2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC

Host Sponsor UNC Charlotte

Paper ID #50145

Authentic STEM Research Experience for Preservice Teachers on Industries of the Future Research

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Abstract

This paper reports a summary of three years' experience from our implementation of the NSF project titled "Industries of the Future Research Experience for Preservice Teachers in STEM Settings." The original goal of the project was to host 10 high school preservice teachers each summer to participate in Industries of the Future (IotF) research fields and then convert their experience into high school curriculum. IotF topics include artificial intelligence (AI), quantum information science (QIS), advanced manufacturing, advanced communications, and biotechnology. This six-week program sought to advance future educators' knowledge of concepts in IotF as a means of enriching high school curriculums defined in the Texas Essential Knowledge and Skills (TEKS) standard. In summer 2023, the first cohort of 8 preservice teachers (PST) from the UH teachHOUSTON (*t***H**) PST program participated in the RE-PST program at UH Cullen College of Engineering (CCOE). In summer 2024, the second cohort also had 8 PSTs. In summer 2025, the third cohort successfully recruited 16 PSTs. In total, 32 PSTs participated in authentic STEM Research on Industries of the Future research topics. Compared to the first two years, the research mentors were more experienced in assigning research topics and working more closely with PSTs in the last year of the program. This paper provides details on the commonality and changes in the third year's implementation, based on the experience obtained from the first two years. Besides lab research, PSTs also participate in workshops, field trips, and lesson plan counseling. Evaluation assesses the knowledge gains, knowledge transfer to lesson plans, impact of lab research, and impact of support activities. The research results show that participants have improved their average knowledge gains and knowledge transfer, and the summer experience will positively impact their future career. Overall, PST participants reported more positive experience with their mentors in the last cohort.

1. Introduction

Preservice teachers are current undergraduate students who are on a career pathway to be a teacher upon graduation. They can be from different majors such as math, physics, biology, chemistry, and computer science. Secondary preservice teachers will work with students in Grade 8 to 12. These students need to decide whether they are going to graduate with a high school diploma and enter the workforce, or they want to go to a college or university. During this stage, what they experience from the school and real world will have a big impact on their career choice. Therefore, the experience of their teachers plays a significant role in their decision making. This project enriches future teachers' STEM research experience and assists them to bring the experience to secondary school classrooms. The mission of this project, Industries of the Future (IotF) Research Experience for Preservice Teachers in STEM Settings, is to provide research experience to 10 preservice teachers each summer under the three-year NSF grant.

The IotF research, comprising artificial intelligence (AI), quantum information science (QIS), advanced manufacturing, advanced communications, and biotechnology were recommended by the President's Council of Advisors on Science and Technology (PCAST) to the President of the USA [1]. The IotF topics are critical for future industry development and thus the workforce development in these areas is of great importance [2]. Meanwhile, K-12 education requires enhanced STEM content in high school curriculum as part of the graduation requirement [3]. The project was designed to host 10 high school preservice teachers each summer to participate in Industries of the Future (IotF) research fields and then convert their experience into high school curriculum. The objectives were to 1) Recruit 10 high school PSTs from the students in the teachHOUSTON (*t***H**) program to engage in IotF research; 2) Provide interdisciplinary and hands-on research experiences to these PSTs; and 3) Develop course modules based on the research experience and meeting Texas Essential Knowledge and Skills (TEKS) standards [4,5,6]. *t***H** is University of Houston (UH)'s secondary STEM teacher preparation program and addresses the critical need for highly qualified STEM teachers in Texas and across the country [7].

The rest of the paper is organized as follows. Section 2 outlines preservice teacher recruitment for the third cohort. Section 3 describes the RE-PST activities for the third cohort. Section 4 presents the results from the RE-PST program assessment for the three summers. Section 5 has the conclusion for the paper.

2. Comparison of Preservice Teacher Recruitment in Two Summers

Preservice teacher (PST) recruitment is a difficult process. We speculated that students are not sure about what to expect from the summer program and dare not apply even though they are interested. For the recruitment of the third cohort, we decided to start much earlier. The PI walked into the *t***H** classrooms to explain the summer program at various times from November 2024 to February 2025. We also moved the application deadline earlier in the school year to give potential applicants a sense of urgency, and this also allowed us more time to process the applications and select the most motivated students. As a result, we received nearly 30 applications and made 16 offers. Just at the beginning of the summer program, one student dropped out due to health issues, and we were able to fill the position from the waitlist right away.

Based on the experiences over three years of the program, it was obvious that recruitment will never be easy even with the information dissemination through different channels. The key is to start early with updated information. It is critical for engineering professors to walk into the PST classrooms to assure potential participants that this program is designed for them.

3. Teacher Activities

One week before the summer program started, Ms. Mateer offered a training session to the research mentors and research assistants. The training prepared the mentors to learn how to better work with the PSTs.

In all three summers, the first one and a half days were the orientation in which PSTs were given an introduction to the program, introduction to faculty research topics, lab safety, curriculum development expectation, and teachengineering.org website. The PSTs signed an agreement for payment and IRB review purposes. A special 3-hour lab safety session was given by UH Environment, Health, and Safety Program Managers. At the end of the first day, each PST spent about two to three hours assembling a 3D printer with assistance from Research Assistants.

Engineering professors provided workshops during the summer program. In summer 2025, we decided to invite more guest speakers, but we made sure to group speakers with similar or relevant backgrounds together. We also provided guidance to the guest speakers to reduce the technical depth of their presentations while maintaining the big pictures. This made it easier for the students to follow the presentations. A side benefit is when professors from different disciplines listen to one another's talk, they found the connections and started to talk about collaboration.

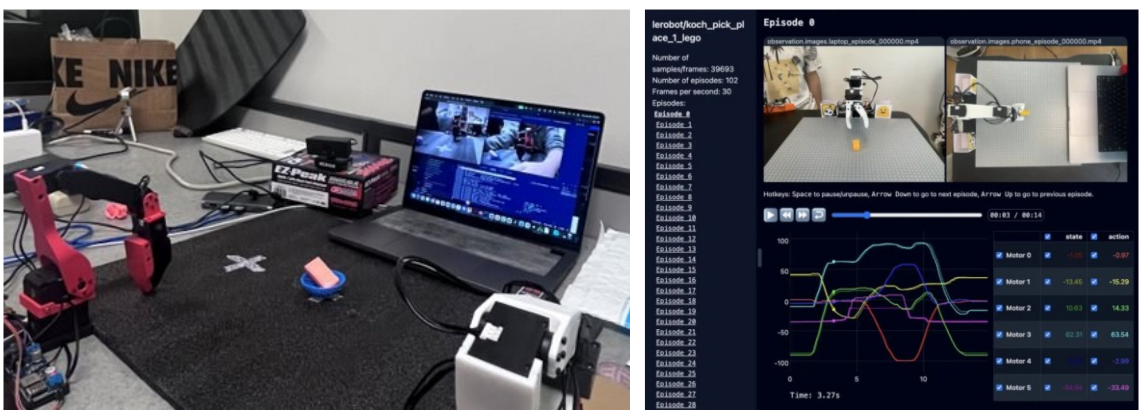
In summer 2025, the 16 PSTs were assigned to several research groups. Assisted by student research assistants, each professor mentored 1-3 PSTs on various projects. The assignment of preservice teachers to mentors was based on the background and interest of PSTs as evidenced by their resumes and essays from the application process. It is challenging to design the projects for the PSTs because the projects should be manageable in six weeks. The support from mentors and RAs is critical throughout the summer experience.

Two project examples in summer 2025 are provided as follows.

1. Two PSTs (one computer science student and one digital media student) were assigned to work on training a robotic arm using collected data so it can autonomously perform specific tasks, like picking up a block and placing it into a basket. This project involved assembling the robot from scratch, calibrating it with test data, and eventually integrating computer vision and neural networks so it can recognize and complete the task on its own (**Figure 1**). They 3D printed and assembled the robotic arms themselves, then calibrated and trained the robotic arms using a dataset composed of multiple "episodes," or demonstrations of the task they wanted the robot to learn. Each episode provided a

different example for the neural network to learn from. In addition to collecting training data, they also worked on setting up the camera input, troubleshooting hardware issues, and testing the robot's ability to generalize the task under different conditions. Based on the knowledge learned from robotic design, they are developing a math lesson plan on proportionality with gearboxes.

2. One student (math student) was assigned to work on developing a wave tank to simulate the waves that are knocking over the planter pots. He created a 3D model of the wave tank in Autodesk Fusion (a computer-aided design software), determined the materials (acrylic sheets and aluminum extrusions), and built the wave tank (**Figure 2**). Some of the components were 3D printed with the printer assigned to him. He also designed a mechanism to generate the wave and controlled the motion with an Arduino board. This student is the only one who has participated in the RE-PST program for the second summer. Thus, he has accumulated some knowledge from the past summer, and he was able to significantly improve his design capability through this hands-on design and implementation project.



(a) Robotic arm experiment setup (b) Signal processing for task training

Figure 1. Robotic arm task completion with imitate learning

(b) Wave tank design and assembly (b) Wave tank experiment setup

Figure 2. Wave tank experiment

In summer 2025, the third cohort visited ARC Specialties, TechnipFMC, Samson Controls, and SLB (**Figure 3**). According to feedback, these field trips were the favorite part for PSTs.

(a) Field trip to ARC Specialties, an industrial robotics company in Houston, Texas

(b) Field strip to SLB Manufacturing and Research Campus in Sugar Land, Texas

Figure 3. Industrial field trips to local companies in Houston

In all three summers, the PSTs worked with the *t***H** lecturer, Ms. Mateer, to apply their learnings to lesson plans for high school students. Each week, they met with Ms. Mateer to discuss options for curriculum development. Course module templates downloaded from teachengineering.org were used to guide course module development. PSTs also met weekly for

Brown Bag PST seminars to share their experiences and discuss curricula. The participants shared their progress in research and knowledge learned. On the final day of the program, the PSTs presented their curriculum prototype for the field teaching to the group and received completion certificates. Ms. Mateer also follows up with these PSTs on the course module implementation in the long semester. The program assessment was led by a professor in human resource development at UH.

Besides the official RE-PST website set up by the research team, a LinkedIn page has been established for the program to disseminate the activities information [8].

4. RE-PST Program Assessment

Each PST was given one pre-program survey at the beginning of the summer and one post-program survey after the summer program was over. Both the pre-program survey and the post-program survey measured the participants' perceptions of their knowledge of IotF technologies and their perceptions of self-efficacy and intentions towards high school STEM teaching. The pre-program and post-program data allowed for within-subjects comparisons to assess the changes in IotF knowledge and skills between orientation ("pre-program") and the end of the summer program ("post-program).

For the summer 2025 cohort, all 16 participants completed both the pre-program survey and the post-program survey. However, three of the participants incorrectly input their data into the ID field used to link their pre- and post-data. Therefore, only data from 13 of the participants appears in this report. Of those 13 participants, 8 identified themselves as women and 5 identified themselves as men. Five participants self-identified as White, five self-identified as Asian/Asian-American, two self-identified Black/African-American, and one participant self-identified as Afro-Caribbean. All 16 participants engaged in a focus group interview at the conclusion of the summer 2025 program.

The following sub-sections ***a***, ***b***, ***c***, and ***d*** address four evaluation questions (EQ), respectively.

1) Do PSTs report improved IotF knowledge and skills after completing the RE-PST research experience?
2) Do PSTs report increased knowledge of how to translate research in IotF technologies to STEM curriculum for high school students?
3) How do mentored research experiences impact RE-PST participants?
4) How do workshops, seminars, and field trips contribute to RE-PST participant outcomes?

In addition, sub-section ***e*** reports the overall satisfaction of the participants.

a. Preservice Teachers Improving Technical Knowledge

Across all three cohorts, the PSTs entered the program with little knowledge about the background in the research topics and almost all the IotF fields. The RE-PST participants had STEM backgrounds from a variety of academic disciplines. Most students were in junior or senior standing. However, they mostly lacked background knowledge needed for conducting engineering research. In the interview, one 2025 PST noted:

"I was just put in here, and I didn't know anything…I needed foundational knowledge before we could actually do the hands-on work."

However, through the RE-PST workshops, all participants obtained basic information in the IotF research areas. Then they obtained in-depth knowledge in certain fields with their mentors. All PSTs completed assembling a 3D printer and some used it in their summer research.

In the pre- and post-program surveys, knowledge of the IotF research areas was assessed using a 5-point Likert scale [1=strongly disagree; 5=strongly agree] on the following survey item for each research area: "*I have knowledge of the latest advancements and trends in the technologies listed below*". As shown in Table 1, most participants in cohort 3 reported increased knowledge of the IotF research areas at the end of the program. Additionally, the average scores show increases in knowledge for all five IotF technologies. Figure 5 uses a bar chart to illustrate the knowledge improvement in IotF. Paired, non-parametric Wilcoxon signed-rank tests were run (13 students × 5 topics) to compare pre- and post- scores and computed two effect sizes per topic. All five topics show statistically significant gains from Pre to Post at $\alpha = 0.05$ (two-sided). Effect sizes are large across the board ($r \approx 0.80$–0.93).

Table 1. Pre-Program and Post-Program Knowledge of IotF Research Areas

	Knowledge of Artificial Intelligence and Machine Learning		Knowledge of Quantum Information Science and Energy System Optimization		Knowledge of Advanced Manufacturing		Knowledge of Communications and Internet of Things		Knowledge of Biotechnology and Sustainability	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
PST-N (2025)	3	5	2	5	4	5	4	5	1	5
PST-O (2025)	1	4	1	3	1	4	1	3	1	5
PST-P (2025)	4	4	4	4	1	5	1	4	4	5
PST-Q (2025)	1	4	1	5	1	5	1	4	1	5
PST-R (2025)	1	1	1	1	1	1	1	4	2	4
PST-S (2025)	3	4	1	2	1	5	1	5	1	5
PST-T (2025)	4	4	1	3	1	3	4	3	1	3
PST-U (2025)	5	5	2	5	2	5	2	5	2	3
PST-V (2025)	1	4	1	2	2	4	5	4	2	5
PST-W (2025)	4	4	2	4	2	4	4	4	4	5
PST-X (2025)	4	5	2	5	4	4	4	4	2	5
PST-Y (2025)	1	5	1	4	1	4	1	4	1	4
PST-Z (2025)	2	5	2	5	2	5	2	--	4	5
AVERAGE	**2.6**	**4.2**	**1.6**	**3.7**	**1.8**	**4.2**	**2.4**	**4.1**	**2.0**	**4.5**

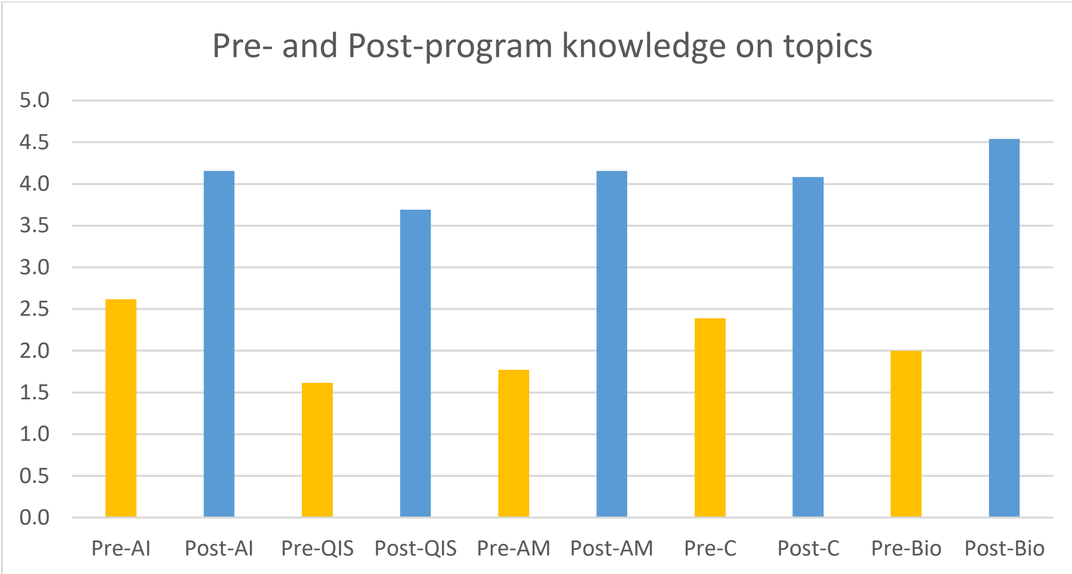


Figure 4. Comparison of knowledge in five general areas of IotF

The interview data also supported the notion that the participants' knowledge of the technology areas grew as a result of participating in the RE-PST program. For example, a 2025 PST commented:

> *"Before coming in, I didn't know what STEM research is really about, but now we really know it."*

b. Preservice Teachers Using New Knowledge to Improve Teaching

In the pre-program survey and post-program survey, participants reported their knowledge of how to translate research in the IotF areas into curriculum content for high school STEM courses. This self-perception was assessed using a 5-point Likert scale [1=strongly disagree; 5=strongly agree] on the following survey item for each research area: "*I know how to translate research in the following areas to improve high school STEM curriculum*". As shown in Table 2, cohort 3 participants mostly perceived that they had more knowledge in this area at the end of the program compared to the beginning of the program. The averages for each research area showed an increased knowledge of how to translate research in these areas. Figure 5 uses a bar chart to illustrate the increased knowledge. Paired, non-parametric Wilcoxon signed-rank tests were run (13 students × 5 topics) to compare pre- and post- scores and computed two effect sizes per topic. The results showed significant improvements in four topics at $\alpha = 0.05$ (two-sided): AI/ML, QIS & Energy Optimization, Advanced Manufacturing, and Biotechnology & Sustainability. Effect sizes are large ($r \approx 0.67$–0.86) and rank-biserial values are high (≈ 0.73–0.94), indicating most non-tied students improved. Communications & IoT shows non-significant change ($p \approx 0.084$) with a moderate-to-large r (≈ 0.55) but more mixed directions ($r\_rb \approx 0.56$), which aligns with the unchanged medians (4 -> 4).

Table 2. Pre-Program and Post-Program Knowledge of Translating Research to High School Curriculum

	Translate Research in Artificial Intelligence and Machine Learning		Translate Research in Quantum Information Science and Energy System Optimization		Translate Research in Advanced Manufacturing		Translate Research in Communications and Internet of Things		Translate Research in Biotechnology and Sustainability	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
PST-N (2025)	2	5	1	3	4	3	4	5	2	4
PST-O (2025)	4	4	2	4	2	5	4	4	3	5
PST-P (2025)	2	1	1	1	1	5	2	5	2	5
PST-Q (2025)	1	5	1	5	1	5	1	5	1	5
PST-R (2025)	4	3	4	3	2	4	4	5	5	5
PST-S (2025)	2	5	2	1	4	4	5	4	1	3
PST-T (2025)	4	5	3	2	3	4	3	4	3	2
PST-U (2025)	4	5	3	5	3	4	4	5	2	3
PST-V (2025)	2	5	1	1	2	4	5	2	2	4
PST-W (2025)	4	4	3	4	4	4	4	4	4	5
PST-X (2025)	2	4	2	5	2	4	4	4	4	5
PST-Y (2025)	2	4	2	5	2	4	2	4	2	4
PST-Z (2025)	2	3	2	3	2	3	2	3	2	5
AVERAGE	**2.7**	**4.1**	**2.1**	**3.2**	**2.5**	**4.1**	**3.4**	**4.2**	**2.5**	**4.2**

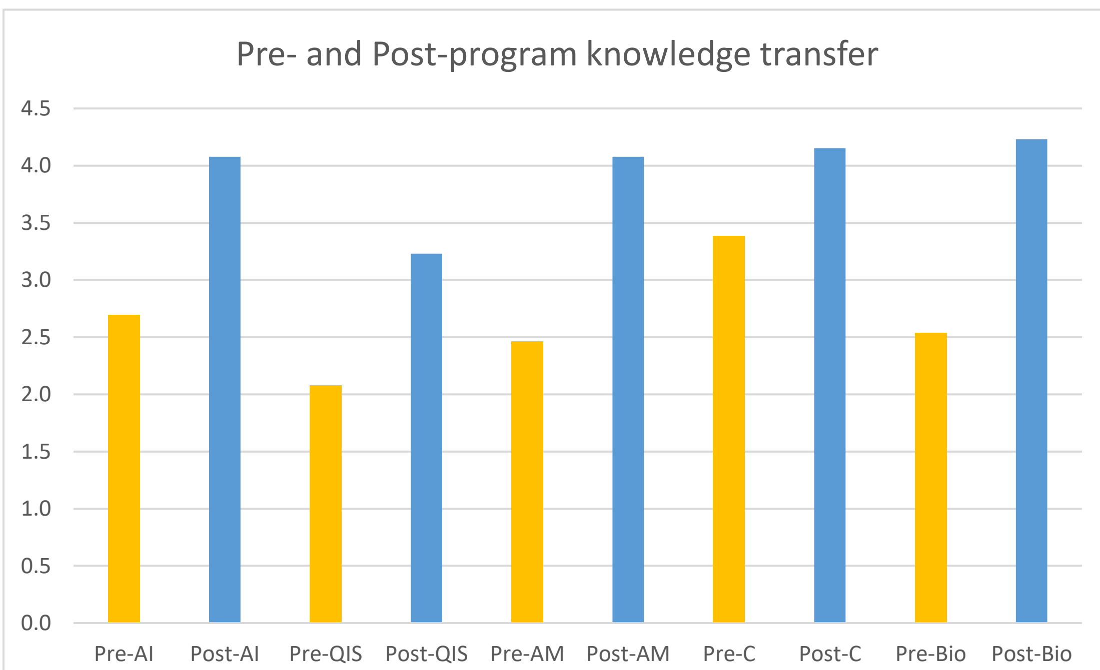


Figure 5. Comparison of knowledge transfer in five general areas of IotF

In the pre-program survey, PSTs were asked which technologies they wanted to add to their instruction when they became teachers. Notably, the 2025 PSTs mentioned a wide range of technologies for use in their classrooms. However, they did not name specific technologies but focused on potential functionalities that they would like to incorporate in their future classrooms. For example, one 2025 PST noted:

> *"I would like to incorporate a diverse amount of technology to my instruction when I become a teacher. I think it would be important to allow students to interact with various types of machines to learn about the variety in technology.*

When asked about using technologies in their teaching at the end of the program, most PSTs demonstrated intentions to integrate a wider range of technologies in their future teaching. For example, the 2025 PST student that provided the vague answer at the beginning of the program provided the following response at the end of the program, incorporating more specific technologies into their response:

> *"I plan to implement using 3D printing, and potentially other biotechnology resources such as DNS, centrifuging, and incubators."*

Presumably, this is a result of the exposure to the IotF technologies and potential instructional applications during the RE-PST program. The data suggested that the RE-PST program created new possibilities related to cutting edge technologies for these preservice teachers, which will ultimately impact the students that they teach in the future.

Furthermore, at the end of the RE-PST program, the participants were asked about the most important things that they learned over the summer. The participants' responses mainly focused on technology application in teaching and learning. For example, 2025 PSTs provided the following responses:

> *"[The most important things I learned from this summer research experience were] how to use technology to solve societal problems, how to adapt research to classroom experience, and develop lessons that evoke student curiosity and that are student centered."*

> *"I learned how to take a small piece of science (conceptually) and fit it together with a math TEK for highschoolers/middle schoolers and make a whole unit out of it."*

These responses provide some evidence that the participants were making connections and actively thinking about how the new technologies can be used to enhance their instruction in STEM classrooms, which is one of the primary objectives of the RE-PST program.

c. Preservice Teachers Learning Real-World Applications

The PSTs were positively impacted by the opportunities to see real-world applications of the new technologies that they were exposed to during the RE-PST. Participants in the 2025 cohort highlighted the experience of hands-on research as a valued aspect of the program. They noted that data collection, experimentation, design tasks were both enjoyable and meaningful for their development as preservice teachers. Conversely, participants who spent extended periods of time reading materials without application or sufficient context expressed frustration. From a 2025 PST:

> *"It was a really diverse experience; a lot more hands-on than I thought it would be, which I think was nice."*

Another 2025 PST noted:

> *"The best parts were being in the lab and actually doing things."*

In the interviews, participants commented on how the RE-PST program encouraged them to make connections between their previous knowledge and new knowledge of the IotF technologies. Identification of real-world applications during the RE-PST program was especially driven by the field trips and the research projects. For example, a 2025 PST commented:

> *"I didn't know what companies existed in Houston… I needed to know what's actually out there."*

Importantly, by learning real-world applications, the PSTs are better equipped to share these applications with their own students.

d. Preservice Teachers Realizing New Professional Opportunities

The RE-PST program seemed to open new options in STEM education and was potentially career-altering for some of the PSTs. For example, a 2025 PST noted that the hands-on research experiences in the RE-PST program will contribute to the decision of what field to pursue in graduate studies:

> *"Now I know that I don't want to do STEM research and maybe in the next semester I will be more involved with humanities research so that I can see which one I really want to pursue for my masters and doctoral degree."*

These data indicate important aspects of growth and development for these future teachers. By widening their view of what is accessible and possible, they can do the same for their students.

e. Preservice Teachers' Satisfaction with the RE-PST Program

Overall, the participants reported positive experiences and highlighted the positive aspects of the program. One PST specifically noted that the program was more difficult than expected but it turned out to be a better experience than originally anticipated:

> "*As teachers, we always talk about how our students are supposed to struggle a bit. But, not like completely struggle. As a student, I felt like coming into this, I was a student who had to learn everything. And I had to*

feel that struggle and I eventually learned how to deal with that struggle and learn from it. So, I think that was a big addition to this – that we had to experience that."

The one PST who was a member of both the 2024 cohort and the 2025 cohort commented:

"[The 2025 program] exceeded my expectations. Like the difference between this program this year and last year, it's like worlds better. Like last year, I think every lab had downtime and no hands on and periods where it was just like, why am I even here? But from what I can tell most people seem to be working on something most of the time, at least from what they can present. And the course modules…Miss Mateer did a much better job this year. But, also I feel like what my peers have produced this year is way, way, way better. Yeah, and maybe it's the people that are in this program this year, but maybe it's just that the program overall has improved too.

The PSTs reported the best aspects of the program included the program faculty and industry partners. A 2025 PST commented:

"I really love the idea of going to different companies and seeing the work that's being done and be able to talk to those engineers and scientists about various topics. That really opened my mind to a new whole level of understanding of these fields and be able to stay connected and even follow up with them as well. So I think my favorite part of the program will definitely be the field trips and the lectures with different professors at University of Houston."

The positive experiences, including learning and developing beyond their initial comfort zone, outweighed the concerns that the participants had about the program. In the interviews, they stated that they were glad they participated in the program, it will positively impact their teaching in the future, and they would recommend the program to future preservice teachers.

5. Lesson Learned

In summer 2025, most mentors had mentoring experience with preservice teachers or in-service teachers in the past. Only two professors were new mentors who then received training from Ms. Mateer and the PI. Overall, we have an experienced team working with the preservice teachers. The lessons are classified into two categories as below.

A. For the Mentors

1) Recruitment for PSTs is never easy. It took a lot of effort to recruit each cohort because we had new students every year, although they may have heard stories from the past years. Most PSTs were math, computer science, and biology undergraduate students. They did not have exposure to engineering and technology which is much needed in high

school teaching. Therefore, even though the RE-PST program was designed for PSTs, it was necessary to explain the program clearly on a one-on-one basis.

2) Communication between faculty mentors and PSTs prior to the RE-PST program was critical. In the third cohort, encouraged by the PI, some students reached out to their mentors months before the summer started and visited their labs. Research tasks and the expectation should be clearly explained to the PSTs at the beginning of the summer program.
3) Getting the students to complete the course module development was not an easy task. It takes a highly self-regulated student and consistent support from the *t***H** program to make it happen. Motivation and execution on the course improved with each cohort.

B. For PSTs:

1) Getting a good curriculum specialist can greatly help teachers in preparing their course modules. It is necessary to keep the communication channels between mentors and curriculum specialists to tune the research tasks. In the weekly PSTs' conferencing call, the PSTs were given half a day to meet together, share their research experience, and discuss how to convert their experience into curriculum.
2) The psychological changes of the PSTs must be considered and watched during the progress of the RE-PST program. Research tasks may need to be tailored to be compatible with teachers' backgrounds to be more relevant and meaningful. It is also helpful to ask PSTs to help each other.
3) PSTs enjoyed the field trips very much and considered them as the critical components of the summer research to get real world engineering experience.

6. Conclusion

The 3-year project started in 2023. Across three cohorts, a total of 32 PSTs has completed the summer program [9]. Compared to the first two summers, our mentors are more experienced in mentoring the students and can adjust the research task scope to the level that can be accepted by the PSTs. The PSTs were exposed to a more diverse set of research topics through workshops from many more guest speakers. All these contributed to a more successful third cohort. There is a list of lessons learned from the past three summers. For the last cohort, we implemented the following changes:

1. Planned much earlier in the student recruitment, and match PSTs and faculty based on their mutual interest.
2. Defined research tasks more clearly for PSTs before the summer starts and make sure both PSTs and faculty mentors understand the expectation.
3. More closely followed with the students after the summer on the course module implementation.
4. We went back to the original dates to start the summer from early June to the end of July.

These changes proved to be effective. Overall, the RE-PST is a great success. We hope that our program has helped build a preservice teacher workforce with higher self-efficacy. We have received a lot of inquiries about the continuation of the program in the future years. Currently we are following up our participants in their lesson plan development.

Acknowledgment

All authors and faculty participating in this project are sponsored by the National Science Foundation grant #2220683. Their support is greatly appreciated. W. Zhu acknowledges the funding from the support from National Science Foundation grant #1855147, #1950036, #2141674, and #2501700, US Department of Education grant P116S230007, and US Department of Agriculture grant #13111855, #13424031, and National Academy of Science grant #200011064 to the University of Houston.

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