Professional Development for STEM Teachers in Rural Counties to Broaden Participation in Engineering

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Taryn Melkus Bayles is a Professor, Teaching Track, in the Chemical & Petroleum Engineering Department at the University of Pittsburgh, and serves as the Undergraduate Program Director. She has spent part of her career working in industry with Exxon, Westinghouse, Phillips Petroleum and Pittsburgh Energy Technology Center (now NETL). Her industrial experience has included process engineering, computer modeling and control, process design and testing, and engineering management. She has also spent 25 years teaching Chemical Engineering at the University of Nevada Reno, University of Pittsburgh, University of Maryland College Park and the University of Maryland Baltimore County. Her current research focuses on Engineering Education and Outreach. The goal of this research is to increase awareness of and interest in pursuing engineering as a career, as well as to understand what factors help students be successful once they have chosen engineering as a major.

Ms. Claudia J. Morrell, STEM Equity Initiative, LLC

Morrell's decades of research and practice have focused on understanding and enacting strategies to increase access and educational equity for all students, including those traditionally underrepresented in rigorous courses and programs in science, technology, engineering, and mathematics (STEM). She knows that an education in a STEM field leads students to life enriching, family supporting, and community building careers. Morrell brings an entrepreneurial spirit to every effort she undertakes. From developing and leading a research center for advancing women and IT at the University of Maryland Baltimore County to creating an international effort on behalf of women and Information and Communication Technology (ICT) for the United Nations and the World Bank to serving as the Chief Operations Officer for the National Alliance for Partnerships in Equity (NAPE). Morrell has developed, led, and managed a number of multimillion dollar federal grants for STEM teacher professional development for Baltimore County Public Schools and NAPE, with resulting publications and professional learning. She began her career as a faculty member at the Community College of Baltimore County working with smart, capable, hardworking, and appreciative minority students who had somehow fallen through the educational cracks. That was her first glimpse into the failure of the education system from teacher training to student learning.

Morrell's quest has always been to answer the question, how do we as a country improve student outcomes in STEM for all students? How do we finally recognize and close gaps in performance? Her resulting lifelong exploration and collaboration with over 50 organizations and hundreds of individuals has led her to develop the NEIR System Change Model for Education. Her work continues.

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Sandra Staklis, Ph.D. is senior research education analyst at RTI International. She is a specialist in mixed-method research designs and has conducted evaluations of STEM education and career and technical education initiatives and programs for state, federal, and private clients, including the U.S. Department of Education, the National Science Foundation, and the Citi Bank, Ford, and JPMorgan Chase foundations. For these clients, she designs and implements research project in collaboration with clients and partners, bringing together diverse stakeholders to create projects that result in meaningful and actionable findings.

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Abstract

The research design for the STEM Excellence in Engineering Equity (SEEE) Project is intended to lay the groundwork for further research and development by 1) identifying indicators of successful model implementation, 2) assessing the feasibility of implementing the curriculum in rural science, technology, engineering and mathematics (STEM) secondary classrooms, and 3) collecting initial data on the program's effect on the classroom environment and student's engagement and interest in engineering. To meet this objective, the research team employed an iterative cycle of development review, testing and revision of the various program components.

Over the last two years of this NSF BPE grant, the program team (engineering faculty and engineering students from rural high-schools, a nonprofit, research partner and advisory board) developed and refined a professional development (PD) program to guide rural-area secondary school teachers to integrate evidence-based engineering content, effective pedagogical practice and innovation indicators of education equity. The NEIR (Normalize, Empower, Inclusive, Relevant) model focusses on classroom equity integrated with the engineering design process used to connect science, technology and math content. Two PD workshops (ranging from 2-3½ days, supplemented by year-long Faculty Learning Communities) have trained twenty-five teachers from seventeen different schools (four counties), and eight returning teachers; in addition, six administrators from two different counties participated in various components of the PD program.

In terms of the three objectives for the research plan, the research study identified the following findings:

1. Indicators of successful model implementation emerged from teacher's feedback on how their classes changed through their use of the NEIR model. The changes observed by the teachers included:
    a. Projects that engage student in problem solving and the design process rather than kits or high structured activities
    b. Examples of how the teachers use NEIR in the classroom
    c. Classroom activities that required collaboration among all students, which included changes to classroom organization
    d. The teacher's role in the classroom changed from providing answers and instructions to serving as a facilitator and advisor, allowing students to work on challenges and failures on their own and with their peers.
2. Assessing the feasibility of implementing the curriculum in rural STEM classrooms: Teacher's feedback during learning community sessions, interview and focus group responses, and responses to the Stages of Concern (SOC) questionnaire from the Concerns-Based Adoption Model (CBAM) suggest that teachers were engaged with the program and found the model usable and feasible to implement.

3. Collecting initial data on the program's effects on the classroom environment and student's engagement and interest in engineering: the researchers collected evidence on changes to the classroom environment through feedback from teachers. All teachers indicated that use of NEIR model and the engineering design process increased student engagement and enthusiasm for coursework overall but acknowledged that engagement for some classes and students remains a challenge.

This paper will describe the details of the PD, the NEIR model, engineering curriculum description, teacher and student survey results, and lessons learned from this innovative approach to equity in engineering education in secondary schools.

NEIR System Change Model

The NEIR (**N**ormalize, **E**mpower, **I**nclusive, **R**elevant) System Change Model (NEIR Model or Model) proposes to create Equitable Learning Environments (ELEs) (Figure 1) in classrooms and schools through the application of a program improvement process. Through the professional development (PD) process, co-PI Morrell provided applications-based instruction more concretely to advance understanding of the Model.

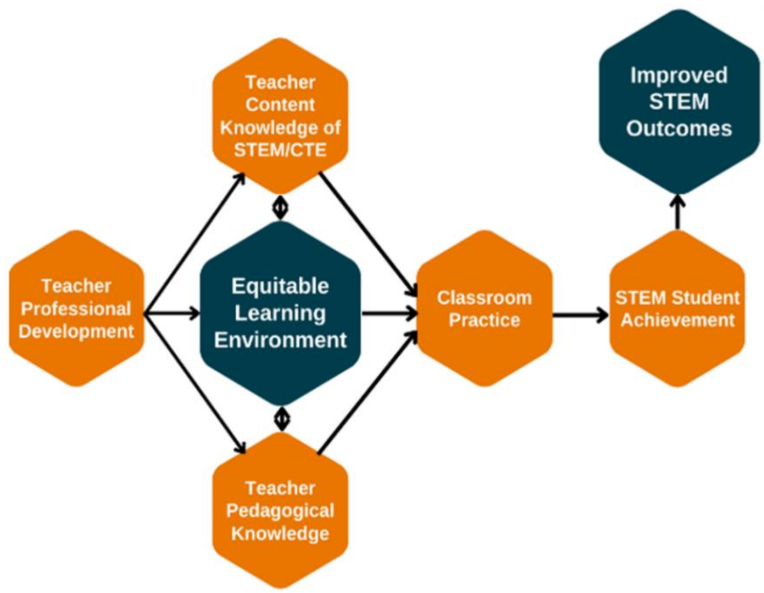

Figure 1. ELE added to the Education Equation

First, the Model advances the hypothesis that equity in education is required to achieve qualitative equal life outcomes (*academic, economic, social, personal…*) for *all students.* Equity and equality are both aspirational goals that first require the *foundation of an equitable learning environment.* Providing for 25 – 30 students (and sometimes more) an equitable learning experience based on the myriad of characteristics that form our identities can be overwhelming to most educators. Balancing academic instruction with quality pedagogical practice and recent student social and emotional challenges and still achieving high levels of student learning can be exhausting and defeating, creating a mass exodus among educators. The NEIR Model for system change requires us to move to the creation of an equitable learning environment in classrooms, schools and campuses where every student can find and embrace what they need to experience equity. This includes:

- A perspective of students as whole people with both assets and deficits that deserve to enjoy safe and nurturing learning experiences.
- A lens focused on the perspective of the student (receiver) rather than the teacher (sender).
- A recognition that all stakeholders that interact with students are important to the learning environment.

Second, the NEIR Model was not developed in a postsecondary institution or education department. Instead, it distinguishes its Model as emerging from grassroots educators over decades and the "wisdom of the practice" and has evolved over time[1]. Entrepreneurs, educators, equity experts, and engineers collaborated to achieve a new approach for academic success in STEM for all students. Research from multiple disciplines was then identified to both support and further advance the Model. The NEIR Model has been assessed and iteratively improved in multiple, diverse classrooms, including this NSF STEM Excellence in Engineering Equity (SEEE) project.

Third, the Model shifts the focus from a deficit model that focuses on simply accommodation of identified "weaknesses" to an *asset model* and is used for working with students and throughout the school. The asset model includes the following:

- Values the complexity of the "whole child"
- Assesses the current state not just the "problem or deficits" of students and colleagues.
- Moves the classroom from a need for educators to address special needs of low performing students to recognizing assets and deficits of us all to be addressed, valued, and utilized. Like a coach on a sports team, educators work to create a team in the classroom to work collaboratively with all students to achieve better outcomes for all.

Finally, the NEIR Model is a sustainable process-based model. Another way of saying this is the NEIR System Change Model is where practice and research intersect with the engineering design process.

- Assimilates the dynamic assets of the community/classroom culture
- Provides a self-study process from initial assessment to continuous improvement using the educator's own action research
- Provides an innovative multidisciplinary problem/solution approach for the school and classroom

As mentioned above, the NEIR System Change Model (shown in Figure 2) is distinguished by four indicators of the foundational or essential conditions for an ELE to exist: normalize (N), empower (E), inclusive (I), and relevant (R). The Model is based on two core beliefs: (1) Students are assets in the classroom. In the traditional deficit model, the teacher is "all knowing" and students simply absorb their instruction. The NEIR Model recognizes that everyone in the classroom has something to teach and something to learn. Each educator and student are uniquely gifted, and those gifts should be brought out and utilized within the classroom and school. (2) The intersectional approach recognizes that we each hold multiple identities. When we focus on one (e.g., females vs. males or Black vs. White), we may inadvertently create stereotypes that reinforce the very biases we are trying to dispel.

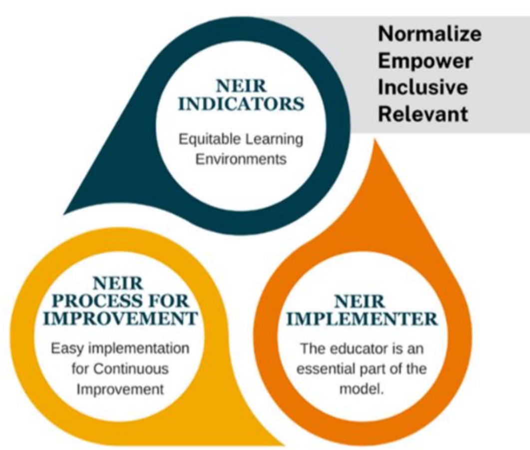

Figure 2. Components of the NEIR System Change Model

Normalize: The cultural, social, regional, and familial experiences that students carry with them into the classroom.

Empower: Students are recognized for their natural and learned gifts and talents and are provided by the agency to develop educational self-efficacy, responsibility, and empathy for others.

Inclusive: Educators are aware of and responsive to the ways that students are marginalized by our current education system. Educators (and all individuals in the building) actively and lovingly address negative bias and integrate affirmations to promote social-emotional growth and well-being for all individuals in the classroom and school.

Relevant Students experience "relatedness" with their teachers and a learning relevant to their lives through direct connections to their community, their country, and the world.

The Engineering Curriculum

PI Bayles co-developed the **INSPIRES** Curriculum (Figure 3)which was designed to specifically target three Standards for Technological Literacy put forth by the International Technology Education Association (ITEA): Students will develop an understanding of the attributes of design, an understanding of engineering design, and abilities to apply design[2].

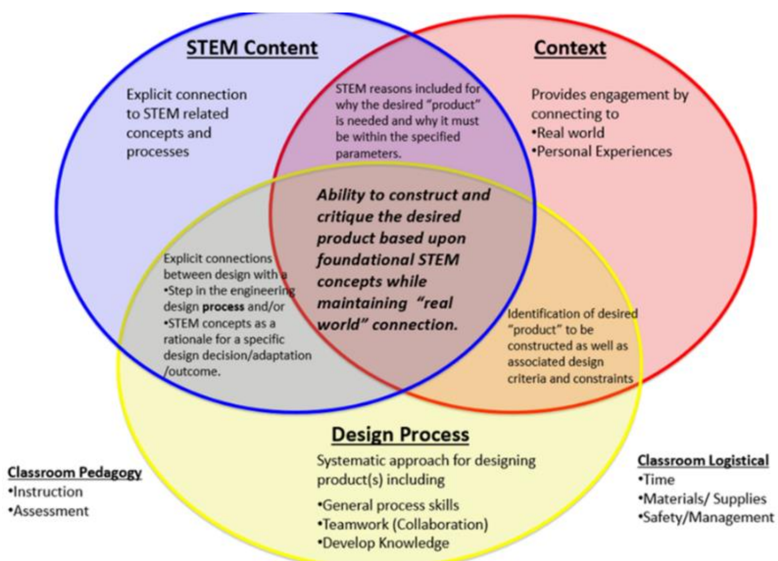

Figure 3: The INSPIRES Curriculum

The Next Generation Science Standards have a focus on threading engineering design throughout the standards, which aligns with the *INSPIRES* curriculum. The curriculum has been designed to provide materials that are challenging, thorough and effective at promoting learning, but at the same time, interest and engage students. Real-world applications that address current societal needs are prominently featured to help students connect fundamental concepts with application. In order to maximize the potential of school systems to adopt the INSPIRES Curriculum, the cost of implementation has been kept low and significant professional development for teachers is offered.

Although the INSPIRES Curriculum is designed around specific content areas, a primary focus is on the development of transferable skills that we believe are foundational for success in the study of STEM-related fields. These skills are often neglected in high school curricula yet must be developed for students to succeed in undergraduate science and engineering programs. The key skills targeted by the INSPIRES Curriculum include:

- The ability to work effectively in teams & communicate technical ideas orally & in writing
- The ability to solve open-ended problems
- The ability to synthesize what is learned in science and mathematics courses and apply the knowledge to real-world problems
- The ability to think creatively with respect to the solution of an open-ended problem
- The ability to describe the natural world using mathematics
- The ability to view and analyze a system as a whole

For this project, we focused on the Engineering in Flight module[3], which introduces students to the engineering design and decision-making process, a theme that is central to all the curriculum, while also teaching basic engineering concepts, a variety of activities including hands-on exercises, demonstrations, and tutorials to target different learning styles. Many of the activities require students to work in groups, thereby promoting teamwork, creativity and leadership skills. Students are evaluated for their ability to work as part of a team and to apply the engineering design process during a short, 45-minute pre-module design activity related to the module topic. Students are introduced to a module via a professionally produced video segment that features an expert in the field. The video provides societal context for the material presented, essentially bridging the gap between fundamental principles and 'real-world' applications. The students then proceed through a series of hands-on activities that explore fundamental scientific principles related to the module topic. These activities are useful in promoting student participation as well as for stimulating interest in the module content. Next, the students are given a challenge to design and build their own system. Before beginning the design project, the students work through a tutorial to learn background information about science and engineering principles relevant to the assigned challenge. The students complete a mathematical simulation, which investigates the relevant parameters to visualize what effect the changes have on the overall design of the system. Students individually determine what they believe to be optimal parameter settings for achieving peak efficiency and low cost. Then, using what they have learned from the tutorial and simulation, student teams design, construct and evaluate their own system.

SEEE Program Development and Pilot – The Professional Development Workshop

An objective of this design and development Broadening Participation in Engineering (BPE) grant was to develop and pilot a PD workshop for teachers in rural communities. Accordingly, the first PD workshop in August 2022 was preceded by a six-month design phase. During this first phase, the PI and co-PI first worked independently to identify and develop content used from their fields with secondary teachers. For PI Bayles, this meant reviewing and selecting content from the NSF-funded INSPIRES curriculum and the PD provided with INSPIRES[4]. Co-PI Morrell identified content and delivery from the NEIR System Change Model, she had been using for several years in development with a state and several local school systems.

The NEIR constructs provide an operational method for embedding "another learning domain" (affective learning) to create the ELE classroom and campus. Research and practice-based content developed and piloted through an iterative, learning process over 10 years in PA resulted in this new, complex, innovative Model for education. The goal of the development and design grant was to embed equitable understanding and practice into classroom content and pedagogy through a co-design model with INSPIRES to benefit and support administrators, counselors, classroom STEM faculty, campus staff, and community partners using the iterative collaborative design process. For this phase, the process continued with Bayles and Morrell working collaboratively formulating the design for this integration of NEIR with engineering curriculum and the delivery process, which provided the pedagogical framework.

The developed PD was then delivered during a full day review to individuals who are Subject Matter Experts (SMEs) with expertise working with secondary STEM education (16 years or more). The SMEs provided expertise in teacher professional development, equity education and service learning, and both science and engineering education.

They were also asked to provide suggestions on how the PD program could be improved. Based on their feedback, the SEEE team revised the PD content and PD materials. They also kept the SMEs suggestions in mind as they delivered the PD in Year One and found that the suggestions would continue to be valuable for the second revision of the professional development program.

The project also had a six-member advisory board with diverse expertise that provided input on a quarterly basis each year for two years to improve the curricular content, support assessment of all elements, and refine delivery of the development and design of the NEIR Model using the engineering design process.

Interestingly, the board members struggled in understanding the unique qualities of the SEEE program and the NEIR Model specifically as distinctive from other current strategies for classroom improvement. As the PI and co-P refined their instruction, as well as meeting with and hearing from the teachers who participated in the PD, the Board became better informed. They each stated there was strong evidence for the potential of the new Model to impact students' interest and academic performance in engineering courses, programs and future career pathways, particularly among those students who have been traditionally underrepresented.

Professional Workshop Delivery

After the six-month program development phase, the SEEE team piloted the program with 14 teachers from eight secondary schools in western and southeastern Pennsylvania (rural counties) during the 2022-23 academic year (Table 1), located in rural and suburban areas. Five of the six comprehensive high schools enrolled fewer than 500 students in 2021-22 (the most recent year of data available). PA has complex educational options that can be difficult to describe. Ten of the teachers were from traditional STEM programs representing six schools and four were from Career and Technical Education (CTE) programs (one from Beaver County and three from Chester County Career and Technical Education Centers (CTCs)). Students who attend the CTCs do so in either the morning or afternoon and attend the "sending school" for the other half of the day.

The pilot began with a 3 ½ day professional development (PD) workshop in August 2022. Of the fourteen original teachers who participated in the training, 12 continued in the program[1]. During the 2022-23 academic year, the teachers taught about 36 STEM and STEM-related classes that enrolled an estimated 960 students. In the monthly FLC meetings and in interviews and logs, the teachers provided feedback on their experiences in using the program. In accordance with the aims

[1] The two teachers took other professional roles outside of secondary education shortly after the PD workshop.

of this design and development grant, the SEEE team used information collected during the pilot to inform updates the program's curriculum and instruction. The teachers found the content effective for engaging students but requested more support on connecting the different elements of the PD. In response, the SEEE team redesigned the PD to better integrate the NEIR and engineering design components and included more guidance on using them together.

Table 1: Schools of Teachers Who Participated in the SEEE Pilot

School name	High School Enrollment	Percent of students free/ reduced price lunch eligible	Location type
Comprehensive schools*			
Aliquippa Junior/Senior High School	293	95%	Suburb
Beaver Falls Area Senior High School	473	94%	Suburb
Burgettstown Middle School/High School	301	36%	Rural
Freedom Area Senior High School	401	38%	Suburb
Hopewell High School	602	23%	Suburb
South Side High School	317	29%	Rural
Career and technical education centers			
Beaver County Career and Technical Center[#]	650	n/a	n/a
Technical College High School Pennock's Bridge Campus	n/a	n/a	n/a

* Source: Common Core of Data, 2021-22 school year. High school enrollments are for grades 6-12.
#Source: BCCTC information https://www.bcctc.org/about-bcctc/state-departments-committees/

The pilot teachers and their schools continued their engagement with the SEEE program following the pilot year. In June 2023, the redesigned PD was offered to 11 more teachers from the Beaver County and Chester County regions (the 'new' schools for these teachers are provided in Table 2). Ten of the teachers from the pilot joined the workshop to share their experiences. During the 2023-24 academic year, the teachers who participated in the SEEE program (either or both PDs) reported that they implemented what they learned during the SEEE PD with approximately 1660 STEM and STEM-related students in their classrooms.

Table 2: New Schools of Teachers Who Participated in the Second SEEE PD Workshop

School Name	School Enrollment	Percent of students free/ reduced price lunch eligible	Location type
Comprehensive schools*			
Beaver Area Middle School	291	21%	Suburb
Beaver Area High School	682	22%	Suburb
Freedom Area Middle School	389	57%	Suburb
Hopewell Memorial Junior High School	619	34%	Suburb
Mohawk High School	453	32%	Rural
Charter School (certificates and trades)			
Midland Innovation & Technical Charter	140	99%	Rural

In fall 2023, the SEEE team delivered an in-service PD workshop to 17 STEM teachers at the request of the principal from one of the pilot high schools. Two University of xxxxx engineering students, who were trained with the NEIR Model and SEEE program and had also graduated from rural high schools (one from the high school where the request was made) assisted in delivering the workshop. Finally, a school district in an adjacent county hired the SEEE team to provide a workshop for 14 teachers from 2 rural schools. Although these activities were outside of the proposed grant activities, they attest to rural schools' interest in teacher PD on engaging students in STEM.

In addition to presentations by the SEEE team, several teachers who participated in the pilot have shared information about SEEE with their colleagues in conferences. In November 2023, four pilot teachers presented on their experiences in the program at the statewide Integrated Learning Conference hosted by Pennsylvania State University and Pennsylvania Department of Education with district funding for travel, substitute teachers, and per diem. In summer 2024, another teacher from the pilot program will present on the SEEE program at the International Society for Technology in Education (ISTE) conference in Denver, Colorado and also at the Computer Science Teachers Association (CSTA) conference in Las Vegas, Nevada.

Research Questions

The research study that accompanied the development and pilot of the SEEE program had three objectives. The research team developed a set of research questions addressing three aspects of the SEEE program.

Indicators of Successful Implementation

- What indicators of classroom change emerge during the SEEE program that emerge during the SEEE program pilot suggest that teachers are successfully implementing the program?

Usability and Feasibility

- How do teachers rate the usability of the PD program material, including appropriateness, ease of use, and potential to engage students?
- To what extent is the NEIR Model feasible for teachers to implement in the classroom?
- What barriers and facilitators do teachers or administrators/counselors encounter when implementing the NEIR Model?
- What improvements can be made to the NEIR PD program to make it more usable for all educators?
- What changes are necessary to increase the feasibility of NEIR Model implementation?

Classroom (Educator and Student) Outcomes

- What changes in the classroom environment do educators perceive as a result of implementing the NEIR Model?
- In what ways do educators and students feel that the NEIR constructs supported the creation of learning environments that were equitable for all students?
- What is the effect of the NEIR Model on students' engagement and interest in STEM and engineering design?

Data Collection

The focus of this design and development grant was on the refining of the SEEE program based on teachers' experiences with implementing and using the program. Accordingly, the research design focused on gathering information from teachers on the usability and feasibility of the program. During implementation, the research team reviewed monthly logs that the participating teachers completed during implementation, conducted interviews in fall 2023 following the SEEE PD workshop, observed meetings of the SEEE faculty learning community, and conducted focus groups and administered surveys at the end of the 2022-23 school year with participating teachers.
Interviews: Researchers conducted phone interviews with eight of the twelve teachers who participated in the pilot following the August 2022 SEEE PD workshop. The semi-structured interview protocol asked the teachers to 1) describe their participation in other initiatives to enhance instruction or student engagement, 2) their understanding of the SEEE program, 3) the alignment of the workshop content with teachers' and students' needs and interests, 4) the feasibility of implementing what they learned in the workshop in their classes, and 5) whether they would recommend the PD to other teachers.

Observations of Faculty Learning Community Meetings: During the pilot, the 12 participating teachers met in October, November, February, April, and May for 1.5 hours to share their experiences in implementing the SEEE program. Four meetings were virtual and one in person. During these meetings, teachers identified experiences and challenges to implementation and described examples of how they were using the program in their classrooms. The research team attended these meetings and took notes on the information the teachers shared.

Feedback logs: Educators completed monthly logs to track their use of the SEEE program utilized in their classrooms, report implementation challenges, and provide suggestions for improvement. Teachers completed logs from December through May 2023. On average, five teachers submitted logs each month, for a total of about 30 log entries.

Focus groups: Researchers conducted four focus groups (three in person and one virtual) with the pilot teachers at the end of the school year. In total, ten teachers of the 12 teachers were able to participate in a focus group. A protocol designed to gauge teachers' understanding and use of the SEEE program guided the interviews. The focus groups also covered teachers' perceptions of the usability and feasibility of the program, barriers to implementation, suggestions for improvement, and effects on their teaching, the classroom environment, and students.

Questionnaire: Eight of the pilot teachers completed the Stages of Concern (SOC) questionnaire from the Concerns-Based Adoption Model (CBAM) to collect information on teachers' reactions, perceptions, and attitudes towards the implementation of the SEEE program, as measured by the CBAM's seven stages of concern. These stages indicate teachers' progression through the change process needed to implement an innovation such as SEEE. Researchers used standard processes to adapt the measure and score teacher responses[5].

Findings

The sections that follow summarize findings related to the SEEE program's usability, feasibility, and effects on the classroom environment.

Indicators of SEEE Program Implementation

A goal of this grant was the identification of indicators of implementation of the SEEE program that could be used to track implementation when the Model is iteratively improved and scaled. Initial input from the pilot teachers immediately following the professional development indicated the teachers believed the 3½ day training was sufficient to be both feasible and usable in their upcoming instruction. Twelve of the original pilot teachers remained in the program for two years. (One teacher became a Vice Principal and one moved to elementary education. No one left the program otherwise.) Following year two of the program, which included two PD workshops and the FLCs. All 12 teachers responded positively related to both their learning and preparedness at the conclusion of the program as provided in Table 3 and 4.

Table 3. Teacher Knowledge and Beliefs after Participation in PD Workshops & FLCs

Please respond to the following prompts related to your knowledge and beliefs after the workshop.	Strongly Agree	Agree	Disagree	Strongly Disagree
I am knowledgeable of the ways in which I contribute to an environment that encourages all students in my classroom.	5	7	0	0
I believe that all students can be successful in STEM courses and/or programs.	7	5	0	0
I advise my students to take as many STEM courses as they can.	5	7	0	0
I understand ways in which the classroom or school campus environment does or does not encourage all students.	4	7	0	0
I am knowledgeable about ways to increase equity in my STEM classroom.	4	8	0	0
Students of all races, genders, ethnicities, and abilities can be successful in STEM.	10	2	0	0
STEM educators can intentionally influence the participation of students in STEM courses and careers.	7	5	0	0
STEM teachers can positively influence the completion of students in STEM courses and programs, including those students traditionally underrepresented.	8	4	0	0

Table 4. Teacher Preparedness after Participation in the PD Workshops

Following the workshops, how important is it for teachers to do the following?	Extremely Important	Very Important	Somewhat Important	Not so Important	Not at all Important
Make connections between engineering design and STEM	6	5	1	0	0
Have students participate in hands-on activities	7	5	0	0	0
Engage and empower students in enquiry-based learning	8	4	0	0	0
Students work collaboratively on group projects	7	5	0	0	0
Engage students in open-ended problem solving with student peer collaboration.	6	6	0	0	0
Reflect on my teaching independently and with peers.	5	4	3	0	0
Connect the abstract to the concrete in culturally relevant ways.	3	8	1	0	0
Use anecdotes or stories related to everyday life that reflect the lived experiences of a diversity of students.	3	8	1	0	0

When asked, “How useable do you believe the NEIR Model indicator integration with engineering design has been in supporting your current instruction in 2022-2023?” the responses are provided in Table 5, from the respondents.

When asked what additional information or preparation they wanted, teachers simply wanted more of everything.

- More examples or experiences on how to use reflections journals.
- More examples or experiences of real-world problems connected to the local community
- More examples or methods for engaging and empowering students in inquiry-based learning.
- More examples or methods to connect the concrete to diverse cultures.

Table 5. Teacher Comments when asked "How useable do you believe the NEIR Model indicator integration with Engineering Design has been in supporting your current instruction"

Teacher Comments
It is the sixth day of school, yet I plan to implement all aspects in some manner.
I believe it's very usable. I hung it on my back wall to remind me of it while teaching throughout the year.
Very. It is easy to see the importance of each part in a lesson.
Very usable
I feel that the NEIR Model will be useful in connecting with students who typically would want to drop out halfway through the year. I believe I will have fewer students drop the class and feel more empowered to stay and show growth throughout the whole year.
I think it's great. Should be easy.
I believe this will remind me that STEM thinking is not just excelling in STEM courses. Often times it is easy to judge students and effort based on their overall grade. It reminds me that I need to monitor growth.
I will try to implement this as much as possible because I feel it is very important.
The NEIR tenants form the base approach that I see becoming / are the foundation to my approach of fulfilling my obligation to my students to include, but not limited to STEAM education; of which engineering design is a primary lesson in my physics classes. I have yet to decide to what depth I will apply the engineering design to chemistry (working on it).
I believe that the NEIR Model with engineering design is very usable within my current instruction. I am finding it more important to include NEIR to help students see the importance of STEM courses in their daily lives.
I will use some of the NEIR Model concepts this year in my IT programming course.
I think I use the NEIR Model already; I just hope to concentrate on integrating the concepts in more detail.
I think the NEIR Model is easy to use and implement in the classroom. It can be applicable to many things, including engineering design.
I believe it will be very useful in the HVAC/R – CTE class. I will work it into as many lessons as possible.

In collaboration with the 14 teachers who participated in the SEEE program pilot, researchers identified the following implementation indicators, based on classroom changes that they attributed to their use of the program:

- A change in the teacher's role in the classroom from providing answers and instructions to serving as a facilitator and advisor who allows students to work out challenges and failures on their own and with their peers.
- Assignments that engage students in problem solving and the design process over time, through multiple iterations, rather than using kits or highly prescriptive instructions.
- Examples of teachers' use of the NEIR elements (Normalizing, Empowering, Inclusive, and Relevant) in the classroom. For example, one teacher shared his use of language and terminology that normalizes STEM for students, such as saying "procedure" and "process" instead of "lab" and "experiment."
- Collaborative classroom activities that allow students to negotiate and select program roles based on their talents and interests, and changes to classroom organization, such as using shared tables rather individual desks, to support collaboration.

- Student “ownership” of classroom spaces, such as student-led reorganization of classroom resources or decorations, and students’ use of the classroom to work on course-related content outside of class time, such as during lunch, free periods, and after school.
- Higher levels of STEM teacher motivation, engagement, and retention.
- Longer term outcomes, such as increases in the number of students who take more challenging STEM courses to meet graduation requirements or take STEM electives or the number of students in lower-level STEM-related CTE course who continue in the program.

SEEE Usability and Feasibility

Feasibility pertains to the organizational and structural factors, which might include administrative support, available class or planning time, and classroom space, needed for the program’s implementation and use. During the FLC meetings, the 12 teachers who participated in the pilot program provided one or more examples of their use of the program in their classes. Teachers identified potential levers for enhancing the program’s feasibility, such as increased support from school and district administration and focusing on courses with lab activities in which engineering design principles can be readily integrated.

Usability relates to whether teachers were able to use the material provided for its intended purpose. In the interviews, observations, focus groups, and feedback logs, the teachers indicated that they were motivated and able to implement SEEE in their classrooms. Teachers affirmed their use of the SEEE components (NEIR and engineering design instruction) in their monthly logs, through information shared during the FLC meetings, and in the focus groups, in which teachers shared examples of how they successfully integrated engineering design and the NEIR Model in their instruction. Their examples typically included their perceptions of how the material enhanced student engagement, such as:

- “This month I did an engineering design challenge in my STEM class. During this challenge, I used the equation provided in the curriculum and had the students work to figure out and debate which variables were most important. This process was very inclusive because it allowed for everyone to express their opinion and how to improve the design.”
- “I had my students research water filtration systems. Then they had to design and build a prototype of the system with a team. Finally, after testing, the students had to submit their design modeling in CAD so others could replicate it.”
- “Students in AP Biology are learning about cell communication. To normalize [a NEIR indicator] this topic we began with a lab where students altered their taste buds to explore how signal transduction cascades work within our cells. Not only did this activity make the topic more relevant [also a NEIR indicator], but it also helped lead into other relevant topics that we focus on, such as cancer development.”

Perceived Changes to the Classroom Environment

In the interviews, focus groups, faculty learning community meetings, and logs, teachers consistently reported improvements in student and teach engagement and student empowerment that they attributed to their use of the SEEE elements.

- Increased student engagement: In three focus groups and nine logs, teachers reported increases in student engagement. Specifically, they observed that showing students the relevance of their learning in STEM classes led to students being more actively involved in classes and seemed to increase their enjoyment of coursework.

- **Increased student empowerment**: In three focus groups and seven logs, teachers reported that increases in student empowerment, meaning that students were more confident and took on more initiative in and responsibility for their learning and the learning of others.
- **Increased participation in STEM coursework**: Two teachers reported increases in higher-level STEM course enrollments during the school year, which they attributed to SEEE implementation. The teachers perceived higher levels of student engagement in lower-level STEM classes than in prior years and felt that the increase in levels of engagement had resulted in relatively more students enrolling in higher-level and more challenging STEM courses.

> *[SEEE] empowered students. It made them grow personally. They got to the point where they were confident enough that they then became the teachers for others in the class. This was a super win for me.*
> – STEM teacher who participated in the SEEE pilot

- **Increased teacher engagement and enjoyment:** At the end of the pilot, the participating teachers reported increased engagement and enjoyment in teaching in the focus groups, which the teachers suggested could contribute to STEM teacher retention. One teacher said "My enjoyment in the classroom increased. I reevaluated things and got that spark back and focused on the fun and laughter in the classroom. Sometimes these are the things kids need most." Another teacher reported that prior to the SEEE program she was considering leaving the teaching profession, but now she has "…been able to focus more on what happens in the classroom and less on what's outside of my classroom. This has been very beneficial to me."

Suggestions for Improving Implementation

Although all teachers were able to provide examples of how they were using SEEE in their classrooms, they also found several challenges to implementation.

- **Preparation time**: In three focus groups and five log entries, teachers reported that the extra preparation time needed to integrate the SEEE program into their teaching as a barrier. One teacher reported spending an extra three to four hours planning certain lessons, while another reported spending an extra four hours a day before the beginning of the school year to prepare for implementing the SEEE program elements.
- **Student motivation and unfamiliarity with the SEEE program content**: In the focus groups and 15 log entries, teachers reported finding it more challenging to use the engineering design process and NEIR elements in lower-level courses and in courses with students uninterested in STEM. For these classes and students, the teacher described providing extra support to get students to engage in the iteration needed for successful design challenges. Teachers also reported that students were unaccustomed to the approaches related to the NEIR Model. One teacher noted that students seemed uncomfortable with teacher efforts at

> *The first challenge that I encountered was getting students to open up and put their ideas on how to make improvements out there [in a design challenge exercise]. In many cases, they are just not used to this type of thinking.*
> – STEM teacher who participated in the SEEE pilot

empowering them, while another reported that students struggled to "buy-in and see the connections to their lives."

- **Subject Integration:** In three of the four focus groups, teachers reported that integrating engineering design elements into biology, mathematics, and career and technical education courses was more difficult than integrating it into physics and STEM elective classes. Curricula in physics and STEM elective classes includes time for lab activities done by students in pairs or groups that opportunities for using the engineering design process. In courses lacking lab time, teachers struggled to integrate the design process. In addition to course structure, a teacher also noted that the pressure of keeping up with the curriculum didn't allow time during teaching for the integration of engineering design principals.

In feedback logs and during focus groups conducted at the end of year 2, teachers recommended three strategies for increasing the feasibility and usability of SEEE program: administrative support, more examples of using SEEE, and more teacher-to-teacher collaboration.

Administrative support: In two focus groups, teachers suggested that the program increase efforts to engage school leaders and administrators, noting that increased buy-in from administrators could result in additional time and resources to implement SEEE. During the pilot, for example, teachers reported different levels of administrator interest in and support for SEEE implementation. In several schools, an administrator served as a point of contact for logistics and scheduling only. The pilot teachers from these schools did not report providing supporting or complementary activities in their schools, and their descriptions of using the SEEE program focused on their own classrooms and students. In contrast, teachers from one school reported involvement from the school principal, vice principal, and the countywide CTE director (representing three schools). The principal and vice principal supported the creation of a school wide "equity team" and supported the teachers continued involvement in the SEEE program after the pilot, including attending the June 2023 SEEE PD workshop and presenting on the project at the statewide Integrated Learning Conference in November 2023. In addition, the district provided funding for a two-day PD workshop for 20 teachers, administrators, and support personnel on the NEIR Model and the engineering design process, bringing in educators from the other two schools under the director. When asked about their support, the administrators reported that the school's environment was shown to be more collaborative among faculty and staff, more positive among staff and students, and demonstrated increased support among their faculty and staff due to the work of the equity team and its use of the NEIR Model. But perhaps equally importantly, the administrators reported improved student academic outcomes in retention and completion compared to the other two schools.

Examples of SEEE application: In two focus groups and 11 logs, teachers suggested that the PD include more examples of how to integrate the NEIR and engineering design applications into specific lessons or activities for different subjects and grade levels. For example, one teacher suggested providing examples of how to integrate the elements of the NEIR Model into a lesson during the SEEE PD workshop session.

Teacher-to-teacher collaboration: In two focus groups and eight logs, teachers reported the need for additional opportunities for collaboration. Teachers wanted more time to collaborate during the PD workshop to share successes and ideas. They also reported the need to collaborate in subject matter-specific groups. For example, a group of teachers could work together to create engineering design projects aligned to certain mathematical topics. Teachers also suggested setting up a website or online group where they could asynchronously exchange ideas and share resources or even create a bank of SEEE-aligned activities organized by content area.

Stages of Concern Questionnaire

In addition to providing feedback on their experiences with implementing the SEEE program, eight of the teachers also completed the Stages of Concern (SOC) questionnaire at the end of the pilot year. The SOC is one of three diagnostic dimensions of the Concerns-Based Adoption Model (CBAM) framework for measuring the implementation of interventions and for facilitating change in schools[6]. Of the three CBAM components, SOC was best aligned with the approach of SEEE. The SOC measures teachers' concerns or focus during implementation. Teacher concerns are categorized into three different levels—self, task, and impact—and seven different stages (Table 6). The higher a teacher's percentile score for a stage (as measured by their SOC survey responses), the greater the teacher's focus on that stage of implementation.

The CBAM model provides a framework for guiding teachers successfully through the change process. Although teachers do not need to complete the lower levels before progressing to the higher, the model's authors note that teachers' concerns about an innovation progress toward the later, higher-level stages over time and with successful experiences and the acquisition new knowledge and skills associated with the intervention[5]. Using information from the SOC, individuals or teams can customize their support to meet teachers' needs during implementation.

Table 6: Stages of Concern Model

Impact	6	Refocusing	Teachers are focused on extending or changing the innovation to improve outcomes.
	5	Collaboration	Teachers are focused on coordination and collaboration with others.
	4	Consequence	Teachers are focused on the impact of the innovation on students and their classrooms.
Task	3	Management	Teachers are focused on the process and tasks of using the innovation.
Self	2	Personal	Teachers are concerned about the effects the innovation might have on them and how if fits within existing school structures.
	1	Informational	Teachers are learning about the innovation.
	0	Unconcerned	Teachers are not focused the innovation or are focused on other tasks or initiatives.

Adapted from George, Hall, & Stieglebauer, 2006[5]

Overall, results from the SOC questionnaire indicate that the pilot teachers' concerns covered all SOC stages in implementing the SEEE program, but the highest average percentile scores were in the level 2 (personal) and level 5 (collaboration) stages (80 each) (Figure 4).

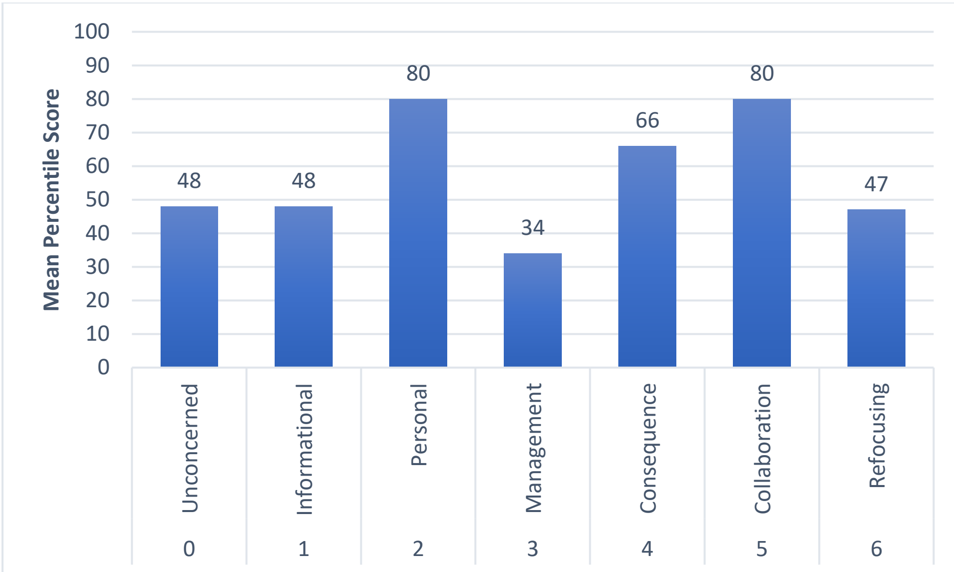

Figure 4: Mean percentile scores by Stage of Concern (n=8)

Level 2 measures teachers' concerns about status, rewards, and how an innovation might affect their professional role. For SEEE, the relatively high level 2 score suggests that the pilot teachers were using the SEEE program elements but were still figuring out the demands of implementing it, including how it fits in the structures of their schools, current curriculum, and classes. In the focus groups, some teachers expressed uncertainty about how their use of the SEEE program affects their teaching as well as their standing among other teachers and with school administration, echoing the need shared in the teacher focus group for more administrator support. Other researchers have noted that this level risks blocking out more substantive concerns about the innovation[7]. The high ratings for the collaboration (level 5) indicate an interest in or need for collaborating with other teachers on using the SEEE program. A consistent finding in the teacher focus group was a recommendation that the SEEE program provide more opportunities for collaboration.

Student Data Collection

The purpose of the SEEE program is to enhance students' interest, engagement, and performance in STEM coursework. Although the focus of this design and development grant was on developing and piloting the SEEE program, the research team piloted strategies for collecting information from teachers on their perceptions of the effects of the program on students.

During the program's second year, the research team administered two surveys to students: a pre- and post-survey on their attitudes and self-efficacy related to engineering design, and a post survey on their attitudes and self-efficacy related to STEM and 21st Century Skills, such as collaboration and communication. Given the exploratory nature of the SEEE program and limitations on the research design (a comparison group was not feasible), the research team did not anticipate these instruments to yield evidence of the program's impact on students. Instead, the researchers assess the instruments alignment with the revised SEEE curriculum and the feasibility of using these surveys with participating schools and teachers to identify facilitators and barriers to inform a rigorous study when implementation expands.

In the fall of 2022, teachers participating in the SEEE program administered a survey to the students enrolled in the STEM related courses that they were teaching. The survey, adapted from the PI's prior NSF-funded programs supporting equitable learning environments in STEM[8] assessed students' interest and attitudes towards engineering and STEM-related skills and careers. For the survey, students rated their agreement (on a scale from 1-5) with sets of statements. The higher a student's average score, the greater their interest and confidence in skills and activities related to engineering design and STEM. In spring 2023, two of the teachers administered the same survey to the same group of students as a post-survey.

The students who took the pre-survey were enrolled in different high schools in rural areas of western Pennsylvania (Table 7). These included comprehensive high schools (Aliquippa Junior Senior High School, Beaver Falls High School, Burgettstown Area Middle/High School, Freedom High School, and Hopewell High School), part-time campuses of the Chester County Career and Technical High School, and a full-time career and technology center (Beaver County Career and Technology Center). The students who took the post-survey were all enrolled in Hopewell Senior High School.

Within these schools, the students who completed the pre- and post-surveys were enrolled in a variety of STEM-related academic and technical PD courses, such as biology, precalculus, and heating, ventilation, and air conditioning (HVAC) (Table 8).

Table 7: Schools Attended by Student Survey Respondents

School	**Pre-survey (n=366)**	**Post-survey (n=112)**
Aliquippa Junior Senior High School	29 (8%)	
Beaver Falls High School	14 (4%)	
Burgettstown Area Middle/High School	47 (13%)	
Freedom Area High School	47 (13%)	
Hopewell High School	97 (27%)	112 (100%)
Chester County Career and Technology High School	84 (23%)	
Beaver County Career and Technology Center	11 (3%)	
Southside High School	37(10%)	

Table 8: Courses Attended by Student Survey Respondents

Course Name	Pre-survey (n=366)	Post-survey (n=112)
Algebra II	32 (9%)	
Auto service technology	37 (10%)	
Biology	15 (4%)	
Chemistry	18 (5%)	50 (45%)
Collision repair technology	11 (3%)	
Computer information systems	12 (3%)	
Geometry	13 (4%)	
Heating, Ventilation, and Air Conditioning (HVAC)	35 (10%)	
Physics	32 (9%)	19 (17%)
Precalculus	2 (>1%)	
STEM	24 (7%)	
CAD		40 (32%)
Course data missing	134 (37%)	3 (3%)
Course type		
STEM courses	84 (23%)	69 (62%)
Technical courses	242 (66%)	40 (32%)
Course type missing	40 (11%)	3 (3%)

Percentages may not add to 100% due to rounding.

Although the survey pilot was not expected to yield measurable changes in student-level outcomes, the research team conducted an exploratory analysis of the results of the pre- and post-survey data among different groups of students and the pre- and post-scores of the subset of students who completed the survey in fall 2022 and spring 2023. Male students had higher scores than females on the pre-test (3.49 versus 3.29), indicating a higher interest and self-efficacy related to engineering ($p < .05$), but the difference in scores was not significant for the post-survey, possibly due to the much small sample size. The difference in scores between students enrolled in STEM and technical courses was not significant in either the pre- or post-survey. The number of students who completed both the pre- and post-surveys was 70. A paired t-test using a 95% confidence interval found no difference in these students' scores between the pre- and post-test. These results could be due to a number of factors, including the post-survey being completed by students with relatively high interest levels in STEM prior to the pilot.

Student Attitudes toward STEM Survey

In spring of 2023, two of the teachers also administered the two sections from the Middle/High School Student Attitudes Toward STEM (S-STEM) survey[9]. One section *was Engineering and Technology Attitudes*, which includes items measuring self-efficacy related to engineering and technology and expectations for future value gained from success in these fields. The students also completed items in the *21st Century Learning* section, which measures students' confidence in communication, collaboration, and self-directed learning[10]. Like the pre-/post-survey, this survey asks students to rate their agreement or disagreement with sets of statements about their interests and skills. The higher a student's average score, the higher their self-efficacy and future value of engineering and confidence using in 21st century skills.

This survey was administered once at the end of the school year allowing us to compare results among groups of students who completed the survey in spring 2023. Although male students had higher ratings for the engineering section and girls for the 21st century learning section the differences were not significant when compare using a *t*-test at the 95% confidence interval. Differences between students in the STEM courses (chemistry and physics) and CAD courses were also not statistically significant.

Lessons Learned and Next Steps

A cornerstone of the NEIR Model and engineering design is an iterative program improvement process. A similar process guided SEEE Program PD development. The SEEE collected feedback on the PD content and materials from the SEEE program's advisory board, experienced secondary teachers, and engineers, and this iterative improvement process was repeated with the teachers who participated in the SEEE program pilot. One result of this process was the development of NEIR-related guided questions and actions for each step of the engineering design process to help teachers use the SEEE program elements together. Anecdotally, teachers reported that the questions helped them to integrate the NEIR elements into open-ended design challenges. Other changes included reducing the duration of the PD workshop from 3.5 to 2 days and inviting teachers who have used the SEEE program to share their experiences during the workshop and FLC meetings.

In accordance with the aims of a design and development grant, the SEEE program tested the usability and feasibility of the program. All teachers involved valued the PD, were able to implement material learned during their PD in their classrooms and reported positive effects of the implementation on their personal engagement and their classroom environments and students. Their feedback and experiences yielded specific suggestions for improving program content and implementation. Based on the pilot findings, the program leaders conducted a redesign of the SEEE program. The redesigned program, called Normalize, Empower, Inclusive, Relevant-Engineering Design (NEIR-ED), better integrates the NEIR and engineering design content, offers more examples of how NEIR-ED can be used in the classroom, and provides more opportunities for teacher collaboration, such as having veteran NEIR-ED teachers participate in PDs for new teachers. The PIs also changed communications for teacher recruitment in response to feedback from teachers who participated in the pilot study and reported that the term "equity" had become politically charged in their communities. As a result, some teachers had been deterred from participating in SEEE in either year or in the CCIU training. NEIR-ED uses alternatives to the term "equity" in the program's name and marketing materials and created videos of the pilot teachers describing their experiences in the program for future teacher recruitment.

The pilot also assessed the viability of strategies for assessing the programs' effects on classrooms, teachers, and students. The pilot teachers observed changes to their classroom environment that can be used as indicators of NEIR-ED implementation in future research. These include changes in the types of programs that students are assigned, the use of classroom resources, and the teacher's role. As a next step for the research design, the researchers will use these indicators to develop rubrics and survey questions to measure the depth and frequency of teachers' use of NEIR-ED. When coupled with measures of students' interest and achievement in STEM, and analysis of data collected through these instruments could better explore associations between implementation indicators and levels and STEM student success. Teachers reported that the program yielded an increase in their enthusiasm for their jobs and, in some cases, motivated them to stay in teaching, suggesting teacher engagement, self-efficacy, and retention as indicators of the effects of NEIR-ED on teachers.

The pilot fielded student surveys adapted from programs aligned with SEEE. For example, the S-STEM 21st Century Learning Skills unit assesses collaboration and working with diverse teams, which are also NEIR constructs. The surveys did not, however, address key aspects of NEIR, such as the perceived relevance of course content for students and a sense of student-teacher trust, which were emphasized as examples of positive change in their classrooms by the teachers in the focus groups. To address these gaps, the research team will identify validated instruments for assessing equitable learning environments that more closely align with SEEE in consultation with the program's advisory committee. Other student outcomes to explore in future research noted by the teachers are increased enrollments in STEM courses, and especially upper-level STEM courses.
Note that while some student data was collected by the teachers for the PIs, one post survey for 2023 did provide some anecdotal information that demonstrated the program provided a positive experience for student STEM learning and supported increasing knowledge and interest among students in STEM and engineering. Of the 196 students who responded to a survey in 2023, 82% responded "I am aware of career opportunities in engineering and technology" with 13% unsure. Fifty-one % responded they were interested in learning more about the different ways to work with engineering or technology in their future career. Thirty % were not sure. This suggests that students (and particularly rural students) were both aware of engineering careers following the program and have some interest in learning more.

The data collection process provided information on the feasibility and usability of student surveys in tandem with SEEE implementation. Feedback indicated that the teachers found the surveys feasible to administer to students, especially in the fall, but the low response rates by class and in the spring suggest a need for more follow-up and for teacher and student incentives. Although data sharing agreements with the participating school districts were not part of this study, they will be a needed step for future analyses to fill data gaps (such as course enrollments, grades, and missing demographic information).

The pilot study indicated a need to extend data collection beyond the teachers participating in the PD (and their students) to include the school environment and administrators. The high level of engagement by administrators in one school and the district suggests that administrative support can result in the dedication of additional resources for the program with the potential to expand the program's effects beyond the grant period and participating teachers.

Finally, this pilot's intention was to lay the groundwork for a rigorous future study of student outcomes when the program is implemented with fidelity to more teachers and schools, including rural schools. This project identified data collection challenges, broader impacts on diverse students and teacher experiences in the classroom, and new approaches for improving STEM interest and learning. The students' positive responses, the teachers' improved experience in teaching and the administration's recognition of the program's impact on the school environment and student academic outcomes indicate the NEIR System Change Model embedded with STEM content is a program from which there is much we need to learn.

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