for whether the student belongs to a minority group (reference group) or was White or Asian. An indicator for whether the student was enrolled at the university by age 20 or not (reference group) was used. Additional sociodemographic characteristics were obtained from the information filled out in the Free Application for Federal Student Aid (FAFSA): family's adjusted gross income (AGI) in units of 10,000 U.S. dollars, and parental education. Parental education was represented with an indicator for whether at least one parent obtained a bachelor's degree or not (reference group). Also, an indicator for whether the student attended a high school with the percentage of African American and Latino students higher than 40% was created. This information was obtained from the Public Elementary/Secondary School Universe Survey Data collected by the National Center for Education Statistics (NCES, 2014). Academic achievement prior to college was captured by adding the verbal, math, and writing SAT scores, divided by 100. For students who took the ACT instead of the SAT, the scores were converted.

The populations of introductory laboratory students were compared using a T-test in STATA-13. An indicator variable was created to capture whether a student took SEA-PHAGES laboratory (reference group) or the traditional laboratory. Table S46 presents means (M) and standard deviation (SD) for each demographic variable. Analysis indicates that students attending each laboratory were very similar with exception of higher SAT scores for the SEA-PHAGES students [$t(1, 5019) = 1.91$, $p<0.01$] as well as a lower entrance age at the university [$t(1, 5019)= -1.87$, $p<0.05$]. (Table S46).

Analytic approach

Two outcomes were considered to compare persistence between students who took the SEA-PHAGES or traditional laboratory. First, a dichotomous variable indicating whether the students took any science course one, two, or three semesters after taking the laboratory course was used as an outcome. The second outcome variable was the number of science classes students took one, two and three semesters after the laboratory. The indicator for the SEA-PHAGES laboratory was entered in OLS regression analysis [Table S47 (not matched)].

To account for differences uncovered in demographic T-test analysis, coarsened exact matching (CEM) was used (*1*). CEM matches individuals based on a set of defined variables and creates matched, categorized groups of individuals with the same exact characteristics, and removing individuals with no match. For each categorized group, only individuals in the same group are used in the subsequent analysis. Students were matched on gender, race/ethnicity (White/Asian or other), enrollment at the institution by age 20, parental education (college degree), percent of minority students at high school if more than forty percent, being a freshman when they took the lab, AGI, SAT scores and intended academic plan. The AGI variable was coarsened into four categories: \$0- \$30,000; \$30,001- \$60,000; \$60,001-\$100,000; over \$100,000. The SAT scores were coarsened into three categories representing very low scores (lower than 1600), low scores [from 1601 to the mean (1925)] and above the mean.

To avoid bias of student intent to persist in the sciences that might differ between the SEA-PHAGES and traditional lab populations, two new variables were generated from the university administrative database for use in CEM. First, an indicator was made for whether a student took the lab in freshmen year. Second, a set of four dichotomous indicators was created for the student's self-specified interest in a science major when enrolling at the institution: high STEM content (including pre-medicine), lower STEM content (ex. other health sciences, environmental geology), humanities and business, or an undeclared interest.

The CEM procedure matched 1,847 students from the traditional lab with 209 students who attended the SEA-PHAGES lab, and created 92 groups. Balance of the matching between the students in the two labs was checked using the multivariate imbalance measure (*1*).

Outcome Measures

Student records were used to determine whether students took any science courses and the number of science courses each student took one, two, and three semesters after participating in the introductory biology laboratory. Courses taken in the following departments at the institution were counted as science courses: Chemistry, Neuroscience, Biology, Physics, Geology, and Mathematics. Students attending the traditional lab took an average of 2.63 science classes one semester later, and students who take the SEA-PHAGES laboratory took an average of 2.92 science classes. Overall, students from both labs took fewer science classes two and three semesters after the lab in comparison with one semester after the course. However, taking the SEA-PHAGES lab was associated with taking an average of one-third more of a science class each semester after the lab, in comparison with students taking the traditional lab.

Table S1. SEA-PHAGES participating institutions

Institution	State	Cohort	Classification[1]
Carnegie Mellon University	Pennsylvania	1	R1
College of William & Mary	Virginia	1	R2
Hope College	Michigan	1	Bac/A&S
James Madison University	Virginia	1	M1
Oregon State University[2]	Oregon	1	R1
Spelman College[2]	Georgia	1	Bac/A&S
University of California, San Diego	California	1	R1
University of California, Santa Cruz	California	1	R1
University of Louisiana at Monroe	Louisiana	1	R3
University of Mary Washington	Virginia	1	M1
University of Maryland, Baltimore County	Maryland	1	R2
Washington University in St. Louis	Missouri	1	R1
Brigham Young University	Utah	2	R2
Cabrini University[3]	Pennsylvania	2	M1
Calvin College	Michigan	2	Bac/A&S
CUNY, Queens College[3]	New York	2	M1
Georgia State University[2]	Georgia	2	R1
Lehigh University	Pennsylvania	2	R2
North Carolina State University	North Carolina	2	R1
Saint Joseph's University	Pennsylvania	2	M1
University of Colorado at Boulder	Colorado	2	R1
University of Montana[2]	Montana	2	R2
University of North Texas	Texas	2	R1
University of Puerto Rico at Cayey	Puerto Rico	2	Bac/A&S
Western Kentucky University	Kentucky	2	M1
Baylor University	Texas	3	R2
Brooklyn College[2]	New York	3	M1
Bucknell University	Pennsylvania	3	Bac/A&S
College of Charleston	South Carolina	3	M1
Culver-Stockton College	Missouri	3	Bac/Diverse
Gonzaga University	Washington	3	M1
Jacksonville State University[2]	Alabama	3	M1
Loyola Marymount University[3]	California	3	M1
North Carolina Central University[2]	North Carolina	3	M1
Purdue University	Indiana	3	R1
Queensborough Community College	New York	3	Assoc/HT-HT[4]
University of Alabama at Birmingham	Alabama	3	R1
University of Texas at El Paso	Texas	3	R2
University of Wisconsin-River Falls	Wisconsin	3	M2
Virginia Commonwealth University	Virginia	3	R1
Brown University	Rhode Island	4	R1
Carthage College	Wisconsin	4	Bac/A&S
College of St. Scholastica	Minnesota	4	M1
Del Mar College	Texas	4	Assoc/MT/C&H-TT[5]
Georgia Gwinnett College[3]	Georgia	4	Bac/Diverse
Gettysburg College[2]	Pennsylvania	4	Bac/A&S
Hampden-Sydney College	Virginia	4	Bac/A&S
Illinois Wesleyan University	Illinois	4	Bac/A&S
Johns Hopkins University	Maryland	4	R1
Miami University	Ohio	4	R2
Montclair State University	New Jersey	4	R3
Morehouse College	Georgia	4	Bac/A&S
Ouachita Baptist University	Arkansas	4	Bac/A&S
Providence College[3]	Rhode Island	4	M1
Smith College	Massachusetts	4	Bac/A&S
Southern Connecticut State University	Connecticut	4	M1
Southern Maine Community College	Maine	4	Assoc/MT/C&H-TT[5]
The Ohio State University	Ohio	4	R1
Trinity College[2]	Connecticut	4	Bac/A&S
University of Florida[3]	Florida	4	R1
University of Maine, Fort Kent	Maine	4	Bac/Diverse

University of Maine, Honors College	Maine	4	R2
University of Maine, Machias	Maine	4	Bac/A&S
Washington State University	Washington	4	R1
Xavier University of Louisiana	Louisiana	4	M3
Chadron State College[2]	Nebraska	5	M2
College of Idaho	Idaho	5	Bac/A&S
Howard University	District of Columbia	5	R2
Montana Tech of the University of Montana	Montana	5	Bac/Diverse
Nyack College	New York	5	M1
Seton Hill University	Pennsylvania	5	M2
University of Pittsburgh	Pennsylvania	5	R1
Doane University	Nebraska	6	Bac/A&S
Florida Gulf Coast University	Florida	6	M1
La Salle University	Pennsylvania	6	M1
Merrimack College	Massachusetts	6	M2
Nebraska Wesleyan University	Nebraska	6	M2
The Evergreen State College	Washington	6	M2
University of Houston-Downtown	Texas	6	M3
Wilkes University[2]	Pennsylvania	6	M1
Florida International University	Florida	7	R1
Indian River State College	Florida	7	Assoc/MB/A
Lincoln University	Pennsylvania	7	M2
North Carolina A&T State University	North Carolina	7	R2
Old Dominion University	Virginia	7	R2
St. Edward's University[3]	Texas	7	M1
Truckee Meadows Community College	Nevada	7	Assoc/MT/C&T-MT/N[6]
University of Kansas	Kansas	7	R1
Albion College	Michigan	8	Bac/A&S
Drexel University	Pennsylvania	8	R2
Durham Technical Community College	North Carolina	8	Assoc/HT-MT/N
Kansas State University	Kansas	8	R1
Lafayette College	Pennsylvania	8	Bac/A&S
LeTourneau University	Texas	8	M2
Massey University (New Zealand)		8	Other
University of California, Los Angeles	California	8	R1
University of Detroit Mercy	Michigan	8	M1
University of Minnesota-Morris[3]	Minnesota	8	Bac/A&S
University of Southern Mississippi	Mississippi	8	R2
University of the Sciences in Philadelphia	Pennsylvania	8	Spec/Health
University of West Florida	Florida	8	R3
Virginia Tech	Virginia	8	R1
Western Carolina University	North Carolina	8	M1
Worcester Polytechnic Institute	Massachusetts	8	R2
Austin Community College	Texas	9	Assoc/MT/C&T-HN[7]
Collin College	Texas	9	Assoc/HT-MT/N[8]
Dominican College of Blauvelt	New York	9	M3
Fayetteville State University	North Carolina	9	M2
George Mason University	Virginia	9	R1
La Sierra University	California	9	M3
Marywood University	Pennsylvania	9	M1
Mount Saint Mary College	New York	9	M2
Northwestern College	Iowa	9	Bac/Diverse
Queens University of Charlotte	North Carolina	9	M2
Rockland Community College	New York	9	Assoc/HT-HT[4]
University of Evansville	Indiana	9	M3
University of Maine, Farmington	Maine	9	Bac/Diverse
University of Mary	North Dakota	9	M1
University of Nebraska-Lincoln	Nebraska	9	R1
University of North Georgia	Georgia	9	M2
University of West Alabama	Alabama	9	M1
Virginia Union University	Virginia	9	Bac/Diverse
Webster University	Missouri	9	M1
Winthrop University	South Carolina	9	M1

[1] Groups of institutions joining the SEA-PHAGES program; Cohort 1 started in Fall 2008. Carnegie classification of institutions. See http://carnegieclassifications.iu.edu/index.php

[2] Left SEA-PHAGES

[3] Not teaching the course in 2016-2017.

[4] Associate's Colleges: High Transfer-High Traditional

[5] Associate's Colleges: Mixed Transfer/Career & Technical-High Traditional

[6] Associate's Colleges: Mixed Transfer/Career & Technical-Mixed Traditional/Nontraditional

[7] Associate's Colleges: Mixed Transfer/Career & Technical-High Nontraditional

[8] Associate's Colleges: High Transfer-Mixed Traditional/Nontraditional

Table S2. PHIRE and SEA-PHAGES Publications (excluding Genome Announcements)

#	Citation	Program[1]	# Co-authors[2]		Total citations[3]
			Faculty	students	(ex. self-citations)
1	Pedulla et al. (2003). Origins of highly mosaic mycobacteriophage genomes. *Cell* **113**, 171-182. PMID: 12705866	**PHIRE**	0	5	509 (443)
2	Hatfull et al. (2006). Exploring the Mycobacteriophage Metaproteome: Phage Genomics as an Educational Platform. *PLoS Genetics*. **2**, e92. PMID: 16789831	**PHIRE**	0	5	198 (134)
3	Hanauer et al. (2006). Inquiry Learning. Teaching Scientific Inquiry. *Science* **314** (5807), 1880-1881. PMID: 17185586	**PHIRE**	0	0	121 (100)
4	Pham et al. (2007). Comparative genomic analysis of mycobacteriophage Tweety: Evolutionary insights and construction of compatible site-specific integration vectors for mycobacteria. *Microbiology* **153**, 2711-2723. PMID: 17660435	**PHIRE**	0	1	58 (33)
5	Morris et al. (2008). Genomic characterization of mycobacteriophage Giles: Evidence for phage acquisition of host DNA by illegitimate recombination. *J. Bacteriol*. **190**, 2172-2182. PMID: 18178732	**PHIRE**	0	1	50 (25)
6	Caruso et al. (2009). Non-STEM undergraduates become enthusiastic phage-hunters. *CBE Life Sciences Education*. **8**, 278-282. PMID: 19952096	SEA-PHAGES	2	0	31 (25)
7	Sampson et al. (2009). Mycobacteriophages BPs, Angel and Halo: comparative genomics reveals a novel class of ultra-small mobile genetic elements. *Microbiology* 155, 2962-2977. PMID: 19556295	**PHIRE**	0	2	47 (23)
8	Hatfull et al. (2010). Comparative genomic analysis of sixty mycobacteriophage genomes: Genome clustering, gene acquisition and gene size. *J. Mol. Biol*. **397**, 119-143. PMID: 20064525	**PHIRE**	0	15	156 (126)
9	Temple et al. (2010). Genomics and Bioinformatics in Undergraduate Curricula: Contexts for Hybrid Laboratory/Lecture Courses for Entering and Advanced Science Students. *Biochemistry and Molecular Biology Education* **38**, 23–28. PMID: 21567786	SEA-PHAGES	2	0	11 (9)
10	Pope et al. (2011). Expanding the diversity of mycobacteriophages: insights into genome architecture and evolution. *PLoS One* **6**: e16329. PMID: 21298013	**PHIRE** **SEA-PHAGES**	31	150	87 (32)
11	Pope et al. (2011). Cluster K Mycobacteriophages: Insights into the Evolutionary Origins of Mycobacteriophage TM4. *PLoS One* **6**:e26750. PMID: 22053209	**PHIRE** **SEA-PHAGES**	11	17	37 (21)
12	Cresawn et al. (2011). Phamerator: a bioinformatic tool for comparative bacteriophage genomics. *BMC Bioinformatics* **12:**395. PMID: 21991981	**PHIRE** **SEA-PHAGES**	1	2	87 (42)
13	Harrison et al. (2011). Classroom-based science research at the introductory level: changes in career choices and attitude. *CBE LSE* **10**, 279-286. PMID: 21885824	SEA-PHAGES	1	0	67 (57)
14	Mageeney et al. (2012). Mycobacteriophage Marvin: a new singleton phage with an unusual genome organization. *J. Virol*. **86**, 4762-4765. PMID: 22357284	**SEA-PHAGES**	2	3	20 (9)
15	Jacobs-Sera et al. (2012). On the nature of mycobacteriophage diversity and host preference. *Virology* **434**, 187-201. PMID: 23084079	**PHIRE** **SEA-PHAGES**	0	1	46 (21)

16	Dunbar et al. (2012). The Rewards and Challenges of Undergraduate Peer Mentoring in Course-Based Research: Student Perspectives from a Liberal Arts Institution. *Perspectives on Undergraduate Research and Mentoring* **1.2**.	SEA-PHAGES	1	3	4 (4)
17	Smith et al. (2013). Phage cluster relationships identified through single gene analysis. *BMC Genomics* **14**:410. doi: 10.1186/1471-2164-14-410. PMID: 23777341	SEA-PHAGES	3	3	19 (13)
18	Lorenz et al. (2013). Genomic characterization of six novel *Bacillus pumilus* bacteriophages. *Virology* **444**, 374-383. PMID: 23906709	SEA-PHAGES	3	5	20 (14)
19	Pope et al. (2013). Cluster J mycobacteriophages: intron splicing in capsid and tail genes. *PLoS One* **8**:e69273. PMID: 23874930	**PHIRE** **SEA-PHAGES**	5	3	13 (7)
20	Gissendanner et al. (2014). A web-based restriction endonuclease tool for mycobacteriophage cluster prediction. *J. Basic Micro*. **54**, 1140-5. PMID: 24740689	SEA-PHAGES	4	0	1 (1)
21	Grose et al. (2014). The genomes, proteomes, and structures of three novel phages that infect the *Bacillus cereus* group and carry putative virulence factors. *J. Virology* **88**, 11846-11860. PMID: 25100842	SEA-PHAGES	3	2	14 (9)
22	Grose et al. (2014). Genomic comparison of 93 *Bacillus* phages reveals 12 clusters, 14 singletons and remarkable diversity. *BMC Genomics* **15**, 1184 doi 10.1186/1471-2164-15-1184. PMID: 25280881	SEA-PHAGES	3	0	8 (7)
23	Merrill et al. (2014). Characterization of *Paenibacillus larvae* bacteriophages and their genomic relationships to firmicute bacteriophages. *BMC Genomics*. **15**, 1471-2164-15-745. PMID: 25174730	SEA-PHAGES	3	1	14 (9)
24	Jordan et al. (2014). A broadly implementable research course for first-year undergraduate students. *mBio* **5**:e01051-01013. PMID:24496795	**SEA-PHAGES**	32	0	64 (29)
25	Pope et al. (2014). Cluster M mycobacteriophages Bongo, PegLeg, and Rey with unusually large repertoires of tRNA isotypes. *J. Virol*. **88**, 2461-2480. PMID:24335314	**SEA-PHAGES**	22	10	17 (11)
26	Cresawn et al. (2015). Comparative Genomics of Cluster O Mycobacteriophages. *PLoS One* **10**:e0118725. PMID: 25742016	**SEA-PHAGES**	33	14	6 (3)
27	Pope et al. (2015). Whole genome comparison of a large collection of mycobacteriophages reveals a continuum of phage genetic diversity. *Elife* 4:e06416. doi: 10.7554/eLife.06416. PMID: 25919952	**SEA-PHAGES**	199	2644	46 (20)
28	Hanauer et al. (2015). Measuring Networking as an Outcome Variable in Undergraduate Research Experiences. *CBE Life Sciences Education*. **14**:ar38; doi:10.1187/cbe.15-03-0061. PMID: 26538387	**SEA-PHAGES**	0	0	5 (2)
29	Halleran et al. (2015). Transcriptomic Characterization of an Infection of *Mycobacterium smegmatis* by the Cluster A4 Mycobacteriophage Kampy. *PLoS One*. Oct 29;**10**:e0141100. PMID: 26513661	SEA-PHAGES	1	2	1 (1)
30	Siranosian et al. (2015). Tetranucleotide usage highlights genomic heterogeneity among mycobacteriophages. Version 2. *F1000Res.* 2015 Feb **4** [revised 2015 Oct 30];4:36. PMID: 27134721	SEA-PHAGES	1	1	0
31	Cross et al. (2015). An optimized enrichment technique for the isolation of Arthrobacter bacteriophage species from soil sample isolates. *J Vis Exp*, Apr. **9**; doi:10.3791/52781. PMID: 25938576	SEA-PHAGES	1	9	2 (0)
32	Berg et al. (2016). Characterization of Five Novel *Brevibacillus* Bacteriophages and Genomic Comparison of *Brevibacillus* Phages. *PLoS*	SEA-PHAGES	3	10	0

	One. 2016 Jun 15;**11**. PMID: 27304881				
33	Dedrick et al. (2016). Function, expression, specificity, diversity, and incompatibility of actinobacteriophages parABS systems. *Mol. Microbiol*. **101**, 625-644. doi: 10.1111/mmi.13414. PMID: 27146086	**PHIRE**	0	3	0
34	Bradshaw et al. (2016). Rapid Verification of Terminators Using the pGR-Blue Plasmid and Golden Gate Assembly. *J. Vis. Exp*. **110** doi: 10.3791/54064. PMID: 27167700	SEA-PHAGES	1	2	0
35	Sauder et al. (2016). Genomic characterization and comparison of seven Myoviridae bacteriophage infecting *Bacillus thuringiensis. Virology **489**, 243-251. PMID: 26773385*	SEA-PHAGES	8	5	4 (3)
36	Staub et al. (2016). Scaling Up: Adapting a Phage-Hunting Course to Increase Participation of First-Year Students in Research. *CBE Life Sci. Educ*. 2016 Summer;**15**. PMID: 27146160	SEA-PHAGES	4	0	2 (0)
37	Delesalle et al. (2016). Testing hypotheses for the presence of tRNA genes in mycobacteriophage genomes. *Bacteriophage* **6**, e1219441. PMID: 27738556	SEA-PHAGES	2	2	0
38	Kelley et al. (2016). Mycobacteriophages as Incubators for Intein Dissemination and Evolution. *MBio* **7**, doi:10.1128/mBio.01537-16. PMID: 2770073	SEA-PHAGES[5]	0	0	0
39	Hanauer et al. (2016). A Measure of College Student Persistence in the Sciences (PITS). *CBE Life Sci. Educ.* Winter 2016; **15**, pii; ar54. PMID: 27810869	**SEA-PHAGES**	1	0	0
40	Merrill et al. (2016). Software-based analysis of bacteriophage genomes, physical ends, and packaging strategies. *BMC Genomics* **17**:679, doi:10.1186/s12864-016-3018-2. PMID: 27561606	SEA-PHAGES	2	2	3 (0)
41	Russell & Hatfull (2016). PhagesDB: The actinobacteriophage database. *Bioinformatics* **1-3** doi: 10.1093/bioinformatics/btw711.	**SEA-PHAGES**	0	0	0
42	Dedrick et al. (2017). Prophage-mediated defense against viral attack and viral counter defense. *Nature Microbiol*. **2** DOI: 10.1038/ nmicrobiol. 2016.251. PMID: 28067906	**PHIRE** **SEA-PHAGES**	33	2	0
		TOTAL # pubs	42		
		TOTAL (SEA-PHAGES)	418	2891	**629 (349)**
		TOTAL (All)	420	2923	1768 (1233)

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[1] PHIRE: Phage Hunters Integrating Research and Education Program; SEA-PHAGES: Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science program. Papers on which Hatfull is senior or corresponding author are shown in bold type.

[2] Faculty co-authors are instructors at participating SEA-PHAGES institutions; Student co-authors are high school or undergraduate students in the PHIRE or SEA-PHAGES programs.

[3] As of February, 2017

Table S2 (cont'd) PHIRE and SEA-PHAGES *Genome Announcement* publications

#	Citation	Program[1]	# Co-authors[2] Faculty	students	Total citations[3] (excl. self-citations)
1	Hatfull et al. (2012). The complete genome sequences of 138 mycobacteriophages. *J. Virol.* **86**, 2382-2384. PMID: 22282335	**PHIRE** **SEA-PHAGES**	0	0[4,5]	48 (34)
2	Hatfull et al. (2013). The complete genome sequences of 63 mycobacteriophages. *Genome Announc.* **1**(6). pii: e00847-13. doi: 10.1128/genomeA.00847-13. PMID: 24285655	**PHIRE** **SEA-PHAGES**	0	0[4,5]	11 (7)
3	Breakwell et al. (2013). Genome sequences of five B1 subcluster mycobacteriophages. *Genome Announc*. **1**(6). pii: e00968-13. doi: 10.1128/genomeA.00968-13. PMID: 24285667	SEA-PHAGES	3	10	0
4	Grose JH, Jensen JD, Merrill BD, Fisher JN, Burnett SH, Breakwell DP. (2014). Genome Sequences of Three Novel *Bacillus cereus* Bacteriophages. *Genome Announc*. **2**(1). pii: e01118-13. doi: 10.1128/genomeA.01118-13. PMID: 24459255	SEA-PHAGES	3	3	10 (5)
5	Merrill et al. (2015). Genome Sequences of Five Additional *Brevibacillus laterosporus* Bacteriophages. *Genome Announc*. **3**(5). pii: e01146-15. doi: 10.1128/genomeA.01146-15. PMID: 26494658	SEA-PHAGES	3	4	0
6	Pope et al. (2015). Genome Sequences of mycobacteriophages AlanGrant, Baee, Corofin, OrangeOswald and Vincenzo: New members of Cluster B. *Genome Announc*. **3**. pii: e00586-15. doi: 0.1128/genomeA. 00586-15. PMID: 26089409	**SEA-PHAGES**	3	35	0
7	Pope et al. (2015). Genome sequences of Cluster G Mycobacteriophages Cambiare, FlagStaff, and MOOREtheMARYer. *Genome Announc*. **3**. pii: e00595-15. doi: 10.1128/genomeA.00595-15. PMID: 26089410	**SEA-PHAGES**	3	26	1 (1)
8	Pope et al. (2015). Genome sequence of Mycobacteriophage Mindy. *Genome Announc*. **3**. pii: e00596-15. doi: 10.1128/genomeA.00596-15. PMID: 26089411	**SEA-PHAGES**	3	8	0
9	Pope et al. (2015). Genome Sequence of a newly isolated mycobacteriophage, ShedlockHolmes. *Genome Announc*. **3**. pii: e00597-15. doi: 10.1128/genomeA.00597-15. PMID: 26089412	**SEA-PHAGES**	3	7	1 (1)
10	Pope et al. (2015). Genome sequence of mycobacteriophage Phayonce. *Genome Announc*. **3**. pii: e00598-15. doi: 10.1128/genomeA.00598-15. PMID: 26089413	**SEA-PHAGES**	3	8	0
11	Pope et al. (2015). Genome Sequences of Mycobacteriophages Luchador and Nerujay. *Genome Announc*. **3**. pii: e00599-15. doi: 10.1128/ genomeA. 00599-15. PMID: 26089414	**SEA-PHAGES**	3	16	0
12	Pope et al. (2015). Genome Sequence of Mycobacteriophage Momo. *Genome Announc*. **3**. pii: e00601-15. doi: 10.1128/genomeA.00601-15. PMID: 26089415	**SEA-PHAGES**	3	14	0
13	Chudoff et al. (2016). Genome Sequence of Mycobacteriophage Cabrinians. *Genome Announc*. 2016 Feb 4;**4**(1). pii: e01562-15. PMID: 26847904	SEA-PHAGES	1	6	0
14	Carson et al. (2015). Genome Sequences of Six *Paenibacillus larvae* Siphoviridae Phages. Genome Announc. **3**(3). pii: e00101-15. doi: 10.1128/genomeA.00101-15. PMID: 26089405	SEA-PHAGES	2	16	4 (1)

15	Erill I and Caruso S. (2015). Genome Sequences of *Bacillus cereus* Group bacteriophage TsarBomba. Genome Announc. **3**(6). pii: e01458-15. doi: 10.1128/genomeA.01458-15. PMID: 26586903	SEA-PHAGES	2	124[6]	2 (1)
16	Erill I and Caruso S. (2015). Genome Sequences of Two *Bacillus cereus* Group Bacteriophages, Eyuki and AvesoBmore. Genome Announc. **3**(5). pii: e01199-15. doi: 10.1128/genomeA.01199-15	SEA-PHAGES	2	96[7]	0
17	Abraham, J, et al. (2016). *Paenibacillus larvae* Phage Tripp Genome Has 378-Base-Pair Terminal Repeats. Genome Announc. **4**(1). pii: e01498-15. doi: 10.1128/genomeA.01498-15.	SEA-PHAGES	2	19	
18	Foltz S, Johnson AA, 2013–2015 VCU Phage Hunters. 2016. Complete genome sequences of nine Bacillus cereus group phages. Genome Announc 4(4):e00473-16. doi:10.1128/genomeA.00473-16	SEA-PHAGES	1	65[8]	
19	Hatfull et al. (2016). The complete genome sequences of 61 mycobacteriophages. Genome Announc. **4**(4). pii: e00389-16. doi: 10.1128/ genomeA.00389-16. PMID: 27389257	**SEA-PHAGES**	0	0[4,5]	0
20	Pope et al. (2016). Genome sequences of *Gordonia terrae* phages Attis and Soil Assassin. *Genome Announc*. **4**(3). pii: e00591-16. doi: 10.1128/ genomeA.00591-16. PMID: 27365347	**SEA-PHAGES**	4	16	0
21	Pope et al. (2016). Genome sequence of *Gordonia* phage Lucky10. *Genome Announc.* **4**(3). pii: e00580-16. doi: 10.1128/genomeA.00580-16. PMID: 27365346	**SEA-PHAGES**	4	10	0
22	Pope et al. (2016). Genome sequences of *Gordonia* phages Hotorobo, Woes, and Monty. Genome Announc. **4**(4). pii: e00598-16. doi: 10.1128/ genomeA.00598-16. PMID: 27516500	**SEA-PHAGES**	4	8	0
23	Pope et al. (2016). Genome sequences of *Gordonia terrae* phages Benczkowski14 and Katyusha. *Genome Announc*. **4**(3). pii: e00578-16. doi: 10.1128/genomeA.00578-16. PMID: 27340062	**SEA-PHAGES**	4	15	0
24	Pope et al. (2016). Genome sequences of *Gordonia* phages BaxterFox, Kita, Nymphadora, and Yeezy. Genome Announc. **4**(4). pii: e00600-16. doi: 10.1128/genomeA.00600-16. PMID: 27516501	**SEA-PHAGES**	4	17	0
25	Pope et al. (2016). Genome sequence of *Gordonia* phage Yvonnetastic. Genome Announc. **4**(4). pii: e00594-16. doi: 10.1128/genomeA.00594-16. PMID: 27389265	**SEA-PHAGES**	4	12	0
26	Pope et al. (2016). Genome sequences of *Gordonia* phages UmaThurman, Obliviate, and Guacamole. *Genome Announc.* **4**(3). pii: e00595-16. doi: 10.1128/genomeA.00595-16. PMID: 27365348	**SEA-PHAGES**	4	18	0
27	Pope et al. (2016). Genome sequence of *Gordonia* phage BetterKatz. Genome Announc. **4**(4). pii: e00590-16. doi: 10.1128/genomeA.00590-16. PMID: 27516497	**SEA-PHAGES**	4	9	0
28	Pope et al. (2016). Genome sequence of *Gordonia* phage Emalyn. Genome Announc. **4**(4). pii: e00597-16. doi: 10.1128/genomeA.00597-16. PMID: 27516499	**SEA-PHAGES**	4	8	0
29	Montgomery et al. (2016). Genome sequences of *Gordonia* phages Bowser and Schwabeltier. Genome Announc. **4**(4). pii: e00596-16. doi: 10.1128/ genomeA.00596-16. PMID: 27516498	**SEA-PHAGES**	4	8	0
30	Pope et al. (2016). Genome sequences of *Gordonia terrae* phages Phinally and Vivi2. Genome Announc. **4**(4). pii: e00599-16. doi: 10.1128/	**SEA-PHAGES**	4	18	0

	genomeA.00599-16. PMID: 27540050				
31	Bollivar et al. (2016). Complete Genome Sequences of Five Bacteriophages That Infect *Rhodobacter capsulatus*. *Genome Announc*. 4(3). pii: e00051-16. doi: 10.1128/genomeA.00051-16. PMID: 27231352	SEA-PHAGES	3	0	1 (0)
32	Russell, D. A. and Hatfull, G. F. (2016). Complete Genome Sequence of Arthrobacter sp. ATCC 21022, a Hπost for Bacteriophage Discovery. Genome Announc**.** **4**(2). pii: e00168-16. doi: 10.1128/genomeA.00168-16. PMID: 27013048	SEA-PHAGES	1	0	0
33	Mills et al. (2016). Genome Sequences of Newly Isolated Mycobacteriophages Forming Cluster S. Genome Announc. **4**(5). pii: e00933-16. doi: 10.1128/genomeA.00933-16. PMID: 27688332	SEA-PHAGES	3	9	0
34	Russell et al. (2016). Complete Genome Sequence of Gordonia terrae 3612. Genome Announc. **4**(5). pii: e01058-16. doi: 10.1128/ genomeA.01058-16. PMID: 27688316	**SEA-PHAGES**	1	0	0
35	Chudoff et al. (2016). Genome Sequence of Mycobacteriophage Cabrinians. Genome Announc. **4**(1). pii: e01562-15. doi: 10.1128/ genomeA.01562-15. PMID: 26847904	SEA-PHAGES	1	19	0
36	Robinson et al. (2016). Genome Sequence of Mycobacteriophage ErnieJ. Genome Announc. **4**(6). pii: e00873-16. doi: 10.1128/genomeA.00873-16. PMID: 27881532	SEA-PHAGES	2	18	0
37	Jackson et al. (2016). Genome Sequence of Mycobacterium Phage Waterfoul. Genome Announc. **4**(6). pii: e01281-16. doi: 10.1128/ genomeA.01281-16. PMID: 27856585	SEA-PHAGES	3	7	0
38	Erill, I. and Caruso, S.M. (2016). Complete Genome Sequence of the Streptomyces phage Nanodon. Genome Announcements. **4** (5). pii: e01019-16. doi: 10.1128/genomeA.01019-16.	SEA-PHAGES	2	130[9]	0
39	Erill, I. and Caruso, S.M. (2016). Genome Sequence of *Bacillus cereus* Group Phage SalinJah. Genome Announcements. 4(5). pii: e00953-16. doi: 10.1128/genomeA.00953-16.	SEA-PHAGES	2	130[9]	0
40	Layton et al. (2016). Genome Sequences of Streptomyces phages Amela and Verse. Genome Announc. 2016 **4**(1). pii: e01589-15. doi: 10.1128/genomeA.01589-15.	SEA-PHAGES	2	13	0
41	Pope et al. (2017). Complete Genome Sequences of 38 Gordonia sp. Bacteriophages. Genome Announc. 5(1). pii: e01143-16. doi: 10.1128/ genomeA.01143-16. PMID: 28057748	**SEA-PHAGES**	1	0	0
42	Flounlacker et al., (2017). Complete Genome Sequences of Bacillus Phages DirtyBetty and Kida. Genome Announc. **5**(10). pii: e01385-16. doi: 10.1128/genomeA.01385-16.	SEA-PHAGES	1	3	0
		TOTAL Gen Ann pubs	42		
		TOTAL Gen Ann authorships	102	342	**78 (50)**
		TOTAL (authorships, all papers)	486	3241	1582 (1180)

	SEA-PHAGES only	**TOTAL (all papers)**		**707 (399)**

[1] PHIRE: Phage Hunters Integrating Research and Education Program; SEA-PHAGES: Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science program. Papers on which Hatfull is senior or corresponding author are shown in bold type.

[2] Faculty co-authors are instructors at participating SEA-PHAGES institutions; Student co-authors are high school or undergraduate students in the PHIRE or SEA-PHAGES programs.

[3] As of February, 2017

[4] PHIRE is listed as a consortium author.

[5] SEA-PHAGES is listed as a consortium author.

[6] SEA-PHAGES student co-authors are members of the 2013 UMBC Phage Hunters

[7] SEA-PHAGES student co-authors are members of the 2014 UMBC Phage Hunters

[7] SEA-PHAGES student co-authors are members of the 2014 UMBC Phage Hunters

[8] SEA-PHAGES student co-authors are members of the 2014 VCU Phage Hunters

[9] SEA-PHAGES student co-authors are members of the 2015 UMBC Phage Hunters

Table S3. Demographic Information and Pearson X^2 for Sample of Traditional Laboratory and SEA-PHAGES (n=2850)

Demographic Category	**SEA-PHAGES (n=1587)**	**Traditional Lab (n=1263)**	**Pearson X^2 (df)**	**Sig.**
Gender				
Male	493	349	3.93	.052
Female	943	790	(1)	
Missing	151	124		
Ethnicity				
URM	420	434	21.93	.0001
White/Asian	1022	713	(1)	
Missing	145	116		
GPA				
Below 2.5	20	75	86.79	.0001
2.6-3.0	244	282	(4)	
3.1-3.5	509	402		
3.6-4.0	645	379		
4.1 and Higher	8	8		
Missing	161	117		
Parent's Educational Level				
No college degree	272	276	21.98	.0001
Bachelor's degree	152	147	(4)	
Associate degree	476	342		
Master's degree	309	248		
Doctorate or Professional degree	231	133		
Missing	147	117		
Parent's Occupation				
Unskilled labor	67	54	21.58	.001
Skilled labor	216	242	(5)	
Clerical	38	42		
Service	145	118		
Managerial	276	214		
Professional	696	480		
Missing	149	124		
Institution Type				
Community College	84	31	179.11	.001
4-Year School	310	230	(3)	
Masters Institution	542	197		
Research University	651	805		

Table S4 Demographic Information and Pearson X^2 for Random Sample of Traditional Laboratory and SEA-PHAGES

Demographic Category	**Traditional Lab (n=1094)**	**SEA-PHAGES (n=335)**	**Pearson X^2 (df)**	**Sig.**
Gender				
Male	336	124	4.66	.03
Female	758	211	(1)	
Ethnicity				
URM	419	107	4.76	.03
White/Asian	681	232	(1)	
GPA				
Below 2.5	72	5	27.73	.0001
2.6-3.0	272	61	(4)	
3.1-3.5	392	115		
3.6-4.0	358	149		
4.1 and Higher	7	3		
Parent's Educational Level				
No college degree	270	72	8.62	.07
Bachelor's degree	146	33	(4)	
Master's degree	336	113		
Doctorate or Professional degree	222	67		
	126	54		
Parent's Occupation				
Unskilled labor	52	17	11.92	.04
Skilled labor	244	244	(5)	
Clerical	54	38		
Service	152	113		
Managerial	279	203		
Professional	596	453		

Table S5. Mean, standard deviations, t-test, average treatment effect on the treated (ATET propensity score matching & nearest neighbor) for traditional laboratory and SEA-PHAGES courses (n=1429)

Estimation Method		**Project Ownership Content**	**Project Ownership Emotion**	**Self-Efficacy**	**Science Identity**	**Scientific Community Values**	**Networking**
Traditional Lab		**3.4 (.02)**	**3.32 (.04)**	**3.99 (.07)**	**3.47 (.03)**	**4.76 (.03)**	**3.03 (.03)**
SEA-PHAGES.		**3.96 (.03)**	**3.82 (.03)**	**4.12 (.03)**	**3.90 (.04)**	**5.13 (.05)**	**3.74 (.05)**
T-test	*t*	11.9	9.33	3.27	8.39	6	12.35
	df	1452	1449	1443	1439	1437	1528
	Sig.	.0001	.0001	.001	.0001	.0001	.0001
ATET	*Coef.*	.53	.41	.05	.44	.38	.69
Propensity	*Std.Err*	.05	.07	.05	.06	.08	.07
Score	*z*	9.49	6.38	1.04	6.88	4.87	9.77
Matching	*Sig.*	.0001	.0001	.29	.0001	.0001	.0001
ATET	*Coef.*	.56	.51	.08	.41	.3	.73
Nearest	*Std.Err*	.05	.06	.05	.06	.06	.06
Neighbor	*z*	10.98	8.7	1.86	7.28	4.83	11.04
	Sig.	.0001	.0001	.06	.0001	.0001	.0001

Table S6. Demographic Information on the Sample for High Intent Students Course-Type Comparison

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	122	30.5
Female	276	69
Missing	2	.5
Ethnicity		
White/Asian	263	65.8
Underrepresented Minority	135	33.8
Missing	2	.5
GPA		
Below 2.5	11	2.8
2.6-3.0	66	16.5
3.1-3.5	137	34.3
3.6-4.0	175	43.8
4.1 and Higher	5	1.3
Missing	6	1.5
Parent's Educational Level		
No college degree	79	19.8
Associate degree	42	10.5
Bachelor's degree	129	32.3
Master's degree	93	23.3
Doctorate or Professional degree	55	13.8
Missing	2	.5
Parent's Occupation		
Unskilled labor	14	3.5
Skilled labor	67	16.8
Clerical	17	4.3
Service	35	8.8
Managerial	80	20
Professional	187	46.8

Table S7. Pearson correlations, means and standard deviations for PITS survey variables on High-Intent Sample (n=400)

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.78	.85
2. Project Ownership Emotion	.74**	1.					3.65	.97
3. Self-Efficacy	.38**	.38**	1.				4.29	.6
4. Science Identity	.48**	.48**	.5**	1.			4.05	.84
5. Scientific Community Values	.2**	.2**	.36**	.42**	1.		5.42	.68
6. Networking	.6**	.59**	.35**	.52**	.25**	1.	3.54	1.07

** p <.001

Table S8. Descriptive statistics for high-intent students in two educational program on the PITS survey variables (n=400)

Variable	**HIGH-INTENT STUDENTS**		
	Course Type	**Mean**	**Std.**
Project Ownership Content	*SEA-PHAGES*	4.15	.61
	Traditional Lab	3.41	.91
Project Ownership Emotion	*SEA-PHAGES*	4.02	.74
	Traditional Lab	3.27	1.02
Self-Efficacy	*SEA-PHAGES*	4.32	.59
	Traditional Lab	4.25	.61
Science Identity	*SEA-PHAGES*	4.23	.76
	Traditional Lab	3.87	.81
Scientific Community Values	*SEA-PHAGES*	5.54	.69
	Traditional Lab	5.3	.65
Networking	*SEA-PHAGES*	4.02	.79
	Traditional Lab	3.02	1.06

Table S9. Univariate results for High-Intent Students in 2 Program Types on 6 PITS Variables

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	1	90.37	.0001	.19	1
Project Ownership Emotion	1	69.85	.0001	.15	1
Self-Efficacy	1	1.08	.3	.003	.179
Science Identity	1	19.99	.0001	.048	.994
Scientific Community Values	1	12.31	.001	.03	.938
Networking	1	121.36	.0001	.23	1

Table S10. Demographic Information on the Sample for 1st Generation Students Course-Type Comparison (n=558)

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	179	32.1
Female	375	67.2
Missing	4	.7
Ethnicity		
White/Asian	300	53.8
Underrepresented Minority	258	46.2
GPA		
Below 2.5	32	5.7
2.6-3.0	161	28.9
3.1-3.5	208	37.3
3.6-4.0	152	27.2
4.1 and Higher	2	.4
Missing	3	.5
Parent's Educational Level		
No college degree	558	100
Associate degree	0	
Bachelor's degree	0	
Master's degree	0	
Doctorate or Professional degree	0	
Missing	0	
Parent's Occupation		
Unskilled labor	98	17.6
Skilled labor	192	34.4
Clerical	26	4.7
Service	82	14.7
Managerial	90	16.1
Professional	68	12.2

Table S11. Pearson correlations, means and standard deviations for PITS survey variables on 1st Generation Student Sample (n=558)

	1	2	3	4	5	6	Mean	SD
1. Project Ownership Content	1.						3.74	.78
2. Project Ownership Emotion	.66**	1.					3.73	.89
3. Self-Efficacy	.5**	.54**	1.				4.05	.73
4. Science Identity	.54**	.51**	.58**	1.			3.75	.93
5. Scientific Community Values	.34*	.29**	.5**	.59**	1.		4.91	1.07
6. Networking	.45*	.49**	.41**	.55**	.37**	1.	3.4	1.02

** p <.001

Table S12. Descriptive statistics for 1st generation students in two educational program on the PITS survey variables (n=558)

Variable	**1st Generation Students**		
	Course Type	**Mean**	**Std.**
Project Ownership Content	*SEA-PHAGES*	3.98	.74
	Traditional Lab	3.51	.75
Project Ownership Emotion	*SEA-PHAGES*	3.99	.81
	Traditional Lab	3.47	.9
Self-Efficacy	*SEA-PHAGES*	4.15	.71
	Traditional Lab	3.93	.74
Science Identity	*SEA-PHAGES*	4.03	.88
	Traditional Lab	3.48	.89
Scientific Community Values	*SEA-PHAGES*	5.16	1.01
	Traditional Lab	4.65	1.07
Networking	*SEA-PHAGES*	3.69	1.03
	Traditional Lab	3.11	.94

Table S13. Univariate results for High-Intent Students in 2 Program Types on 6 PITS Variables

	df	F	Sig.	Partial Eta Squared	Power
Project Ownership Content	1	52.56	.0001	.09	1
Project Ownership Emotion	1	49.58	.0001	.08	1
Self-Efficacy	1	12.42	.0001	.02	.94
Science Identity	1	51.69	.0001	.09	1
Scientific Community Values	1	32.47	.0001	.06	1
Networking	1	48.47	.0001	.08	1

Table S14. Demographic Information on the Sample for Female Students Course-Type Comparison (n=480)

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	0	0
Female	480	100
Ethnicity		
White/Asian	240	50
Underrepresented Minority	240	50
GPA		
Below 2.5	19	4
2.6-3.0	97	20.2
3.1-3.5	170	35.4
3.6-4.0	185	38.5
4.1 and Higher	2	.4
Missing	7	1.5
Parent's Educational Level		
No college degree	116	24.2
Associate degree	57	11.9
Bachelor's degree	123	25.6
Master's degree	114	23.8
Doctorate or Professional degree	68	14.2
Missing	2	.4
Parent's Occupation		
Unskilled labor	29	6
Skilled labor	81	16.9
Clerical	13	2.7
Service	49	10.2
Managerial	100	20.8
Professional	208	43.3

Table S15. Pearson correlations, means and standard deviations for PITS survey variables on Female Student Sample (n=480)

	1	2	3	4	5	6	Mean	SD
1. Project Ownership Content	1.						3.71	.78
2. Project Ownership Emotion	.73**	1.					3.59	.91
3. Self-Efficacy	.45**	.45**	1.				4.05	.59
4. Science Identity	.54**	.52**	.52**	1.			3.75	.79
5. Scientific Community Values	.36*	.31**	.39**	.63**	1.		4.88	.98
6. Networking	.57**	.56**	.34**	.56**	.42**	1.	3.47	.93

** p <.001

Table S16. Descriptive statistics for female students in two educational program on the PITS survey variables (n=480)

Variable	FEMALE STUDENTS		
	Course Type	Mean	Std.
Project Ownership Content	*SEA-PHAGES*	3.99	.56
	Traditional Lab	3.42	.86
Project Ownership Emotion	*SEA-PHAGES*	3.91	.7
	Traditional Lab	3.27	.99
Self-Efficacy	*SEA-PHAGES*	4.12	.55
	Traditional Lab	3.98	.64
Science Identity	*SEA-PHAGES*	3.96	.71
	Traditional Lab	3.53	.81
Scientific Community Values	*SEA-PHAGES*	5.14	.87
	Traditional Lab	4.63	1.02
Networking	*SEA-PHAGES*	3.87	.8
	Traditional Lab	3.08	.89

Table S17. Univariate results for female Students in 2 program types on 6 PITS variables

	df	F	Sig.	Partial Eta Squared	Power
Project Ownership Content	1	72.77	.0001	.13	1
Project Ownership Emotion	1	64.15	.0001	.12	1
Self-Efficacy	1	6.56	.01	.01	.72
Science Identity	1	35.54	.0001	.07	1
Scientific Community Values	1	33.75	.0001	.07	1
Networking	1	101.9	.0001	.18	1

Table S18. Demographic Information on the Sample for Under-represented Minority Students Course-Type Comparison (n=476)

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	236	49.6
Female	240	50.4
Ethnicity		
White/Asian	0	0
Underrepresented Minority	476	100
GPA		
Below 2.5	33	6.9
2.6-3.0	121	25.4
3.1-3.5	175	36.8
3.6-4.0	137	28.8
4.1 and Higher	2	.4
Missing	8	1.7
Parent's Educational Level		
No college degree	153	32.1
Associate degree	62	13
Bachelor's degree	116	24.4
Master's degree	84	17.6
Doctorate or Professional degree	60	12.6
Missing	1	.2
Parent's Occupation		
Unskilled labor	39	8.2
Skilled labor	87	18.3
Clerical	16	3.4
Service	50	10.5
Managerial	82	17.2
Professional	200	42
Missing	2	.4

Table S19. Pearson correlations, means and standard deviations for PITS survey variables on under-represented minority student sample (n=465)

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.72	.84
2. Project Ownership Emotion	.76**	1.					3.68	.91
3. Self-Efficacy	.53**	.52**	1.				4.03	.66
4. Science Identity	.57**	.57**	.63**	1.			3.79	.86
5. Scientific Community Values	.36**	.36**	.45**	.59**	1.		4.94	.99
6. Networking	.59**	.57**	.44**	.63**	.46**	1.	3.48	.98

** p <.001

Table S20. Descriptive statistics for under-represented minority students in two educational program on the PITS survey variables (n=465)

Variable	**FEMALE STUDENTS**		
	Course Type	**Mean**	**Std.**
Project Ownership Content	*SEA-PHAGES*	3.96	.67
	Traditional Lab	3.47	.92
Project Ownership Emotion	*SEA-PHAGES*	3.92	.79
	Traditional Lab	3.44	.96
Self-Efficacy	*SEA-PHAGES*	4.09	.62
	Traditional Lab	3.97	.69
Science Identity	*SEA-PHAGES*	3.97	.85
	Traditional Lab	3.63	.84
Scientific Community Values	*SEA-PHAGES*	5.13	.93
	Traditional Lab	4.75	1.01
Networking	*SEA-PHAGES*	3.81	.93
	Traditional Lab	3.17	.93

Table S21. Univariate results for under-represented minority students in 2 program types on 6 PITS variables

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	1	41.71	.0001	.08	1
Project Ownership Emotion	1	35.29	.0001	.07	1
Self-Efficacy	1	3.8	.052	.008	.49
Science Identity	1	19.36	.0001	.04	.99
Scientific Community Values	1	17.85	.0001	.04	.98
Networking	1	54.96	.0001	.11	1

Table S22. Demographic Information on the Sample for Under-represented Minority male Students Course-Type Comparison (n=236)

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	236	100
Female	0	0
Ethnicity		
White/Asian	0	0
Underrepresented Minority	236	100
GPA		
Below 2.5	18	7.6
2.6-3.0	64	27.1
3.1-3.5	88	37.3
3.6-4.0	61	25.8
4.1 and Higher	1	.4
Missing	4	1.7
Parent's Educational Level		
No college degree	74	31.4
Associate degree	30	12.7
Bachelor's degree	67	28.4
Master's degree	37	15.7
Doctorate or Professional degree	27	11.4
Missing	1	.4
Parent's Occupation		
Unskilled labor	18	7.6
Skilled labor	45	19.1
Clerical	8	3.4
Service	27	11.4
Managerial	37	15.7
Professional	99	41.9
Missing	2	.8

Table S23. Pearson correlations, means and standard deviations for PITS survey variables on under-represented minority male student sample (n=236)

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.67	.89
2. Project Ownership Emotion	.79**	1.					3.66	.95
3. Self-Efficacy	.63**	.59**	1.				4.03	.71
4. Science Identity	.65**	.65**	.69**	1.			3.74	.95
5. Scientific Community Values	.42**	.45**	.53**	.59**	1.		4.98	1.02
6. Networking	.65**	.64**	.55**	.72**	.54**	1.	3.47	1.08

** p <.001

Table S24. Descriptive statistics for under-represented minority male students in two educational program on the PITS survey variables (n=236)

Variable	**FEMALE STUDENTS**		
	Course Type	**Mean**	**Std.**
Project Ownership Content	*SEA-PHAGES*	3.94	.77
	Traditional Lab	3.4	.91
Project Ownership Emotion	*SEA-PHAGES*	3.91	.9
	Traditional Lab	3.42	.94
Self-Efficacy	*SEA-PHAGES*	4.15	.68
	Traditional Lab	3.92	.72
Science Identity	*SEA-PHAGES*	3.99	.93
	Traditional Lab	3.49	.92
Scientific Community Values	*SEA-PHAGES*	5.16	1
	Traditional Lab	4.82	1.03
Networking	*SEA-PHAGES*	3.83	1.03
	Traditional Lab	3.12	1.02

Table S25. Univariate results for under-represented minority male students in 2 program types on 6 PITS variables

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	1	22.24	.0001	.09	.99
Project Ownership Emotion	1	15.72	.0001	.07	.98
Self-Efficacy	1	5.79	.017	.03	.67
Science Identity	1	16.11	.0001	.07	.98
Scientific Community Values	1	6.43	.012	.03	.71
Networking	1	27.39	.0001	.11	.99

Table S26. Demographic Information on the Sample for Gender Comparison

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	400	50
Female	400	50
Ethnicity		
White/Asian	549	31.1
Underrepresented Minority	249	68.6
Prefer not to Answer	2	.3
GPA		
Below 2.5	9	1.1
2.6-3.0	142	17.8
3.1-3.5	281	35.1
3.6-4.0	355	44.4
4.1 and Higher	2	.3
Parent's Educational Level		
No college degree	149	18.6
Associate Degree	74	9.3
Bachelor's degree	264	33
Master's degree	171	21.4
Doctorate or Professional degree	139	17.4
Parent's Occupation		
Unskilled labor	35	4.4
Skilled labor	116	14.5
Clerical	21	2.6
Service	85	10.6
Managerial	149	18.6
Professional	390	48.8

Table S27. Pearson correlations, means and standard deviations for PITS survey variables

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.9	.68
2. Project Ownership Emotion	.66**	1.					3.77	.86
3. Self-Efficacy	.53**	.47**	1.				4.13	.67
4. Science Identity	.59**	.54**	.62**	1.			3.9	.85
5. Scientific Community Values	.41**	.34**	.52**	.56**	1.		5.1	1
6. Networking	.48**	.44**	.47**	.54**	.39**	1.	3.67	.99

** p <.001

Table S28. Descriptive Statistics by gender for the PITS survey variables

Variable	**SEA-PHAGES**	
	Male (n=400)	**Female (n=400)**
Project Ownership Content	3.85 (.69)	3.95(.68)
Project Ownership Emotion	3.72 (.86)	3.8 (.87)
Self-Efficacy	4.16 (.64)	4.1 (.69
Science Identity	3.86 (.88)	3.92 (.82)
Scientific Community Values	5.12 (.96)	5.1 (1)
Networking	3.57 (1)	3.77 (.92)

Table S29. Univariate results for Gender on 6 PITS Variables in SEA-PHAGES Program

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	1	2.17	.03	.006	.56
Project Ownership Emotion	1	1.5	.16	.003	.29
Self-Efficacy	1	.73	.2	.002	.25
Science Identity	1	.78	.3	.001	.18
Scientific Community Values	1	.13	.72	.0001	.07
Networking	1	7.66	.006	.01	.79

Table S30. Demographic Information on the Sample for Ethnicity Comparison

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	292	36.5
Female	504	63
Prefer not to Answer	3	.4
Ethnicity		
White/Asian	400	50
Underrepresented Minority	400	50
GPA		
Below 2.5	13	1.6
2.6-3.0	153	19.1
3.1-3.5	283	35.4
3.6-4.0	337	42.1
4.1 and Higher	2	.3
Parent's Educational Level		
No college degree	178	22.3
Associate Degree	80	10
Bachelor's degree	244	30.5
Master's degree	166	20.8
Doctorate or Professional degree	130	16.3
Prefer not to Answer	2	.3
Parent's Occupation		
Unskilled/Skilled labor	42	5.3
Skilled	124	15.5
Clerical	24	3
Service	77	9.6
Managerial	147	18.4
Professional	382	47.8
Prefer not to Answer	4	.5

Table S31. Pearson correlations, means and standard deviations for PITS survey variables

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.9	.7
2. Project Ownership Emotion	.63**	1.					3.82	.84
3. Self-Efficacy	.51**	.46**	1.				4.12	.66
4. Science Identity	.57**	.56**	.64**	1.			3.93	.83
5. Scientific Community Values	.38**	.35**	.48**	.57**	1.		5.1	.98
6. Networking	.45**	.44**	.46**	.53**	.36**	1.	3.7	1

** p <.001

Table S32. Descriptive Statistics by ethnicity for the PITS survey variables

Variable	**SEA-PHAGES**	
	URM (n=400)	**White/Asian (n=400)**
Project Ownership Content	3.96 (.71)	3.92(.69)
Project Ownership Emotion	3.88(.83)	3.75 (.85)
Self-Efficacy	4.1 (.64)	4.14 (.67)
Science Identity	3.93 (.87)	3.92 (.79)
Scientific Community Values	5.13 (.92)	5.1 (1.04)
Networking	3.69 (1.05)	3.7 (1)

Table S33. Univariate results for Ethnicity on 6 PITS Variables in SEA-PHAGES Program

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	1	.84	.36	.001	.15
Project Ownership Emotion	1	4.74	.03	.006	.59
Self-Efficacy	1	.46	.5	.001	.1
Science Identity	1	.003	.95	.0001	.05
Scientific Community Values	1	.098	.75	.0001	.06
Networking	1	.016	.9	.0001	.05

Table S34. Demographic Information on the Sample for Socio-Economic Status Comparison

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	136	34
Female	259	64.8
Prefer not to Answer	5	1.3
Ethnicity		
White/Asian	283	70.8
Underrepresented Minority	116	29
Prefer not to Answer	1	.3
GPA		
Below 2.5	3	.8
2.6-3.0	67	16.8
3.1-3.5	142	35..5
3.6-4.0	180	45
4.1 and Higher	2	.5
Parent's Educational Level		
No college degree	100	25
Associate Degree	21	5.3
Bachelor's degree	79	19.8
Master's degree	100	25
Doctorate or Professional degree	100	25
Parent's Occupation		
Unskilled/Skilled labor	88	22
Clerical	12	3
Service	38	9.5
Managerial	92	23
Professional	170	42.5

Table S35. Pearson correlations, means and standard deviations for PITS survey variables

	1	2	3	4	5	6	Mean	SD
1. Project Ownership Content	1.						3.94	.67
2. Project Ownership Emotion	.66**	1.					3.76	.84
3. Self-Efficacy	.53**	.44**	1.				4.12	.66
4. Science Identity	.58**	.48**	.61**	1.			3.93	.84
5. Scientific Community Values	.46**	.34**	.56**	.56**	1.		5.2	.98
6. Networking	.49**	.43**	.48**	.56**	.43**	1.	3.7	.9

** p <.001

Table S36. Descriptive Statistics by Socio-Economic Status for the PITS survey variables

Variable	**SEA-PHAGES**			
	No College and Unskilled and Skilled Labor (n=100)	**Associates or BA degree and Service or Managerial Occupation (n=100)**	**MA and Managerial or Professional Occupation (n=100)**	**Phd and Professional Occupation (n=100)**
Project Ownership Content	4.02 (.65)	3.99 (.59)	3.86 (.61)	3.88 (.81)
Project Ownership Emotion	4.02 (.73)	3.8 (.72)	3.62 (.85)	3.61 (.97)
Self-Efficacy	4.14 (.66)	4.08 (.49)	4.12 (.87)	4.1 (.87)
Science Identity	4.05 (.86)	3.88 (.84)	3.92 (.78)	3.84 (.89)
Scientific Community Values	5.16 (1.04)	5.16 (1.02)	5.2 (.77)	5.12 (1.05)
Networking	3.8 (.84)	3.68 (.79)	3.69 (.99)	3.8 (.99)

Table S37. Univariate results for Socio-Economic Status on 6 PITS Variables in SEA-PHAGES Program

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	3	1.44	.23	.01	.38
Project Ownership Emotion	3	5.22	.002	.038	.93
Self-Efficacy	3	.16	.92	.001	.08
Science Identity	3	1.12	.35	.008	.29
Scientific Community Values	3	.11	.95	.001	.07
Networking	3	.58	.63	.004	.17

Table S38. Demographic Information on the Sample for Gender Comparison

Demographic Category	Frequency	Percentage
Gender		
Male	215	35.8
Female	381	63.5
Prefer not to answer	4	.5
Ethnicity		
White/Asian	399	66.5
Underrepresented Minority	199	33.2
Prefer not to Answer	2	.3
GPA		
2.6-3.0	200	33.3
3.1-3.5	200	33.3
3.6-4.0	200	33.3
Parent's Educational Level		
No college degree	120	20
Associate Degree	63	10.5
Bachelor's degree	191	31.8
Master's degree	119	19.8
Doctorate or Professional degree	105	17.5
Parent's Occupation		
Unskilled labor	28	4.7
Skilled labor	97	16.2
Clerical	18	3
Service	58	9.7
Managerial	112	18.7
Professional	284	47.3

Table S39. Pearson correlations, means and standard deviations for PITS survey variables

	1	**2**	**3**	**4**	**5**	**6**	**Mean**	**SD**
1. Project Ownership Content	1.						3.9	.71
2. Project Ownership Emotion	.64**	1.					3.78	.84
3. Self-Efficacy	.49**	.47**	1.				4.11	.65
4. Science Identity	.57**	.57**	.63**	1.			3.89	.84
5. Scientific Community Values	.38**	.35**	.51**	.61**	1.		5.08	1.03
6. Networking	.46**	.45**	.49**	.56**	.39**	1.	3.66	1.04

** p <.001

Table S40. Descriptive Statistics by GPA for the PITS survey variables

Variable	**SEA-PHAGES**		
	2.5-3 (n=200)	**3.1-3.5 (n=200)**	**3.6-4 (n=200)**
Project Ownership Content	3.87 (.73)	3.85 (.77)	3.99 (.62)
Project Ownership Emotion	3.8 (.79)	3.71 (.92)	3.83 (.81)
Self-Efficacy	4.05 (.64)	4.14 (.69)	4.16 (.64)
Science Identity	3.73 (.9)	3.89 (.86)	4.03 (.72)
Scientific Community Values	4.89 (1.05)	5.09 (1.02)	5.25 (1)
Networking	3.57 (1.09)	3.58 (1.03)	3.81 (.98)

Table S41. Univariate results for GPA on 6 PITS Variables in Gender x Ethnicity Comparison

	df	**F**	**Sig.**	**Partial Eta Squared**	**Power**
Project Ownership Content	2	2.64	.07	.009	.52
Project Ownership Emotion	2	1.06	.35	.004	.24
Self-Efficacy	2	1.85	.16	.006	.39
Science Identity	2	6.43	.002	.02	.9
Scientific Community Values	2	6.21	.002	.02	.89
Networking	2	3.46	.03	.01	.65

Table S42. Demographic Information on the Sample for Institution Type Comparison

Demographic Category	**Frequency**	**Percentage**
Gender		
Male	109	28.1
Female	236	60.8
Prefer not to answer	43	11.1
Ethnicity		
White/Asian	224	57.7
Underrepresented Minority	123	31.7
Prefer not to Answer	41	10.6
GPA		
Below 2.5	6	1.5
2.6-3.0	66	17
3.1-3.5	124	32
3.6-4.0	148	38.1
Prefer not to answer	44	11.3
Parent's Educational Level		
No college degree	65	16.8
Associate Degree	42	10.8
Bachelor's degree	121	31.2
Master's degree	69	17.8
Doctorate or Professional degree	50	12.9
Prefer not to answer	41	10.6
Parent's Occupation		
Unskilled labor	15	3.9
Skilled labor	62	16
Clerical	9	2.3
Service	41	10.6
Managerial	159	15.7
Professional	347	41
Prefer not to answer	41	10.6

Table S43. Pearson correlations, means and standard deviations for PITS survey variables

	1	2	3	4	5	6	Mean	SD
1. Project Ownership Content	1.						3.9	.69
2. Project Ownership Emotion	.62**	1.					3.81	.82
3. Self-Efficacy	.48**	.53**	1.				4.17	.65
4. Science Identity	.59**	.59**	.64**	1.			3.92	.81
5. Scientific Community Values	.27**	.3**	.42**	.61**	1.		5.19	.88
6. Networking	.52**	.48**	.54**	.58**	.37**	1.	3.73	.92

** p <.001

Table S44. Descriptive Statistics by Institution Type for the PITS survey variables

Variable	SEA-PHAGES			
	Community College (n=88)	4-Year School (n=100)	Master's Institution (n=100)	Research University (n=100)
Project Ownership Content	4.05 (.8)	3.96 (.6)	3.82 (.67)	4.02 (.65)
Project Ownership Emotion	4.07 (.85)	3.77 (.85)	3.67 (.72)	3.74 (.78)
Self-Efficacy	4.22 (.69)	4.12 (.69)	4.1 (.62)	4.25 (.56)
Science Identity	3.95 (.85)	3.93 (.75)	3.74 (.78)	4.06 (.83)
Scientific Community Values	5.1 (1)	5.16 (.91)	5.04 (.84)	5.42 (.69)
Networking	3.72 (1)	3.82 (.92)	3.62 (.77)	3.74 (.92)

Table S45. Univariate results for Institution Type on 6 PITS Variables the SEA-PHAGES Program

	df	F	Sig.	Partial Eta Squared	Power
Project Ownership Content	3	1.78	.15	.016	.46
Project Ownership Emotion	3	3.84	.01	.033	.82
Self-Efficacy	3	.99	.394	.009	.27
Science Identity	3	2.34	.07	.02	.59
Scientific Community Values	3	3.22	.02	.028	.74
Networking	3	.98	.4	.009	.27

Table S46. Demographic characteristics for persistence analysis

	Traditional	**SEA-PHAGES**
	N=3975	N=220
	M (SD) or %	M (SD) or %
Female	61%	62%
White or Asian	86.80%	88.18%
Enrolled by age 20	95.16%	99.5%
US citizen	95%	0.95
Parent Education: college	85.58%	89.08%
Adjusted Gross Income	135,813 (145,906)	139,022 (88,992)
High minority High School	27%	21%
SAT total	1924.9 (186.9)	1984.5 (169.6)

Table S47. Results of weighted regressions predicting persistence in science

	Taking any science class						**Number of science classes**				
	Not matched			CEM			Not matched			CEM	
	Odds ratio	S.E.		Odds ratio	S.E.		Coeff.	S.E.		Coeff.	S.E.
1 semester later (N=2,053)											
SEA-PHAGES	3.03**	1.17		1.87	0.74		0.48***	0.08		0.29***	0.08
Intercept	10.06***	0.56		15.40***	0.50		2.42***	0.02		2.63***	0.03
2 semesters later (N=1,957)											
SEA-PHAGES	4.08***	1.28		2.80***	0.93		0.59***	0.10		0.32***	0.10
Intercept	4.32***	0.18		6.66***	0.47		1.93***	0.02		2.23***	0.03
3 semesters later (N=1,923)											
SEA-PHAGES	2.75***	0.62		1.96**	0.47		0.70***	0.12		0.34**	0.13
Intercept	2.76***	0.10		4.15***	0.25		1.96***	0.03		2.36***	0.04
Note. ***p < .001 **p < .01											

REFERENCES & NOTES

1. S. M. Iacus, G. King, G. Porro, Multivariate matching methods that are monotonic imbalance bounding. *Journal of the American Statistical Association* **106**, 345-361 (2011).