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Research Experience for K-5 Educators to Enrich the STEM Ecosystem by Producing Accessible Curricula Based on National Standards

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Introduction

In order to sustain economic growth, maintain national security, and endure as a global leader, the U.S. needs to further develop a qualified STEM workforce [1]. The STEM pipeline is a metaphor used to describe the recruitment and retention of students through STEM education. Early in this STEM pipeline, elementary educators' beliefs and attitudes towards STEM have a significant impact on their students' attitudes and confidence in STEM subjects. Elementary educators are trained to teach cohorts of students for an entire day and are not assigned to subjects; therefore, their classrooms have the unique opportunity to integrate multiple subjects including science, engineering, and language arts. Even with this comprehensive teaching expectation, there is inadequate exposure for K-5 educators to learn and integrate STEM concepts and then confidently support STEM interests and skills in their classrooms. This indicates a clear need for professional development (PD) experiences in STEM education that will build a strong foundation and confidence for elementary educators. There are currently fifty-three Research Experience for Teachers (RET) sites in Engineering and Computer Science that are actively funded by the National Science Foundation [2]. Only seven out of the fifty-three programs include K-5 educators, with ours being the only one exclusively developed for primary school educators. The goal of this Multidisciplinary Research Experience for Teachers (MRET) program is to increase interest and preparedness for K-5 educators and translate local community impacts to the national stage by creating accessible curricula based on national standards for educators across the nation.

TeachEngineering (TE) is a digital library comprised of standards-aligned engineering curricula for K-12 education. TE is a dynamic platform where university engineering faculty, graduate students, and K-12 teachers develop and publish curricula to make applied science and math come alive through engineering design. Educators have free access to publications from across the nation that incorporate the Next Generation Science Standards (NGSS). NGSS developed their standards based on *A Science Framework for K-12 Science Education* which emphasizes the importance of integrating science and engineering practice, crosscutting concepts, and disciplinary core ideas. We hope our program will provide K-5 educators with the tools and confidence to create and publish curricula to TE to improve STEM education locally and nationally.

Methods

In the three previous offerings of our program, we followed a decentralized Scientist-Teacher Partnership (STP) model in which the individual teachers are embedded in research laboratories, paired with a graduate student scientist mentor, and participate as contributing members of the research group. This decentralized model aligns with characteristics of both the "SciRes" and "SciPed" programs as described by Enderle et al [3], and similarly their limitations. In the past three programs, K-5 educators were assigned to different labs in the University of Florida's

Herbert Wertheim College of Engineering. They were mentored by graduate students with a variety of research themes. For example, some labs focused on tissue mechanics and cellular processes, some worked on biomedical applications of magnetic micro-and nanoparticles, and some studied engineering solutions that reduce wind damage to buildings from hurricanes. The wide range of engineering displines provided K-5 the opportunity to explore different aspects of engineering and share with their peers what they learned at the end of the program via presentations. However, this decentralized model presented many challenges. Logistically, it was a challenge to contact multiple principal investigators and assign graduate students to mentor the attendees. Furthermore, this model could not guarantee all K-5 educators received the same level of STEM exposure. There was also a lack of community-building within the teacher cohort, since their day-to-day laboratory activities were in different facilities.

During the centralized STP in which all educators were embedded in one dedicated teaching laboratory for six weeks, the participants were team-taught by a collection of university faculty and undergraduate student scientist mentors. The K-5 educators were exposed to tissue engineering concepts and taught how to mechanically characterize samples and fabricate hydrogels. They used STEM concepts and engineering design principles to mimic native tissue properties in hydrogels. They read experimental journal articles, documented laboratory work in notebooks, and shared project results with poster presentations.

After this immersive research experience, MRET participants were encouraged to develop their own TE curriculum based on their experience. Most importantly, the educators used their general engineering design principles and STEM confidence to develop curricula suited for elementary levels. Although all K-5 educators were able to independently fabricate hydrogels at the end of the summer program, they were not expected to teach their K-5 students the fabrication process. Their TE curricula could be on any scientific topic and were not limited to the hydrogel fabrication process. Our team implemented hydrogel fabrication as a tool to expose the K-5 educators to the engineering process. The engineering principles the educators learned throughout their hydrogel experiments can be translated to their classrooms at a level appropriate for elementary students. Learning these principles at a higher level allows for greater confidence when translating to their classroom and grade level. The goal of the curriculum was to make them feel comfortable about fundamental STEM concepts and to become familiar with the engineering process.

The direct relationship between K-5 educators and scientist mentors allowed for the integration of the NGSS into their research experience. Educators were encouraged to ask questions, analyze data, design solutions, and obtain, evaluate, and communicate information. This structure facilitated relationships and scientific debates that deepened their understanding of the engineering problem and process. The educators had authentic engineering experience in the centralized teaching laboratory during morning sessions, followed by afternoon sessions dedicated to curriculum development. The K-5 educators integrated the engineering design skills into classroom applications by creating STEM-inspired curricula, which facilitated technical and PD relationships.

The afternoon session was led by faculty members from the College of Education at Univeristy of Florida. They discussed how to incorporate what they learned from the morning session into their curricula based on their students' needs. Although all the educators had the same experience making hydrogels, their students were at different levels of the K-5 spectrum. Educators focused on 1st grade may need to create their curriculum vastly different from educators teaching 5th grade. During the afternoon session, the educator reflected on their students' needs and integrated key engineering concepts such as observing tissue samples, taking measurements, making stock solutions, and analyzing results for their respective classrooms.

In order to study the significance of the curricula created by MRET participants, our research team acquired information directly from the TE website. In the Supplemental section, we created Tables 1, 2, and 4 to visualize the subject area and NGSS covered by each educator's curricula. We also include Table 3 to list the descriptions of the various NGSS categories. Out of the 23 curricula created by the MRET participants, 16 had official NGSS assignments. For the rest of the curricula, our research team assigned the appropriate NGSS based on the descriptions outlined in the curricula. Table 1 indicates the curricula without official NGSS assignments. All the curricula have official subject area assignments.

Results and Discussion

Our MRET site has supported four summer immersive experiences exclusively for K-5 educators. To date, our MRET program participants have has published 23 curricula on TeachEngineering. Out of 78 NGSS categories for K-5, 15 unique standards were implemented in the 23 curricula [4]. Among the 15 standards represented in our MRET program output, two standards were dominantly used by our MRET participants. Out of the 23 curricula, 22 incorporated ETS1-1, and 18 incorporated ETS1-2. ETS1-1 for K-2 expects students to ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool. ETS1-1 for 3-5 expect students to define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. ETS1-2 for K-2 expects students to develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem. ETS1-2 for 3-5 expect students to generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. Based on the nature of their immersive research experience, it makes sense that ETS1-1 and ETS1-2 are strongly represented in the teachers' curricula.

In the three previous offerings of our program, the K-5 educators produced a variety of curricula that met the NGSS. While some of the curricula closely related to what the educator was exposed to in the assigned lab, other curricula incorporated core engineering concepts but deviated from the research topic of the lab. Although publications to TE from educators who completed this program do not directly correlate to what they worked on in the collegiate setting, they meet NGSS and reflect core engineering concepts. For example, one educator was assigned to a lab with the main research focus on soft matter 3D printing. The educator created an activity designed to give students an understanding of one aspect of what an engineer does and the ability to experience various steps in the engineering design process as it relates to a 3D printing task. On the other hand, one educator's publications, who was assigned to a research laboratory that focused on tissue mechanics and cellular processes, did not relate to tissue engineering but aligned with standards that emphasize the design process. Many of the curricula included activities such as making observations, making prototypes, improving prototypes based on feedback, learning about constraints (money, resources, time), encouraging teamwork and discussion, and connecting their work to real-world applications. The educators implemented these core concepts of the engineering process with the hope to demonstrate to their students what engineering is like, boost their interest in STEM, and inspire them to explore the world with an engineering mindset.

Educators from the summer 2021 MRET cohort are still finalizing their TE curricula and have not submitted their final work. However, we are able to comment on their current drafts. Their proposed classroom engineering projects show how they were able to apply the STEM skills learned through hydrogel experimentation to a variety of different topics. Examples of projects proposed include designing a water bottle holder for a desk, designing a new lamp that uses light more efficiently, and developing a high yielding method to extract milkweed seeds. In their proposals, the teachers emphasized the importance of identifying needs and constraints, creating a prototype, evaluating the design, and adjusting the design based on information acquired. This aligns with the engineering design process identified by TE. Their proposals mimicked the iterative process used during the summer research hydrogel experiment, which demonstrates comprehension of the engineering design process. The educators were able to adapt their experiences from the hydrogel experiments to their classroom level, ranging from 5th graders designing new lamps to better utilize light, to kindergarteners developing methods to extract milkweed seeds for monarch butterflies. Throughout the educator's experimentation with mimicking hydrogels to native tissues, they internalized the steps of the engineering design process. By immersing them in this environment and mindset, it increases confidence and ability to translate it to the classroom at various levels.

Conclusion

This unique program enables K-5 teachers to translate the engineering design process such as prototyping, data analysis, and iterative processes into their classrooms. Elementary educators are empowered to confidently teach STEM concepts and lay the foundation of STEM interests and skills for their students. With a new cohort every year, 68% of Alachua County schools have had alumni from this program as shown in Figure 1. The goal of the program is to equip individual teachers with the skills required to impact the community. The alumni network of the MRET program fosters collaboration among K-5 educators in Alachua County. This collaboration not only benefits the local community but also produces high-quality curricula that will have a significant impact on the national level.

All K-5 educators have free access to TE curricula and can collaborate locally or with educators across the globe. Nationally, the curricula our MRET alumni produced can inspire other educators with classroom experiments that meet the NGSS. In the three previous offerings of our program, we followed a decentralized STP model in which the individual educators were embedded in research laboratories and worked with a graduate student scientist mentor within a university research group. Our current offering uses a centralized STP model which we believe provides K-5 educators with a more thorough understanding of STEM concepts and practices and provides an authentic experience in integrating engineering and language arts. We are currently exploring if the centralized versus decentralized program model impacts the TE curricula outcome such as science content, engineering design, and science terminologies developed by participating teachers.

As the program continues, our goal is to increase the number of Alachua County schools with alumni in order to ensure STEM confidence coverage across the county and collaboration between schools, hence fortifying a supportive STEM educator ecosystem. Within our centralized Scientist-Teacher Partnership model, there are many choices and details we look forward to investigating further. This includes the exploration of one long-term versus multiple short-term sequential projects and infusion of K-5 practices into the laboratory experience like skills badges. The RET site experience along with participant publishing in Teach Engineering has both local and national impacts on educational environments.

Acknowledgments

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References

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Supplemental

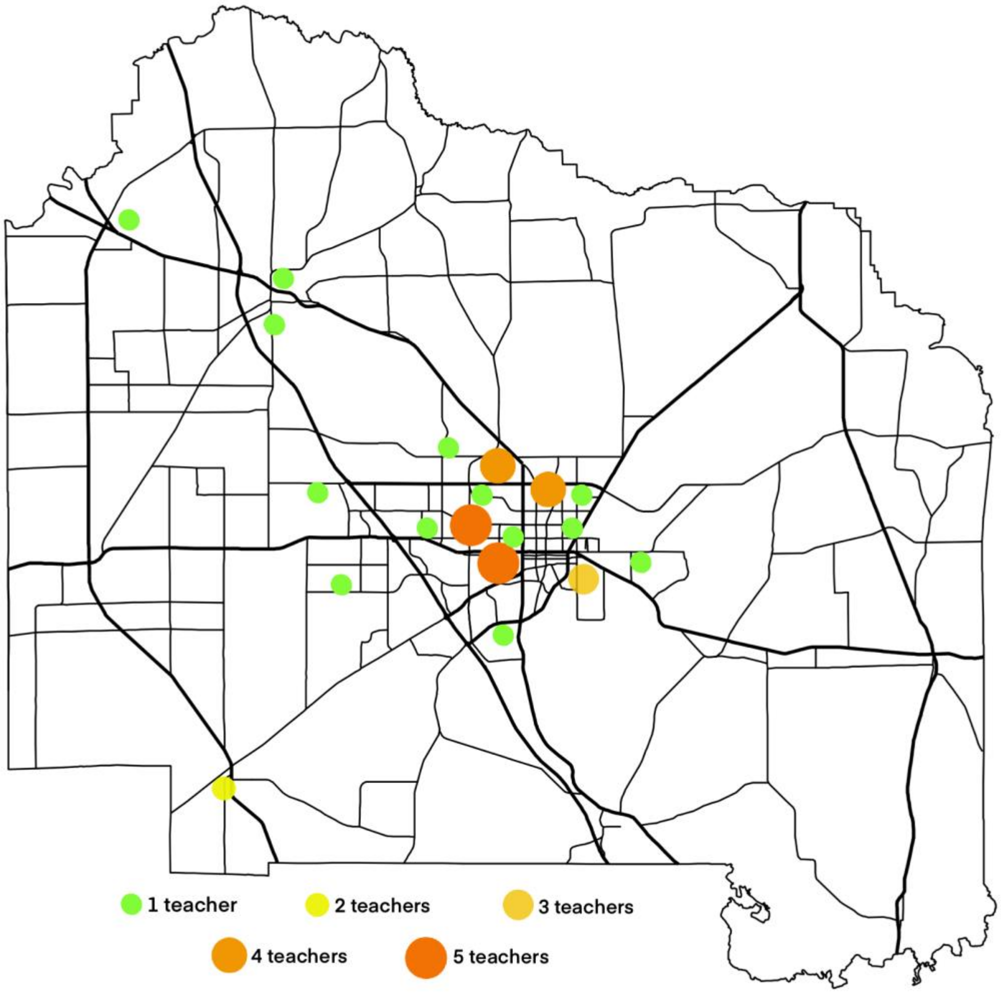

Figure 1 Alachua Elementary Schools Coverage Map

Table 1 TeachEngineering Curricula Created by MRET Participants

Curriculum Number	Teacher	Cohort	Published Date	Curriculum Grade Level	Instructional Time (mins)	Group Size
1*	Teacher 1A	2017	2018	1	60	4
2	Teacher 1B	2017	2020	2	270	N/A
3	Teacher 2A	2017	2018	2	90	2
4	Teacher 2B	2017	2021	1	315	2
5	Teacher 3	2017	2021	K	90	2
6	Teacher 4	2017	2021	3	150	3
7	Teacher 5	2018	2020	1	900	4
8	Teacher 6	2018	2019	K	240	5
9	Teacher 7	2018	2019	2	450	4
10	Teacher 8	2018	2019	4	540	4
11	Teacher 9	2018	2019	5	75	4
12	Teacher 10	2018	2019	1	540	4
13	Teacher 11A	2018	2018	3	495	4
14*	Teacher 11B	2018	2020	K-5	180	N/A
15*	Teacher 11C	2018	2020	K-5	180	N/A
16*	Teacher 11D	2018	2020	K-5	180	N/A
17	Teacher 12A	2018	2019	4	660	5
18*	Teacher 12B	2018	2020	K-5	135	N/A
19*	Teacher 12C	2018	2020	K-5	45	
20	Teacher 13	2019	2020	1	270	4
21*	Teacher 14	2019	2021	5	45	N/A
22	Teacher 15	2019	2020	4	135	4
23	Teacher 16	2019	2020	1	60	2

** indicates a curriculum did not have an official NGSS assignment*

Table 2 Subject Areas Covered by TE Curricula Created by MRET Participants

TE Subjects / Teachers	Teacher 1A	Teacher 1B	Teacher 2A	Teacher 2B	Teacher 3	Teacher 4	Teacher 5	Teacher 6	Teacher 7	Teacher 8	Teacher 9	Teacher 10	Teacher 11A	Teacher 11B	Teacher 11C	Teacher 11D	Teacher 12A	Teacher 12B	Teacher 12C	Teacher 13	Teacher 14	Teacher 15	Teacher 16	Total
Algebra																								0
Biology							Δ				Δ	Δ									Δ			4
Chemistry										Δ											Δ			2
Computer Science																								0
Data Analysis and Probability																								0
Earth and Space						Δ																Δ		2
Geometry																								0
Life Science			Δ				Δ		Δ			Δ	Δ	Δ	Δ		Δ				Δ			9
Measurement		Δ				Δ		Δ	Δ	Δ		Δ									Δ			7
Number and Operations								Δ																1
Physical Science		Δ		Δ		Δ		Δ		Δ			Δ	Δ	Δ	Δ		Δ	Δ	Δ	Δ		Δ	14
Physics																								0
Problem Solving	Δ							Δ	Δ	Δ				Δ	Δ		Δ	Δ	Δ	Δ		Δ	Δ	12
Reasoning and Proof	Δ											Δ											Δ	3
Science and Technology			Δ	Δ		Δ					Δ													4

The green box with a Δ in it indicates a subject area is covered by the respective teacher.

Table 3 NGSS Descriptions

NGSS Categories	Grades	NGSS Performance Expectation
K-ESS3-1	K	Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
K-ESS3-3	K	Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.
K-2-ETS1-1	K-2	Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.
K-2-ETS1-2	K-2	Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.
K-2-ETS1-3	K-2	Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.
2-PS1-1	2	Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties.
2-PS1-2	2	Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.
3-ESS3-1	3	Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.
3-LS4-3	3	Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.
3-LS4-4	3	Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.
3-5-ETS1-1	3-5	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2	3-5	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3	3-5	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
5-PS1-4	5	Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
MS-ETS1-4	6-8	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Table 4 NGSS Categories Covered by TE Curricula Created by MRET Participants

Standards / Teachers	Teacher 1A	Teacher 1B	Teacher 2A	Teacher 2B	Teacher 3	Teacher 4	Teacher 5	Teacher 6	Teacher 7	Teacher 8	Teacher 9	Teacher 10	Teacher 11A	Teacher 11B	Teacher 11C	Teacher 11D	Teacher 12A	Teacher 12B	Teacher 12C	Teacher 13	Teacher 14	Teacher 15	Teacher 16	Total
K-ESS3-1							Δ																	1
K-ESS3-3									Δ															1
K-2-ETS1-1	Δ	Δ	Δ	Δ	Δ		Δ	Δ	Δ			Δ								Δ		Δ		11
K-2-ETS1-2	Δ	Δ	Δ					Δ	Δ											Δ			Δ	7
K-2-ETS1-3												Δ												1
2-PS1-1				Δ																				1
2-PS1-2				Δ																				1
3-ESS3-1																	Δ							1
3-LS4-3													Δ											1
3-LS4-4																	Δ							1
3-5-ETS1-1						Δ				Δ			Δ	Δ	Δ	Δ	Δ	Δ	Δ		Δ	Δ		11
3-5-ETS1-2						Δ				Δ			Δ	Δ	Δ	Δ	Δ	Δ	Δ		Δ	Δ		11
3-5-ETS1-3						Δ				Δ	Δ		Δ				Δ				Δ	Δ		7
5-PS1-4										Δ											Δ			2
MS-ETS1-4											Δ													1

The green box with a Δ in it indicates an NGSS category is covered by the respective teacher.