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Bringing Research Into the Classroom: Bacteriophage Discovery Connecting University Scientists, Students, and Faculty to Rural K-12 Teachers, Students, and Administrators

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ABSTRACT: Bringing Research into the Classroom (BRIC) engaged rural K-12 science teachers in sustained, mentored science research. BRIC's goal was to equip teachers with the knowledge, skills, and dispositions to provide high-quality biomedical research opportunities for K-12 students and teachers. Programmatic elements included authentic, place-based, microbiology outreach in K-12 classrooms, summer teacher research academies focused on content knowledge and research, and a capstone symposium. Over 9,000 Montana students collected and tested environmental samples to isolate new-to-science bacteriophages (viruses that infect bacteria). University scientists, faculty, and students mentored K-12 teachers and students during classroom outreach visits and teacher research academies. BRIC aimed to increase teacher and student bacteriophage content knowledge and research skills through meaningful, mentored research projects. BRIC researchers hypothesized greater program impacts from intensive teacher professional development combined with classroom outreach, compared to classroom outreach visits alone. Program evaluation compared two cohorts of teachers, which each received all programmatic elements through a four-year, staggered rollout. Teachers and students were assessed for gains in knowledge, skills, and science attitudes. A subset of our evaluation instruments and outcomes, program dissemination, lessons learned, and recommendations for replicating the BRIC model are discussed.

INTRODUCTION

Bringing Research into the Classroom (BRIC) was a 5-year National Institutes of Health Science Education Partnership Award (NIH SEPA) project (2014-2019). Programmatic elements included authentic, place-based, microbiology outreach in K-12 classrooms, summer teacher research academies focused on content knowledge and research, and a capstone symposium. BRIC scientists brought genuine scientific discovery research to classrooms and provided teachers with professional development that resulted in novel scientific discoveries with potential lifesaving biomedical applications. Over 9,000 Montana students collected and tested environmental samples to isolate new-to-science bacteriophages (viruses that infect bacteria). University scientists, faculty, and students mentored K-12 teachers and students during classroom outreach visits and teacher research academies. The BRIC project created and delivered meaningful, relevant teacher and student research programs that are feasible, expandable, and replicable.

Science Accessibility. COVID-19 highlighted the impact of science on our everyday lives, yet public mistrust was evidenced by low vaccination rates, online misinformation, and lack of adherence to public safety measures (Ojikutu et al., 2022; NCSES, 2023). Science is often perceived to be inaccessible, difficult, or irrelevant; however, it is critical for students to understand the benefits for individual and public health, comfort, and economic development from advancements in medicine, science, technology, and engineering. A scientist-to-citizen bridge can strengthen positive perceptions of science and was exemplified by Kizzmekia Corbett, a female scientist of color, who communicated the message of vaccines and science in churches. (Rodriguez-Espinosa, 2005; NCSES, 2023). Corbett, as well as popular scientific communicators Science Whiz Liz and Bill Nye the Science Guy, aim to uncloak the 'black box' and make science 'understandable' to citizens (Marnik, 2023; Nye, 2023).

Scientific role models are critical within communities and schools. Science role models in schools increase science relatability and influence early STEM career decisions for students, especially female students. In 2021, 65% of the STEM workforce was male, and 35% was female (NCSES, 2023). In contrast, 76.6% of K-12 teachers are female with only minor changes in demographics over the last 20 years (NASEM, 2020). Additionally, the current demographic composition of K-12 educators provides limited diverse role models for minority students. Intentional, meaningful inclusion of minority scientist role models in science classrooms is essential. Role models positively influence science attitudes, and students often find a community role model in science, including teachers, when neither parent is in a STEM career (Nair and Majetich, 1995).

Isolation from science can also be based on locale. Rural areas are rich in science-based learning opportunities and prime areas to increase STEM professional diversity by focusing on local knowledge and place-based inquiry. Interactions between scientists and rural teachers are confounded by hard-to-reach locations which may lack mailing addresses and internet connectivity; therefore, exposure to both outreach and to a variety of STEM professional opportunities is limited (Avery, 2013). The majority of Montana's geography is defined as rural, with 7.4 people per square mile (U.S. Census Bureau, 2022). Each of the school districts involved in the project meet the federal standard for rurality, with populations less than 50,000 in any area (U.S. Census Bureau, 2023). Some of the school districts served had community populations of less than 5,000 residents.

In addition, rural K-12 schools often have lower budgets for science equipment (National Research Council, 2006). Weiss et al. (2001) analyzed a national survey and reported rural science teachers have markedly less to spend on laboratory equipment, an average of $994, than urban ($2,957) or suburban ($2,905) science teachers. Often, hometown citizens who enter STEM professions leave these communities, termed a 'learning to leave' phenomenon, limiting science role models available to students in rural communities (Avery, 2013).

According to the 2023 report, Montana had 397 school districts, 823 public schools, and 150,126 students enrolled in public schools. Five (of the 14) school districts involved in the project were considered 'persistently low achieving and poor academic preparation' at the start of programming (MT OPI, 2023). Of BRIC target area school districts' students, 41% were children whose incomes are below the federal poverty threshold. In these districts, the high school dropout rate exceeds state and national averages. Only 33% of Montana adults have a bachelor's degree, and nearly 66% of the state's students are potential first-generation college students, (MT OPI, 2023). In total, the BRIC project partners served 28 teachers, 25 schools, 14 school districts, one private school, and 9,189 students. The BRIC project's scientists traveled over 30,000 miles by car, averaging more than 6,000 miles per school year during the five-year grant period to reach highly rural and isolated districts.

Thirty teachers were recruited for the BRIC project at the onset of the project and then randomly assigned to Cohort 1 or 2. Cohort 1 started immediately with classroom visits and professional development while Cohort 2 initially received classroom visits only. The demographics of the BRIC teachers were consistent with the demographics of Montana overall. In Cohort 1, there were nine women and six men who participated, with teaching experience ranging from 5 years to more than 20. There were nine high school teachers and six middle school teachers in this cohort. In Cohort 2, there were 11 women and four men. Twelve were high school teachers, and three were middle school teachers. Within Cohort 2, teaching experience ranged from two years to more than 20.

BRIC connected rural schools to authentic science experiences and mentors by providing long-term opportunities for teachers and students to experience the excitement of scientific discovery. Developing teachers into local, scientific role models connects STEM to rural places as both an accessible topic and as a potential career.

Science Pedagogy: A Generational Gap. When science is presented as a set body of facts, its relatability to one's life and its ability to find solutions to complex problems is lost (NASEM, 2021). Guided by national reform, professionals within and supporting the educational system have been working to transform science education to engage students in authentic, relevant opportunities utilizing the practices and tools of scientists and engineers as recommended by the National Research Council (National Research Council, 2012; NASEM, 2021). Teachers are instrumental in this transformation, yet their own K-12 science education as students often focused on a pedagogy of knowledge reproduction rather than knowledge construction. Teachers' science pedagogies are informed by their own K-12 science experiences, creating a gap between historical pedagogy and current best practices in science education (Hanuscin et al., 2016). A STEM-based society relies on K-12 schools to recruit students into STEM professions and to build fundamental science literacy for all students (NCSES, 2023), and teacher self-efficacy significantly impacts student motivations and achievements in science (Bal-Taştan et al., 2018). The BRIC project aimed to engage teachers in authentic science research projects utilizing the best practices of science education recommended by the K-12 Framework for Science Education and the newly developed Next Generation Science Standards to hone teachers' research skills and to increase their teaching self-efficacy.

BRIC's model of mentoring teachers through sustained, authentic STEM research immerses teachers in current STEM pedagogical recommendations, fosters teaching efficacy, and elevates teachers to scientific role models within the school. Authentic research experiences have been shown to positively affect student achievement, help students identify research skills, and close achievement gaps (Davis, 1999; Krim et al., 2019; Nagda et al., 1998; NASEM, 2017; Murdoch-Eaton et al., 2010; Sadler et al., 2010). We posit that when students can connect to high-efficacy teachers who have participated in their own authentic, science-based, research experiences, science becomes clear as a process based on investigations, rather than being perceived as changing, unreliable facts or recommendations. By conducting authentic research, students and teachers are able to engage in authentic science within their own communities.

BRIC Context: Authentic, Scientific Research. Complementary to their scientific richness and motivating biomedical potential, bacteriophages provide excellent teaching tools that allow teachers and young scientists to engage in significant and technically feasible research projects. These projects encompass basic microbiology, biochemistry, molecular biology, and bioinformatics analysis (Hendrix et al., 1999; Pedulla et al., 2003; Hatfull et al., 2006). Bacteriophages, or phages, are viruses that infect bacteria and are found everywhere that bacteria exist. Phages have long served as model systems in molecular biology, and their study has laid the foundation for our understanding of basic processes common to all life forms. The vast number of phages has only recently been appreciated, estimated at 10^{31} (Wommack et al., 2000). Phages have been demonstrated to play important roles in ecology (carbon turnover) and make wonderful models to study both viral evolution and biodiversity (Suttle, 2007). The fact that phages do not infect human cells makes their discovery and characterization ideal to train junior scientists in practicing science process skills.

Medical applications of the discovered phages were only theoretical at the start of the BRIC project but have since manifested into clinical successes. Published case studies described the use of phages to treat and cure antibiotic-resistant mycobacterial infections (Dedrick et al., 2019; Nick et al., 2022; Little et al., 2022). A recent study describes successful outcomes for 11 of 20 patients with drug-resistant mycobacterial infections treated by phage therapy (Dedrick et al., 2023). Changing the classroom delivery from "Maybe, someday, phages like the ones discovered in this classroom *could* be used to treat a patient," to "Phages, like the ones discovered in this classroom, *have* been used to treat patients and save lives" has provided inspiration for scientists, teachers, and students alike.

METHODS

Program Overview. Bringing Research Into the Classroom (BRIC) was a five-year program founded on seven years of collaborative efforts between the Montana Tech Phagedigging Program and the Clark Fork Watershed Education Program (CFWEP). Dr. Marisa Pedulla, Professor of biology at Montana Tech, served as the BRIC Principal Investigator, developed and delivered scientific content in both teacher professional development setting and in student classroom visits. CFWEP and BRIC Program Director Rayelynn Brandl recruited teachers and developed and delivered pedagogical content, BRIC provided intensive teacher professional development combined with in-class bacteriophage (phage) discovery and mentoring by faculty, CFWEP scientists, and undergraduate students. BRIC engaged rural K-12 science teachers in mentored, sustained, genuine microbiology science research. BRIC's overall project goal was to equip teachers with the knowledge, skills, and dispositions to provide highquality biomedical research opportunities for students.

Teachers were recruited through Montana's Office of Public Instruction (Appendix A). Each teacher received two years of professional development and four years of classroom visits. Teacher deliverables included completion of professional development courses and projects, completion of teacher surveys, management of student survey completion, and hosting BRIC scientists for three days each school year.

Professional development included two online graduate-level courses and two summer research academies.. Graduate courses had both biological and pedagogical course objectives aimed to increase teachers' ability to incorporate authentic research experiences for their students (Appendix B). Summer academies were intensive and targeted molecular and microbiological research approaches and techniques. For example, teachers sampled soil from the banks in undamaged, restored, and unrestored sections of a local waterway. These samples were taken to laboratories at Montana Tech, soaked in sterile buffer, and plated on non-selective media (Luria Broth Agar Plates), and incubated for bacterial colony growth. The genera and species of the colonies were identified via polymerase chain reaction (PCR) for 16S ribosomal RNA amplification, DNA sequencing, followed by bioinformatic analysis (BLAST at NCBI). The identified colonies were grown in liquid culture and frozen at -80º C for long-term storage. In another academy session,

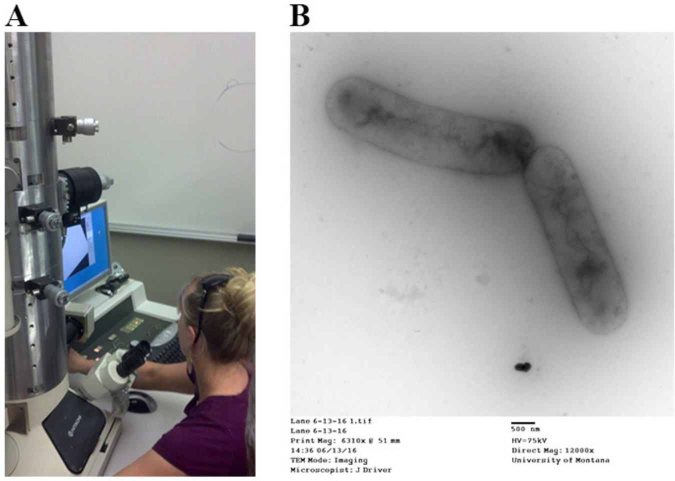

Figure 1. Teacher research project. A middle school teacher (A) is shown imaging bacteria (B) that she isolated in the 2015 summer teacher research academy. The teacher's manuscript describing this organism has been accepted for publication (Lane and Walter, In press).

teachers became versed in the protocols in which BRIC engaged their students. The basic procedures for bacteriophage isolation using the non-pathogenic *Mycobacterium smegmatis* as a host were covered in the academies. Teachers collected and tested soil samples for the presence of a bacteriophage capable of productively infecting *M. smegmatis* (form plaques on a lawn of cells). Teachers participated in transmission electron microscopy (TEM) as shown in Figure 1. See Appendix C for a sample academy agenda. As a professional development capstone, teachers designed and conducted an authentic, scientific research project, mentored by BRIC scientists and/or University faculty. Mentoring included guidance for research question development, review of research plans, and support for procedures including equipment, supplies, and lab facilities. Mentoring took place according to the schedules of mentor and mentee pairs with the addition of an intensive writing workshop group to assist teachers in completing their scientific research reports. This program description follows the timeline of BRIC activity from teacher recruitment to capstone presentations at the symposium (Appendix D).

Phagedigging as Science Education Pedagogy. BRIC's strategies were informed by published literature demonstrating the effectiveness of near-peer mentoring and long-term, experiential professional development and refined throughout the program (Ingersoll and Strong 2011; Marzano et al., 2001; NASEM, 2015; Tennenbaum, 2014; Zaniewski and Reinholz, 2016). Key programmatic elements included summer teacher research academies focused on content knowledge and research, a teacher capstone symposium, and authentic, place-based, microbiology outreach in classrooms. All participating teachers received financial compensation and continuing education or graduate credits for their participation in the program.

The BRIC model connected scientists, university students, and faculty to rural K-12 teachers, students, and administrators. Twenty-eight science teachers engaged in two cohorts over four years. Multiple levels of mentoring led to bi-directional learning. University scientists, faculty, and students served as mentors to teachers during classroom outreach visits and teacher research academies. BRIC scientists, undergraduate students, and teachers in turn mentored K-12 students. Near-peer mentoring was purposefully cultivated. Over four years, 9,189 students collected and tested environmental samples to isolate new-to-science bacteriophages. Dissemination included outreach to K-12 and University administrators, state and national conference presentations, press releases, publications, and professional video production. Publications included annotated phage genomes in GenBank, the National Library of Medicine's National Center for Biotechnology Information public DNA sequence repository.

The program partners elected to provide intensive in-person teacher summer academies which were one week in duration coupled with online graduate work during the school year. The online courses were designed to assist teachers with the completion of their individual research projects, from project design to final research reports and symposium presentations. As part of the course, teachers were given mentoring and support regarding their experimental question and design, coupled with scientific experts when needed, and provided with coaching for writing scientific papers. The blended learning design drew upon Picaano (2009), Owston et. al (2008), and Collison et. al (2000) and followed the recommendations for online engagement, relevance to classroom instruction, and application of new learning. In addition, the program partners utilized robust formative assessment during the project, gaining insights from the teachers as to the efficacy of both the online and in person elements of the project. The second cohort of teachers likely benefited from the changes recommended by their first cohort colleagues. The in-person summer academies were designed to deliver both background knowledge and skills for phage discovery and pedagogy development aligned to the newly adopted Next Generation Science Standards. The project partners utilized the constructs outlined by the National Research Council as a basis for the pedagogical instruction (NRC, 2012).

Phagedigging Program Origins and Phagedigging in Montana before the BRIC Project. The Montana Tech "Phagedigging" program has its roots at the University of Pittsburgh, where Dr. Pedulla coordinated Dr. Graham Hatfull's "Phage-hunting" program. Howard Hughes Medical Institute (HHMI) has adopted Dr. Hatfull's phage discovery project for its Science Education Alliance (SEA) program intended to revolutionize undergraduate introductory biology courses by providing genuine research and discovery to first year college students (Jordan et al., 2014; SEA-PHAGES, https://seaphages.org/). Montana Technological University (Montana Tech) joined this program and has hosted the HHMI SEA-PHAGES course since the fall of 2012.Dr. Pedulla piloted phagedigging in Montana classrooms prior to the BRIC project, completing visits for more than 3,000 students and 100 classroom visits between October 2005, and May 2012. These students discovered 60 new-to-science phages (viruses). Written post-assessments and thank you cards (Figure 2) were collected during five years of outreach visits from 481 middle school students who participated in classroom visits. The thank you notes were analyzed for their content. Analysis consisted of grouping student responses into general categories related to students' a) enjoyment of the phage discovery activity, b) disposition toward science and higher education, and c) interest in science as a career option. Student comments were consistently and strongly positive. One teacher who participated in phage discovery classroom outreach from 2006-2012 joined the BRIC project staff as teacher-liaison, and another long-term teacher phagedigging partner joined as one the 28 participating teachers in the BRIC program. A key educational element of the project is that Montana Tech undergraduates participated in the outreach and served as mentors and ambassadors. These undergraduate "Phagediggers" not only demonstrated their knowledge and enthusiasm for scientific endeavors, but they contributed to the demystification of science. In turn, the undergraduates gained experience teaching in a classroom setting and garnered many rewards including enhanced self-confidence while contributing meaningfully to their community. These preliminary outreach projects and preliminary results led to the development of the BRIC project.

Phagedigging Outreach: Bacteriophage Discovery and Characterization. Discrete project steps that begin with simple techniques and continue with increasing complexity and sophistication allow "ramping up" of young scientists. Success at the early steps builds confidence and enthusiasm among student researchers. Problem-based learning is stealthily embedded into the classroom visits. For example, there is a need to separate the viruses from larger biological and non-biological substances in the students' samples. Instead of merely instructing the students to filter their sample, BRIC program scientists and the undergraduate mentors present the problem and let the participating students generate possible solutions. These solutions are discussed and evaluated considering the tools and materials that are available. Subsequently, the method of using syringes and filters to separate the viruses from the sample is demonstrated. The students work in small teams of two or three and achieve success in filtering each sample. The programmatic features of the Phagedigging program ensure that the program is replicable and meaningful for students.

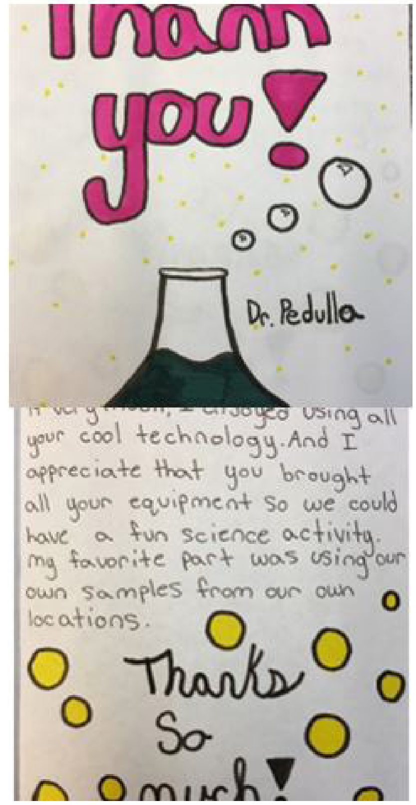

Figure 2. Thank you card. One example of a student thank you card after three-day BRIC scientist classroom phage discovery visits.

Programmatic Features of Phagedigging.

- Focuses on technically feasible and scientifically meaningful content.
- Provides student project ownership. Students choose a location where they collect their own sample and name the virus they discover.
- Provides peer and near-peer mentoring opportunities to many students.
- Phagedigging is (relatively) inexpensive and safe for classroom microbiology.

Phagedigging is a three-day classroom research experience, each tailored to the individual teacher's schedule, which ranged from 40-136 students, 42- to 55-minute class periods, and from 4-7 class periods per day. Phagedigging activities are adapted to match the partner school schedule with each day's activities taking place during one typical class period. The program prioritizes school instructional goals and schedules and is adaptable to how many periods, how long the periods last, and whether the program takes place over consecutive days. Day one, delivered by PI Dr. Pedulla, includes an overview of the project, including the importance of phage research, the diversity and abundance of phages on earth, and discussion of bacterial evolution and antibiotic resistance. During the second and third days, led by CFWEP staff scientists, students complete their investigations by 1) filtering, infecting, and plating their samples, 2) looking for phage plaques and replating picked plaques to test on a new lawn of bacteria, 3) exploring the Actinobacteriophage Database with a focus on student-found phages, and 4) providing potential phage names in case their plate was positive for phage. See Appendix E for Classroom Phage Discovery Protocols (adapted from The Actinobacteriophage Database, 2013).

The BRIC phage discovery classroom visits create an educationally rich mathematics component via discussion of the number of bacteriophages on the planet. Only by discussing the "powers of 10" can the magnitude of the phage population be addressed. This begins by asking what a "big" number is. "Give me a big number…a really big number…how much money makes a person wealthy? How many people are on planet Earth?" These are written in extended and exponential formats on the whiteboard followed by a review of the concepts of exponents. Next, the conversation moves onto larger numbers, such as the number of cells in a human body followed by the number of bacterial cells a human body carries as part of its biome. Then really big numbers, such as the numbers of bacteria and phages on Earth are explored. Finally, BRIC staff discuss the application of a million (10^6), a billion (10^9), and a trillion (10^{12}) in understanding not only biological populations, but national and global economics. Grasping fundamental, mathematical, exponential powers of ten transcends biology and provides students critical comparative thinking skills.

The BRIC partners offer scale-up activities and deeper research experiences for students during the summer. In the classroom, students are able to get test samples and isolate their phages. During summer experiences and within teachers' satellite labs during research classes and after-school activities, students are able to complete additional steps as outlined below.

Steps of Bacteriophage Discovery and Characterization by K-12 Students.

- Collect environmental samples (dirt, compost, etc.).*
- Isolate plaques on *Mycobacterium smegmatis*.*
- Amplify large quantities of phages.
- Characterize the phage life cycle as lytic or temperate.
- Perform electron microscopy.
- Purify phage genomic DNA.
- Use bioinformatic approaches to annotate the sequenced genome and compare to other phage genomes. Prepare and present posters and/or talks.

(*=classroom visits; thereafter at satellite or University labs)

Program Evaluation Methodologies. Program evaluation compared the two cohorts of teachers and their students. Teachers in both cohorts received all programmatic elements through a four-year, staggered rollout. Metrics were gains in knowledge, skills, and science attitudes. Evaluation instruments included surveys, interviews, focus groups, project-developed surveys and questionnaires, and document collection. BRIC evaluation methods were designed to a) provide formative feedback to project leaders for continuous improvement, b) assess implementation, and c) assess the project's overall success. The study deployed a quasi-experimental design for key portions of the evaluation to allow ethical comparison of the two intervention groups. Multiple methods of evaluations of both teachers and students demonstrated attainment of project aims. Results pertaining to teacher self-efficacy and student research extensions are described below as initial metrics of project success. Additional analyses of survey and document data will be published in separate manuscripts. External program evaluation was conducted by Education Northwest (Roccograndi, 2019).

BRIC's aims for teacher outcomes were to: 1) Increase teacher science content knowledge in bacteriophage discovery research; and 2) Increase teacher pedagogical skills and discipline-specific research practices through meaningful and engaging professional development, including mentored research projects. BRIC's aims for student outcomes were to: 1) Increase student content knowledge especially as related to phage discovery research; 2) Improve student awareness of health science careers, as well as attitudes, and dispositions toward the health science; and 3) Engage students in relevant, meaningful classroom research experiences.

RESULTS

Teacher Outcomes.

To what extent does the BRIC project improve 6–12th-grade science teachers' content knowledge? Preliminary findings from the 2019 BRIC annual evaluation report completed by Education Northwest outline the results of this question:

> *Teachers' knowledge of phage discovery increased during the years they participated in the BRIC intervention compared to when they received classroom-only visits. Especially by participating in the second Summer Academy, they learned about the taxonomy and characteristics of phages and the roles they can play in combatting antibiotic-resistant bacteria. Over time, they became more positive about the work of scientists and the importance of building public support for science by sharing scientific findings* (Roccograndi, 2019).

To what extent do participant teachers engage in authen-

tic health-science research? During the BRIC intervention, particularly the summer academies and online courses, teachers received resources to support them in conducting authentic health science research. As a result, they successfully completed research projects which in turn increased their confidence to design original science research studies, implement rigorous research in the classroom, and better support students engaged in research. During their time participating in BRIC, teachers developed their skills in sampling, recording, following and describing methods, and perfecting reference writing. Formative feedback was critical to this part of the program (Roccograndi, 2019).

In interviews, focus groups, and surveys conducted by Education Northwest, teachers reported that planning, implementing, and reporting on a science research project increased their confidence to implement rigorous research in the classroom and to mentor students engaged in research. After teachers completed their mentored research plans and final reports, program leaders recognized teachers needed additional support in clearly stating their research question, analyzing their data, and presenting results. Finally, additional support in sharing their findings via introductions, abstracts, and conclusions was critical to strengthen their science writing and communication skills (Roccograndi, 2019). To assist teachers in completing the research paper, a Saturday writing workshop day was added to the program, providing teachers the opportunity to have BRIC mentors and fellow teachers physically present in a supportive environment. A culminating task for teachers in the first fall online class was to complete a research plan for a study they would carry out in the coming year. During the time between the two classes, they engaged in an authentic research project. At the end of the second online class, as a capstone project, teachers completed a research report summarizing their projects' findings. To explore the extent to which teachers applied content knowledge from BRIC professional development sessions, evaluators assessed teachers' research plans and research reports. Using online course materials delivered to teachers, in consultation with the course instructors, a rubric was developed with key expected components of the plan (Appendix F) and report (Appendix G). For the research plan, participants were asked to incorporate five key elements of research design: research question, hypothesis, research methods, timeline, and references. A sixth construct was added to analyze the extent to which participants made explicit connections to the core content taught in the BRIC course (Roccograndi, 2019).

For evaluation of the research paper, the rubric developed for review of teachers' research plans was extended, with standards included for high quality science manuscripts (Hesselbach et al., 2012). The final research reports incorporated an abstract and introduction including a literature review; a research question and methods; project components such as sampling and data recording methods and analyses; results and findings; a discussion; references; and, again, connections to BRIC science content. BRIC researchers expected participants' research reports to be of the quality that could be submitted to a professional or peer-reviewed journal (Roccograndi, 2019).

Table 1. *Matched Mean Cohort 1 Teacher Research Confidence Responses Over Time.*

Assessment Item	March 2015	Fall 2015 (N=13) June 2016 (N=8) Fall 2017 (N=10) Spring 2018 (N=9)
I am confident in my ability to design original science research studies.	69%	54% (-15)
	63%	75% (+12)
	50%	80% (+30)
	44%	77% (+33)
I have carried out health science research including collecting and analyzing data and presenting findings.	54%	54% (+_0)
	63%	50% (-13)
	50%	80% (+30)
	56%	100% (+44)

Teachers' research reports displayed evidence of their engagement in, and learning of, health science research and phage discovery. All teachers' research reports included connections to BRIC-related content. One of the teachers' manuscripts was submitted and accepted for publication in a peer-reviewed journal. (Lane and Walter, In Press.)

Table 1 shows the survey results for Cohort 1 teachers, who markedly increased their confidence in designing research studies (Figure 3A) and self-identified that the work they carried out could be characterized as health science research (Figure 3B), including analyzing data and presenting findings (Roccograndi, 2019). Baseline teacher responses are from March 2015, prior to BRIC program teacher professional development activities. Subsequent scores in Years 1 and 2 represent post-summer academy survey results. Finally, Years 3 and 4 scores represent results at the close of school years without summer academies. Preliminary (March 2015) scores were reanalyzed using responses from only those teachers completing the subsequent surveys, thus the change in Table 1 values reported for March 2015 "baseline." Teacher scores were matched for each survey to ensure means were not affected by teacher attrition or missing data. The survey instrument, a six-item Likert scale, is included in Appendix H.

Teachers' reduced confidence occurred after their first summer academy but then increased with continued BRIC program interventions in academies, graduate courses, and classroom visits. The dissonance experienced after the first research academy is evident in Year 1 results for confidence in developing research studies (Figure 3A). Cohort 1 teachers' papers were completed before the survey results in Year 3, which corresponds with a marked increase in confidence.

Teachers expressed gains in their confidence to design

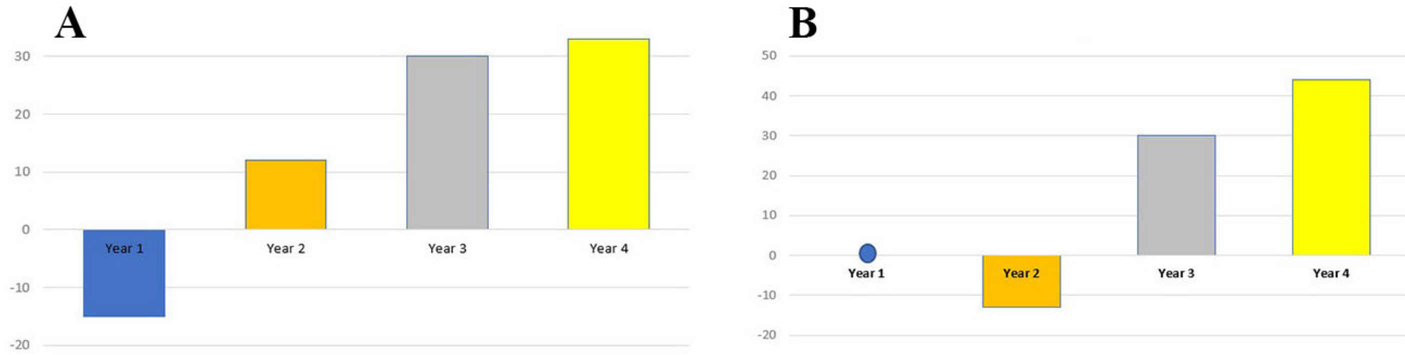

Figure 3. Change in Cohort 1 Teachers' Research Confidence. A) The % change in cohort 1 teacher responses agreeing or strongly agreeing to "I am confident in my ability to design original science research studies" is shown. B) The % change in cohort 1 teacher responses to "I have carried out health science research including collecting and analyzing data and presenting findings" is shown. The dark circle indicates no change (Roccograndi, 2019).

original science research studies and carrying out health science research. Teachers in both cohorts expressed increased agreement in their confidence to design original science research studies and, by their final year in the project, all agreed they had carried out health science research. Cohort 1 teachers witnessed consistent year-to-year increases in their confidence to design research. A quote from a participating teacher during structured interviews illustrated the impact of research, "I firmly believe that having teachers perform an actual scientific investigation is a great way for us to become excited and confident about performing investigations with our own students," (Roccograndi, 2019). Figure 3B illustrates the change in percentage of Cohort 1 teachers "agreeing" or "strongly agreeing" to "I have carried out health science research including collecting and analyzing data and presenting findings."

To what extent does participation in the BRIC project increase teachers' self-efficacy in using discipline-specific scientific inquiry with students? Over the course of the BRIC project, teachers increased the frequency with which they employed science and engineering practices as outlined by the National Research Council and Next Generation Science Standards as well as BRIC-related activities including high-quality health science research opportunities. Teachers included science investigations of varying length and focused on health science research in their classrooms. In addition to increasing their frequency of using these activities, they also gained teaching self-efficacy. In surveys, interviews, and focus groups conducted by Education Northwest, teachers reported larger gains during the years they participated in the BRIC intervention compared to when they received classroom-only visits. In the evaluation data, teachers reported their classroom application and confidence were bolstered by engaging in pedagogical practices in inquiry-based science. Using state-of-the-art lab techniques and equipment, such as the sterile technique and transmission electron microscopy, and engaging in hands-on research activities during the Summer Academy helped to build their knowledge and confidence. After finishing the complete intervention—two academies, two online courses, and completing a research plan and project—teachers reported the most gains in their science teaching self-efficacy (Roccograndi, 2019).

Figure 4 shows the change in participating teachers' science teaching self-efficacy over time for each year of the BRIC program (Appendix H). Scores were matched by individual teacher to ensure data were not skewed by teacher attrition and/or missing data. Interviews and quotes from teachers attribute gains, in part, to their completion of the individual research projects (Roccograndi, 2019). Table 2 outlines science teaching self-efficacy changes and effect sizes over time by cohort. In each cohort, the effect size grows with each year of BRIC participation. Scores after the first year of participation are medium to large in magnitude. In the last year of the program, the effect size for Cohort 2 is large (Roccograndi, 2019). The large effect size of Cohort 2 indicates the practical significance of BRIC professional development, and the growing effect sizes highlight the effectiveness of program responsiveness to formative evaluation.

BRIC Teacher Awards, Accomplishments, and Recognitions. Participating BRIC teachers were followed via follow up emails, phone calls, and surveys regarding their accomplishments, awards, and leadership appointments, beginning with project initiation in 2014 to spring 2023.

Table 2. *Science Teaching Self-Efficacy Effect Sizes.*

Cohort 1			Cohort 2		
	Change	Effect Size		Change	Effect Size
Fall 2015	0.1	0.1	Fall 2016	-0.1	0.1
Spring 2016	0.4	0.5	Fall 2017	-0.2	0.3
Fall 2017	0.4	0.5	Fall 2018	0.2	0.3
Spring 2019	0.5	0.6	Winter 2018	0.6	0.8

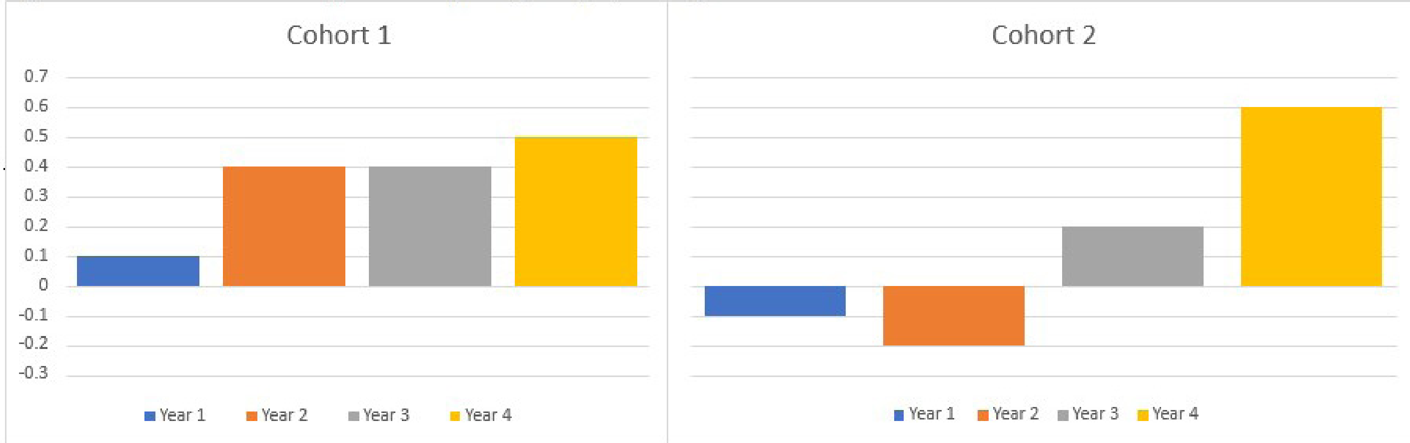

Figure 4. Matched Mean Science Teaching Self-Efficacy Subscale Scores by Cohort, Over Time. The figure shows Cohort 1 (left) and Cohort 2 teachers' matched mean science teachering self-efficacy rating by cohort before intervention "Baseline" and during the first one to three years of the program. Cohort 1 participated in summer academies and graduate courses in 2015 and 2016, while Cohort 2 had professional development in 2017 and 2018. For both cohorts these intervention years are shown as year 1 and two on the graph. Cohort 1 year three represents the 2017 year in which they received classroom visits only (Roccograndi, 2019).

Accolades and higher education degrees are noted. Several teachers who were involved in the initial BRIC project have continued on to the second NIH SEPA project offered by this team, PHAGES (Phages Helping Acquire Genuine Experiences in Science). The title of the program was invented by a BRIC teacher, illustrating ownership and buy-in for the second project. Accolades include 11 National awards, including one National Teacher of the Year finalist, two Presidential Awards for Excellence in Mathematics and Science Teaching, and four nominees for the 2023 PAEMST; 14 regional awards, including two Montana Teachers of the Year and a Teresa Veltkamp Advocacy Award for Excellence in Indian Education. Higher education degrees earned by this group of teachers include three PhDs and three Master of Science degrees. Along with a peer-reviewed manuscript, another BRIC teacher was a coauthor on a recent GenBank publication of a Mycobacteriophage genome that was discovered in her classroom, (Burgmeier et al., 2022). A BRIC-participating teacher attended the 2019 NIH SciEd Conference in Washington, D.C. and presented her journey in the BRIC project with a poster titled, "Turning the Phage: A Teacher's Unexpected Journey with Authentic Graduate Research." She credits her 2023 PhD in Curriculum and Instruction in STEM Education to participation in the BRIC project. The BRIC teacher-liaison presented a poster, "Classroom Phagedigging Fostered by University Collaboration and Teacher Mentors Increases Student STEM Interest and Confidence," at the 2022 NIH SciEd Conference.

In April of 2019, after the conclusion of the teacher professional development and classroom visits, 12 of BRIC's participating teachers and our teacher-liaison presented their projects and insights gained through the five-year project at a culminating symposium. This celebration was attended by Montana Tech administrators, including the Chancellor, as well as the Vice Chancellor of Research and Dean of the Graduate School, the President of the Montana Tech Foundation and Vice Chancellor for Advancement and University Relations and the Dean of the College of Letters, Sciences and Professional Studies. Administrators of the school districts with participating BRIC teachers and schools also attended the symposium, including one high school principal and another high school's vice principal. Administrators' support of teacher participation in the program was necessary, and their inclusion in this symposium that showcased their teachers' accomplishments was intentional. The symposium program, including a letter of appreciation and summaries of the teachers' presentations, is included within the supplemental materials (Appendix I).

Student Results: Selected Experiences and Activities.
In what ways do students engage in classroom research experiences?

New Satellite Labs for Research During the School Year. In the BRIC project, several teachers requested materials and support to provide on-going research opportunities for their students during the school year. These satellite classroom labs were extremely effective as the teachers were able to give students long-term research experiences. BRIC leaders assisted the teachers and their students with project development, supplying materials, and mentoring of the student projects, assisting with poster development and application and travel to present their findings. These projects were remarkably successful in statewide, regional, national, and international science symposia and science fair competitions.

Two Helena Capital High School BRIC students worked in a satellite lab at their high school and isolated, purified, amplified and characterized a mycobacteriophage (Figure 5).

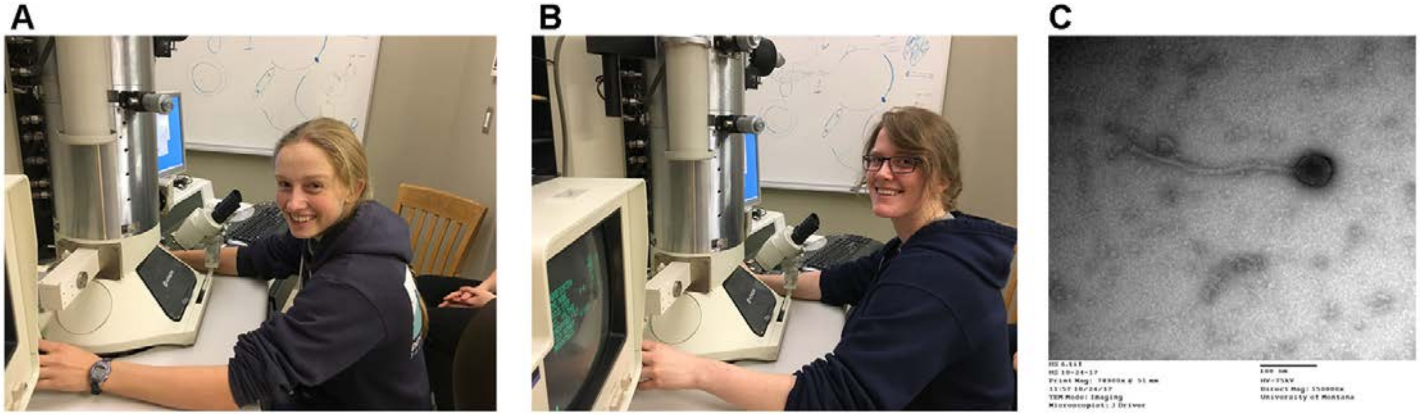

Figure 5. Students Experiencing Electron Microscopy. Images of the high school students (A and B) and the electron micrograph (C) of the phage they discovered, purified, and studied by transmission electron microscopy are shown.

The two students received Gold Medals at the Montana State Science Fair, a Biophysics Award, the Reuben Diettert University of Montana Division of Biological Sciences Award, Grand prize Awards for Best Team and Overall Projects, and named as finalists including a trip to compete at the Intel International Science and Engineering Fair in Pittsburgh, PA. Their cash prizes totaled over 600 dollars. Their annotation of the phage's genome has been published in GenBank, with the students as coauthors (Dreesbach et al., 2018).

In rural Baker, Montana, a BRIC teacher established a satellite lab and then developed and facilitated an independent science research class. She mentored students to compete at regional and state research competitions and qualify for the National Junior Science and Humanities Symposium and the Intel International Science and Engineering Fair, where one of her students won fourth prize.

SEPA-INBRE Summer Research Scholar Pipeline: Mentored Research on Montana INBRE Campuses. Based on BRIC's aim of increasing the numbers of Montana students entering STEM-based educational programs and careers, the team asked, "*How can SEPA and INBRE partner to foster a pipeline from high school to undergraduate researchers?*" The team met with the leadership from the National Institutes of Health Montana IDeA Networks of Biomedical Research Excellence (MT INBRE) and the resulting collaborative effort was piloted in the summer of 2018. For this pilot, a flier was prepared and distributed to BRIC teachers and students (see Appendix I), and an online application portal was developed and opened. The project received very enthusiastic responses from students who had participated in BRIC classroom visits and wanted to participate in paid summer research experiences. BRIC had applications from more students than could be supported through BRIC funds alone. Additional funds were leveraged from AmeriCorps, MT INBRE, and the Deans of Research and the College of Letters, Sciences, and Professional Studies at Montana Tech. Five students, including students traditionally underrepresented in STEM fields, were placed into paid intensive summer research experiences at Montana Tech and Montana State University (MSU). Students received training in Responsible Conduct of Research, safety, microbiology, molecular biology, bioinformatics, electron microscopy, opportunities for college and graduate studies in STEM fields, and poster presentations. The pipeline project was formalized in the 2019 PHAGES SEPA project, and 22 students have since participated (3 at MSU and 19 at Montana Tech) for in-depth, paid, summer research internships. One SEPA-INBRE pipeline student participant secured an internship at the NIH Rocky Mountain Laboratory in the summer of 2023. One of the 2019 pipeline students began her graduate studies in molecular and cellular biology in the fall of 2023.

DISCUSSION

The five-year BRIC project provides a model for expandable and meaningful teacher professional development and genuine research experiences in classrooms. Feedback from teachers was used to iteratively improve the experience of those teachers, as well as those in the subsequent teacher cohort and next SEPA project. A full-circle research experience for teachers included developing the research question and proposal, completing the research, and preparing a research report summarizing the project, results, and conclusions. Self-efficacy of the teachers to design, conduct, and mentor research increased through this process and supported a multi-tiered system of mentors and mentees. The full-circle research experience for teachers continued when they, in turn, mentored students in authentic science research projects. Scientist outreach to classrooms provided a scientist-to-classroom bridge for both students and teachers resulting in continued authentic, classroom-based science research.

Providing Opportunity to Talent. The BRIC project allowed teachers who had the confidence to apply for a rigorous professional development project to have opportunities to grow into research areas, develop deeper skills for scientific enterprise, and increase their confidence and efficacy for performing and mentoring science research. The BRIC project outcomes supported the hypothesis that, over classroom visits alone, talented educators who are provided with long-term support and authentic opportunities in science research, will rise to the challenge, gain self-confidence, identify as science researchers, and provide authentic STEM research opportunities for their students.

The 2018 SEPA-INBRE student pipeline pilot project grew into a formalized, multi-institution summer partnership in subsequent years. The pipeline students are immersed in a full-time research environment, and experience and become a part of the culture of university laboratory research. As of 2023, pipeline students remain engaged in biomedical education and research endeavors and are poised to contribute to the field.

Applicable Lessons Learned: A Win-Win. Critical to the project was providing the teachers with outstanding laboratory experiences, scientific mentoring, and peer team support. The participating teachers developed into a collaborative group of exceptional science educators who provided support, encouragement, and feedback for each other outside of the project-designed timeframes.

In the midst of the project, several teachers expressed frustration with the process of designing and completing independent research projects, including completing the written research report. Extensive support from the BRIC staff, including one-on-one mentoring and group writing support, helped nearly all of the teachers complete their projects. The Montana Tech graduate thesis template was utilized as a resource for mentoring teachers' writing (Montana Technological University, 2023). Teachers were met with individualized mentor experiences according to their project and mentor expertise in the topic. In retrospect, most teachers credited the research projects, including the aforementioned struggles, for their growth as science educators. Their ability to mentor student researchers through similar struggles also grew, as their personal experience informed the process.

Extensive logistical support was needed to schedule classroom visits and summer academies, arrange for transportation, lodging and accounting/paperwork to provide teacher financial remuneration and university or office of public instruction education credits. Additionally, last-minute schedule changes (usually a result of school testing or extracurricular activities) frequently interrupted the planned BRIC classroom visits, and nimble adjustments were required. The flexibility of the BRIC staff and willingness to adapt to unforeseen circumstances were paramount to the project's success.

For many microbiological investigations, core supplies and equipment are required. The BRIC project began to establish functional laboratories "satellite labs" for two teachers as a pilot program. The subsequent successes these teachers had in mentoring extra-curricular/honors student research projects led BRIC leaders to include the establishment of satellite labs for ALL schools participating in the 2019-2024 NIH SEPA PHAGES project. These teachers and schools now have a wide array of equipment and can support classroom or independent student research projects into the foreseeable future.

Throughout the course of the project, several of the initial 28 participating teachers left the BRIC program. Each departing teacher had individual reasons for withdrawing from the program, including health issues, retirement, changing teaching positions, being overwhelmed with their professional workload, and being laid off by the school district. Teacher time and effort were valued monetarily with financial payments and graduate credits to foster relationships of collegial respect. To address these issues in the current PHAGES project, monthly remote video check-in meetings were added during the academic year, and new teachers were paired with a teacher who had successfully completed the BRIC project to provide a local support system. A network of teachers who participated in the project was fostered by their many interactions over five years, including intensive summer research academies. The bonds formed during these interactions continue long after the BRIC programming ended. Six of the BRIC teachers joined the current PHAGES SEPA project, creating a longstanding network of support and collaboration. BRIC teachers still communicate regularly regarding best practices and, confident in their voice, come together for coordinated responses to state legislative proposals that impact the K-12 education community.

Utilizing teacher feedback throughout the course of the project, by open lines of communication and the deliberate inclusion of a "teacher-liaison" (a high school teacher who had many years of collaboration with Dr. Pedulla and Montana Tech) greatly aided project success. Treating the teachers as respected colleagues, providing the technical and mentoring support they needed, along with a cadre of peer support, scheduling flexibility, and rapid responses to communications fostered the current relationships that continue in ongoing collaborative projects. Bi-directional learning occurred during the project, as the BRIC team learned much about the challenges faced by K-12 teachers and students and adopted strategies to meet their classroom and networking needs.

SUMMARY

BRIC accomplished the three aims it set for more than 9,000 students. Students learned about phages and phage research. They better understood how bacteria can evolve over time and develop resistance to antibiotics. With some training in lab techniques (such as using sterile techniques) and equipment (such as using micropipettors), they learned they could participate in phage discovery and make scientific contributions that impact the lives of real people. They better understood the challenges researchers face while conducting research, changed the way they engaged around science with their family and friends, and were encouraged to continue to study phages and attend Montana Tech (Roccograndi, 2019). Participating K-12 classrooms received three-day classroom outreach phage discovery visits. Newly discovered phages, along with their electron micrographs, DNA sequences, and annotated genomes were entered into national databases, with teachers and students as authors. The development of satellite labs at participating schools was supported by the project. Paid summer research opportunities with students at Montana Tech and Montana State University were piloted in collaboration with the NIH INBRE-funded research program.

The connection of higher education professionals to K-12 professionals was invaluable for both systems to reflect and refine measures for student success. BRIC was an opportunity for K-12 teacher talent to develop skills through funded, authentic science experiences which resulted in MS and PhD degrees, a multitude of awards, and a student entry point into science as a profession. The National Science Teaching Association (NSTA) featured a video of the BRIC program to showcase authentic science teaching and learning in classrooms and satellite laboratories in K-12 schools and is available at http://cfwep.org/phages/. This video expanded the BRIC project's dissemination and elevated participant teachers as science role models (NSTA, 2019).

Ongoing and Future Work. A current project, Phages Helping Acquire Genuine Experiences in Science (PHAGES) is underway, funded by NIH SEPA. The PHAGES project pairs teachers who completed the BRIC project with new mentee teachers in their schools. These teacher pairs are developing their abilities to independently prepare the materials, deliver the classroom phage discovery, and develop a support network within their own school and district. The BRIC foundation of a multilayered, connected mentor network provided the conceptual framework to foster sustainability and expand the program. BRIC teachers and their students will use the equipment and lessons provided through BRIC and PHAGES for many years to come. The value of the project is still unfurling as participating teachers continue to provide innovative, meaningful learning experiences in diverse educational settings.

ASSOCIATED CONTENT

Supplemental material mentioned in this manuscript can be found uploaded to the same webpage as this manuscript.

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ABBREVIATIONS

BRIC: Bringing Research into the Classroom; CFWEP: Clark Fork Watershed Education Program; HHMI: Howard Hughes Medical Institute; MSU: Montana State University; MT INBRE: Montana IDeA Networks of Biomedical Research Excellence; NIH: National Institutes of Health; PCR: Polymerase Chain Reaction; PHAGES: Phages Helping Acquire Genuine Experiences in Science; RCR: Responsible Conduct of Research; SEA: Science Education Alliance; SEPA: Science Education Partnership Award; TEM: Transmission Electron Microscopy

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