# Paper: Bringing Science Education and Research together to REACT

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# Bringing Science Education and Research together to *REACT*


## Abstract

This "Innovation in Engineering Teaching Practices" paper will describe the student led co-curricular REACT (Research Education and Activities for Classroom Teachers) program at the University of Michigan. REACT was formed in 2017 to bring K-12 math and science teachers from Michigan together for a one-day, interactive learning experience to help incorporate research into their classrooms. Teachers listen to graduate student talks, go on research lab tours and are provided novel lesson plans and materials for two hands-on activities that can be used in their K-12 classrooms. Graduate students from eleven engineering and science departments collaborate to develop these materials and ensure they meet the Next Generation Science Standards (NGSS). Teachers earn continuing education credits for attending. REACT is an opportunity not only for teachers to learn about the cutting-edge research happening at University of Michigan, but also serves as a professional development tool for graduate students, giving them the opportunity to work on science communication skills as well as participate in curricula development. The program has also developed a unique funding model, where university professors and departments sponsor individual teachers, so attendance and all materials are free for educators. Since 2017, REACT has hosted ninety K-12 teachers from seventy different school districts. Similar workshops are being developed at other universities based on REACT's model. At times, the distance between graduate school and K-12 education can seem very large, but as one REACT participant stated: "REACT has been an effective way to bridge the gap between the research community at the University and the education sphere."


## I. Introduction & Background

With the rising focus on engineering and inquiry-based science education, it is becoming more crucial to incorporate real-world concepts and applications of science and engineering into the classroom[1]. This need is heightened by the profound impact of such education on a student's career choice[2], [3]. K-12 educators often do not have opportunities to form long-term relationships with the scientific researchers applying the concepts taught in classrooms[4]. Programs such as NSF Research Experience for Teachers (RET) aim to alleviate this disconnect by placing primary and secondary school teachers in summer positions within research laboratories. These programs show a measurable impact on the beliefs and pedagogy of the participating teachers, especially in RET programs which directly focused on incorporating the gained skills and knowledge in the teacher's classrooms[5]. There have also been efforts on a more local scale. North Dakota State University started *GraSUS*, a graduate student-led collaboration with area educators where graduate students worked alongside teachers to develop activities to augment the science curriculum[6]. This partnership ran from 2001-2010, funded by the National Science Foundation (NSF, 2001-2009) and local/internal funds (2010).

Establishing a connection to a university setting with the potential for future collaboration provides a crucial piece in the incorporation of research into science education. To increase the number of connections available to teachers within our region, we founded Research Education and Activities for Classroom Teachers (REACT), a one-day workshop focused on opening the doors of research laboratories and facilities to K-12 STEM teachers. Providing these connections increases the likelihood of teachers continuing their self-study of research topics, students visiting campus, and starting conversations between educators and researchers. An important aspect of this mission is to *involve* teachers in the conversation on the incorporation of these ideas. Participating researchers understand that they are providing *access*, not teaching instruction, to the educators, as teachers' expertise is too often undervalued in the development conversation[7], [8].

The idea for REACT's structure grew out of our classroom–based outreach efforts, in which we trained graduate student volunteers to bring polymers–based lessons to K-12 classrooms[9]. As the demand for classroom visits exceeded our resources, particularly volunteer availability and constraints on travel distance, we realized that we could increase our efficiency and reach by inviting teachers to campus and equipping them with the activities our graduated students normally led. This would also address the call from the educator population for more professional development which allows teachers to exchange ideas and resources and the geographic reach of such resources[10]. As the planning continued, we expanded the event to include multiple departments and identified additional elements of scientific research beneficial to education professionals. The resulting schedule included student speakers, lab tours, and training in these hands-on lessons and activities, for a total of 4 eligible continuing education credits. A key component to long-term impact is continued contact, thus we also engaged with participants through social media and follow-ups and provided all workshop materials on our website for download and reference.

We expanded the breadth of REACT to include multiple departments and workshop components. The mission of the event is to provide connections between science researchers and science educators and disseminate activities practiced by student outreach groups on campus. We proposed this idea in April 2017 to the University of Michigan's Center for Educational Outreach (CEO), and it was first planned for June 2017. REACT 2017 was attended by 19 teachers and received universal acclaim from its participants. With this success, we planned REACT again for June 2018 and again in July 2019 and broadened the scope, expanding the event to approximately 50 teachers.

## II. Summary of Goals

REACT aims to close the gap between higher education and primary/secondary education by focusing on providing school educators with physical and academic resources that will enable them to translate their exposure to university STEM research into the classroom. This is achieved by providing classroom-sized demonstrations that teachers can take back to their schools and is supplemented with research facility tours and researcher engagement over a day-long workshop. A main consideration with REACT's structure is sustaining long-term impact on university-teacher engagement, primarily achieved through curriculum access and feedback follow-through. Additionally, university graduate students are tasked with communicating their science to a broader audience through novel demonstrations and scientific talks for these teachers to translate to their students. This professional development element provides an incentive structure for professional societies, student organizations, and various university departments, which serve as the main sources of funding. A critical aspect of REACT's organization is the sustainability of the funding structure. Through aligning incentives between university outreach goals ("Institutional Missions"), university student-based organizations and academic departments ("STEM Leaders"), and primary/secondary teachers (“Educators”), REACT promotes a successful and sustainable model to achieve K-12 student STEM engagement (Fig. 0).

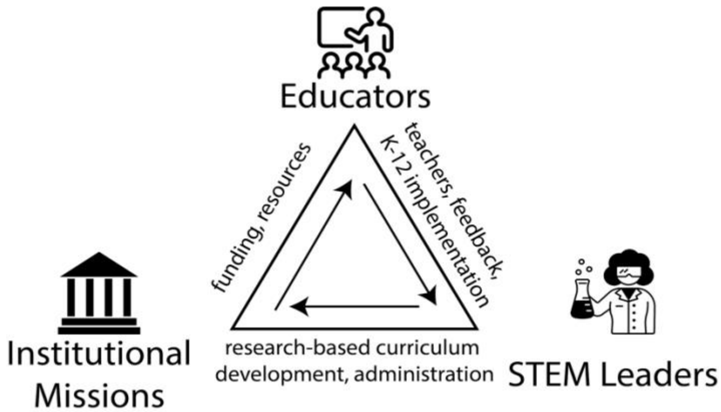


**Figure 0.** The incentive structure that considers all major players in the REACT ecosystem. “Educators” are mainly teachers but may be other community members. “Stem Leaders” are primarily graduate student researchers, which may be sourced from academic departments or student organizations. “Institutional Missions” refers to university outreach goals to promote STEM education and access in local communities. Funding is acquired through diverse pools of institutional organizations, such as departments, labs, student organizations, and other offices.

## III. Model

REACT’s model prioritizes the breadth and longevity of its educational impact. The overarching structure of REACT is an “inverted classroom visit” model. Where a classic classroom visit structure involves graduate students travelling to classrooms and teaching a lesson or demonstrating an activity, this inverted structure has participants visit the university’s campus. The REACT workshop is divided into three primary components: 1) research talks by graduate students and researchers, 2) lab and facility tours, and 3) demonstration of hands-on activities for the classroom. These components are structured to maximize interaction between graduate students and educators, as well as give educators opportunities to interact as a group[11], [12]. The flow of these tracks throughout the day is shown in Fig. 1.

**Graduate Student Research Talks** The workshop begins with 15-minute research talks presented by graduate students. Prospective student speakers are chosen anonymously based on their responses to applications answering the questions “What would your talk be about? Explain in four sentences or fewer.” and “How do you think teachers could use this information in their classrooms?” This process led to greater number of under-represented science researchers being selected for talks, as anonymous screening of applicants has been shown to increase diversity in many fields[5], [13]. The diversity of the speakers, both in their identities and research, provided teachers (and through video recordings, their students) with a more concrete and accurate image of today’s scientists and engineers. A few weeks prior to the event, we provide the speakers with a communications skills workshop, pulling experts from the nearby area to help with the critiques, including from the Huron Valley Toastmasters organization, the University of Michigan Natural History Museum, and the University of Michigan Center for Education Outreach.

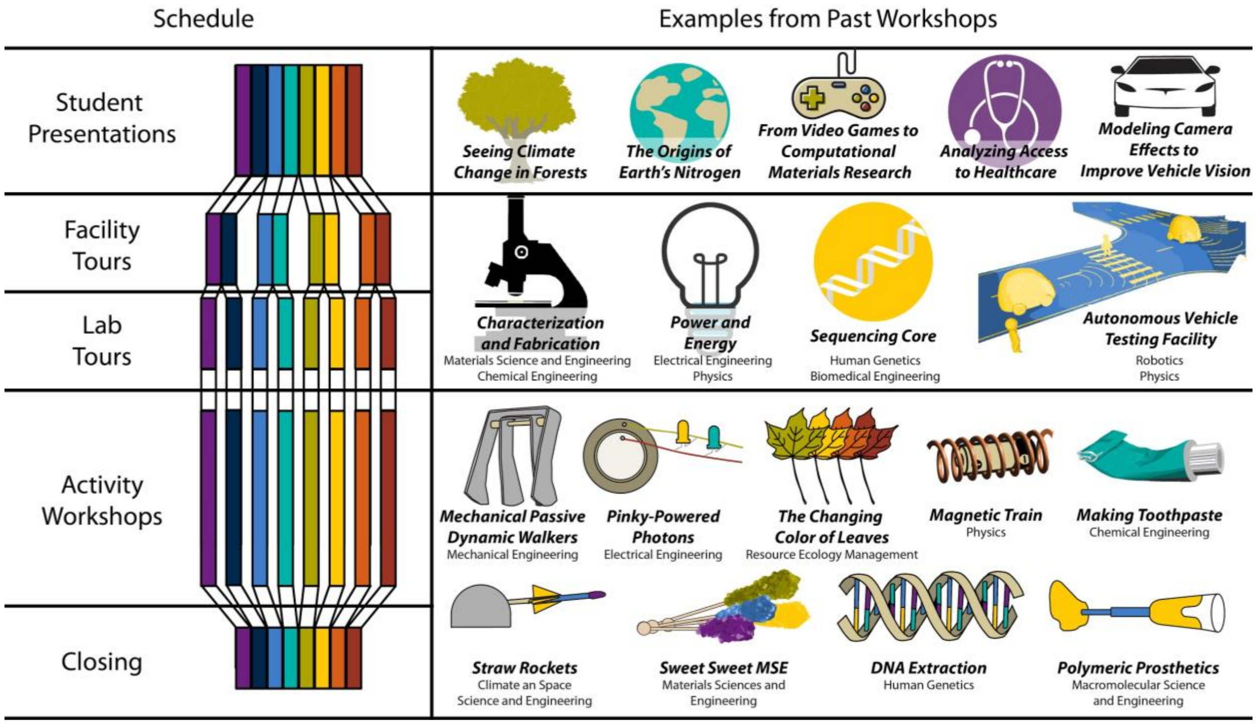


**Figure 1.** The general schedule of a REACT workshop with past examples. **Left:** grouping of tracks throughout the day, where participants experienced some components (i.e. student talks) as a large group, with other components (tours and workshops) occurring in smaller groups. **Right:** general examples from past workshops labeled with their respective tracks.

During the feedback sessions, each student speaker presented a practice talk and the reviewers would provide feedback on their use of jargon, body language, or visual aids. In 2017, we had four students give broadly focused talks on the research in the fields of physics, materials science and engineering, environmental sciences, and biomedical engineering. In 2018, the talks were focused on research in physics, materials science and engineering, robotics, electrical engineering, industrial and operations engineering, and design science. In 2019, the talks covered astronomy, mechanical engineering, bioinformatics, and chemistry. Beginning in 2018, we filmed the student talks and made them available on YouTube, to provide public access to the talks after the event.

**Research Lab and Facility Tours** After the graduate student talks, the participants are split into subject-specific tracks for the remainder of the day. Each group of teachers is led on tours of research labs and facilities relevant to their track, using charter buses to allow the participants to visit as much of the campus as possible. The aim of the lab and facility tours is to provide a concrete view of "science in action", and teachers are encouraged to take pictures (where permitted) and ask questions of the graduate students, research technicians, and professors they meet on the tours. In 2017, the tours included research labs in chemical engineering, materials science, biomedical engineering, and robotics. In 2018 and 2019, we expanded to include larger tours of an on-campus autonomous vehicle testing facility (MCity), Lurie Nanofabrication Laboratory, and the University of Michigan Natural History Museum in addition to tours of research facilities in multiple disciplines.

**Activity Demonstration and Instruction** The final component of the workshop is two 45-60 minute activity demonstrations. For each activity, a group of graduate students provides background information, track-specific activity instructions, and a supply kit with all the materials required for the activity. To encourage wider adoption and sustainability, each kit has a budget of approximately $50 and with a focus on reusable materials. Also, should the financial burden of replenishing the kits fall upon the teachers, we wanted to make continued usage more cost-effective, especially given the proportion of teachers who provide resources for their classroom out-of-pocket[14].

**Example Curriculum: Chemical Engineering** During the afternoon portion of the REACT workshop, teachers were divided up into subject specific tracks for lab tours and activity demonstrations. These tracks were chosen as part of the registration process and aimed to reflect the subjects a teacher taught at their home school. Here, we are providing a detailed outline of one of these tracks, chemical engineering.

The track begins a tour of the facilities of three different research labs in the chemical engineering department. Teachers were transported to each of the facilities where graduate students demonstrated the equipment and experiments they do on a daily basis. One month prior to the event, event volunteers contacted the graduate researchers from each lab and asked if they'd be willing to give a 30 minute tour of their lab space and explain their current research. No specific guidelines were given to researchers other than the target audience was K-12 teachers who want to see current research happening in the real world. This allowed teachers to interact directly with more researchers and lowered the barrier for more graduate students to be involved with REACT given the very low time commitment.

The chemical engineering department at U-M boasts three "types" of chemical engineering research: bio-chemical, foundational experimental, and computational. Care was taken to ensure that teachers could see a research lab in each of these fields so they could experience the largest breadth of knowledge. Consideration was also taken to ensure that the labs toured had "real world" applications. First, teachers toured a drug delivery lab working on a transport mechanism for cancer therapeutics. Teachers were able to observe the translation of drug development from preliminary bench top experiments to implementation in animal studies. The graduate student tour guide was able to demonstrate the real time injection of a therapeutic using confocal microscopy. Next, the teachers toured a complex fluids and soft matter lab. Here, the graduate student tour guide was able to demonstrate how the same microscope used to observe cancer therapeutic injections, can be used to image micro and nanoparticles found in consumer products, such as nail polish. They also demonstrated how consumer products are quality tested using rheometers and light scattering equipment. Finally, the teachers toured a computational lab. Here, teachers heard from researchers who are writing computer code based on chemical engineering theory and mathematics to predict the behavior of different materials.

Following the lab tours, teachers were given demonstrations of two different "real world" activities they could implement in their classroom. For each activity, teachers were provided kits containing enough materials to implement the activity in a classroom of approximately 30 students. The activities were designed by the chemical engineering and material science and engineering graduate student societies on campus, modeled after hands-on outreach lessons the groups would typically present to classrooms in the community. Prior to the workshop, the student societies were responsible for developing the activity, writing detailed lesson plan instructions, and assembling the kit materials. On the day of the event, representatives from the student society had approximately forty-five minutes to demonstrate the activity to the teachers and answer any questions. Teachers were also encouraged to discuss the activity with their fellow participants and brainstorm incorporation into the science curriculum.

Two different chemical engineering activities were presented. The first one was called “Sweet Sweet Material Science and Engineering” and contained three different food science experiments. In the first experiment, students explore the concept of crystallization by making rock candy. Students make a supersaturated sugar solution and observe as rock candy crystals form over the following days. The next experiment took a detailed look at the temperature-sensitive properties of hard candies (the volunteers here used a branded candy with an amorphous substructure). Using a hot plate, students can heat up the candy, causing the candy to go from brittle to ductile, where it can be pulled to several times its original length. Finally, the last experiment explored how composition impacts the structural integrity of a material. Students can test the impact that different compositions (i.e. solid chocolate or with nuts, nugget, caramel) have on the integrity of the material.

The second activity student made toothpaste using drugstore ingredients (i.e. baking soda, corn starch, food coloring, hydrogen peroxide, water) to explore the product design elements of chemical engineering. Each of these ingredients is given a specific purpose and cost. Students are split into groups tasked with designing a toothpaste that fits basic design parameters. In order to scale this activity across grade levels, additional factors can be incorporated. For example, there is an option to assign each group a “client” looking for specific needs to be met (for example: whitening ability, flavor, or cost). Additionally, there is an option to assign each student in the group a “role” such as design engineer, research scientist or economist. Materials are provided for higher level students to do a cost analysis or scale up calculations. Finally, teachers can incorporate soft skills by having the groups present their product to the class or write a report on their findings.

**Website** Because REACT is an annual event, it is important to maintain contact with the participants throughout the rest of the year, particularly throughout the school year. Our website (reactmi.org) includes activity guides from all years of REACT and information about any research labs or facilities that were highlighted.

## IV. Results

After each event, two rounds of anonymous feedback were solicited, both at the end of the workshop and 6 months afterwards. Furthermore, in 2019 we solicited comprehensive anonymous feedback from all past participants, the 25 responses we received are summarized here.

**Demographic Information** We collected three pieces of demographic data related to REACT attendees: subject and grade taught and school district.

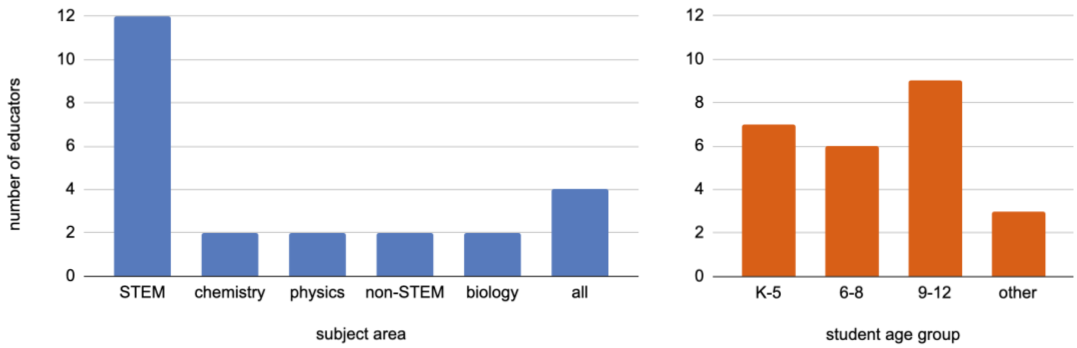


**Figure 2:** Demographic data for the educators that responded to the most recent polling. **Left:** counts of each broad-subject area, where "all" refers to teaching all subjects, "STEM" refers to teaching general STEM or STEAM classes, and "non-STEM" are any respondents that teach Language Science & Arts or other general classes that are not specifically STEM. **Right:** Ages taught by the respondents. Respondents that taught multiple grade levels were counted in each age category.

Within the first year of REACT, the majority of the teachers traveled from within 1 hour of our campus, coinciding with the amount of travel reimbursement we were able to provide. In later workshops, teachers traveled from up to three hours from campus. We also include the Area Deprivation Index (ADI), gathered from the University of Wisconsin Neighborhood Atlas[15]. The ADI is a decile score between 1 and 10 which encodes the level of resources available to a geographic area, with 1 and 10 corresponding to the least and most disadvantaged areas, respectively. These results, calculated for the corresponding schools of the participants, are summarized in Fig. 3.

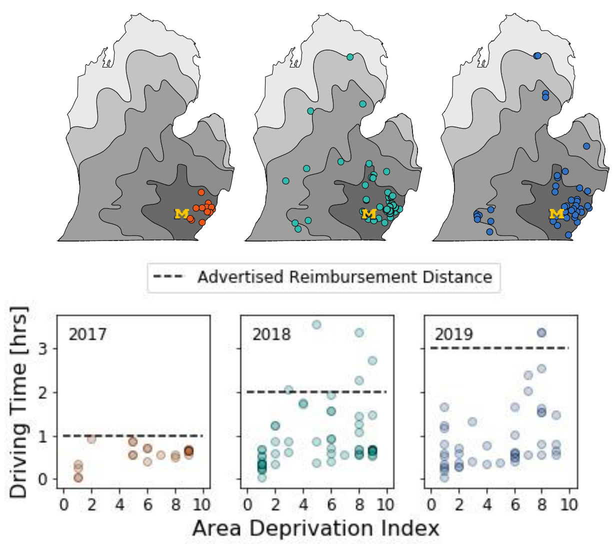


**Figure 3.** Left: Geographic and socioeconomic spread of the schools of the participants. The Area Deprivation Index encodes the amount of resources available to a geographic area, with 1 and 10 corresponding to low and high deprivation, respectively. Right: A map of the state of Michigan with the University of Michigan represented by the block M. Each gradient band represents approximately one hour of driving time and the colored markers show approximate locations of the participants.

**Satisfaction** Overall, the program has very favorable ratings, with the workshop consistently rated highly in all three iterations, as seen in Fig. 4. In general, teachers praised the program noting several areas of feedback that were valuable to the organizers. First, many teachers with positive ratings identified the event as useful. They found the information presented in the program relevant to their classrooms and that they could easily pass the knowledge on to their students. Additionally, many teachers responded that the physical activity materials given to them were very valuable when translating the ideas into their classrooms. One teacher responded "The workshop gave me lessons, ideas, and tools, I can USE!"

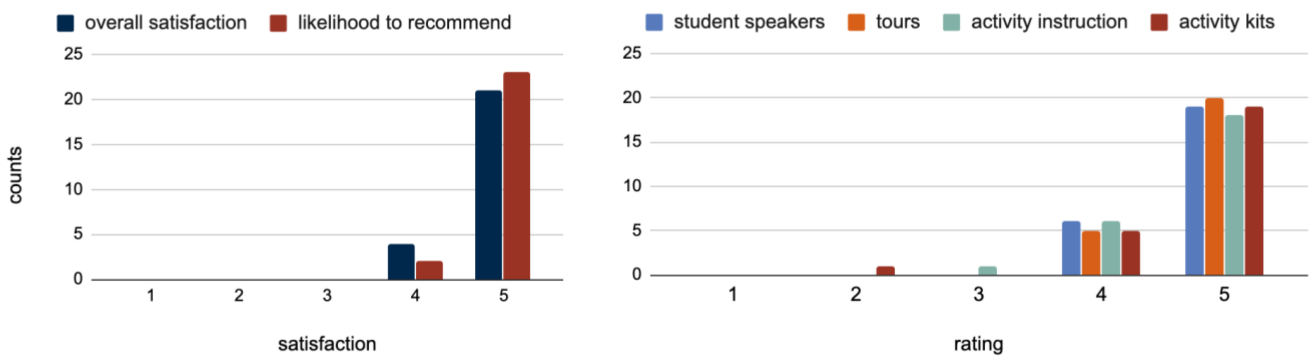


**Figure 4:** Satisfaction metrics rated on a scale of 1-5, from Very Poor (1) to Excellent (5), or Would Not Recommend (1) to Would Definitely Recommend (5). **Left:** Counts for each overall satisfaction rating score, including likelihood to recommend to a colleague. **Right:** Specific ratings for each subcomponent of the workshop.

Next, teachers provided feedback on the real-world nature of the event. As one teacher commented, getting to see cutting edge science allows them to answer the question their students often ask: "when will I use this in the real world?" Teachers were able to learn about the current advancements in the fields they teach and interact with scientists making these discoveries. As one teacher summarized, "I found it to be a rewarding event that really brought me up to speed on the different types of research happening in chemistry and biology, along with current techniques." Another real-world element of the workshop was its setting on a college campus. Many teachers spoke of their appreciation of getting to interact with college students and seeing facilities where their own students may one day work.

Finally, the teachers also praised the execution and logistics of the event. Several participants commented on the program being "teacher focused" with an emphasis on their comfort and exploration throughout the day. "It was clear that a lot of thought was put into anticipating the needs of teachers and their students." "We were treated as professionals which teachers rarely are anymore." Next, teachers responded that they appreciated the program was free with all activity materials provided for their classrooms. Finally, many teachers responded that the program was well organized, and consideration/accommodations were made for those with specific needs.

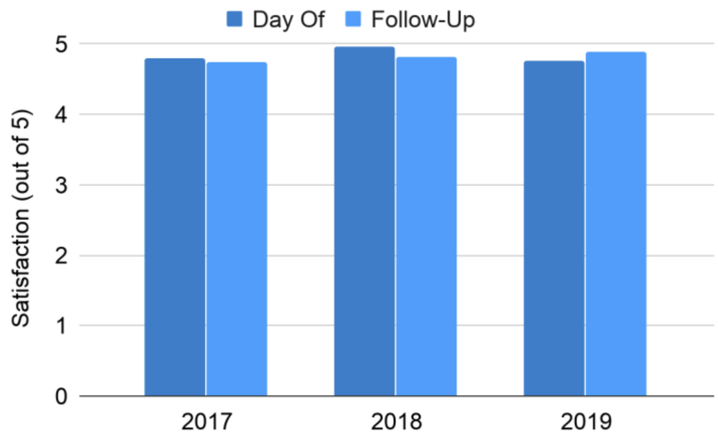


**Figure 5:** Average satisfaction ratings for all three years REACT workshops were hosted.

The majority of the feedback was positive; however several teachers did provide critiques and suggestions for improvement. Local teachers made the suggestion to start the program earlier in the day, however with some teachers traveling 3+ hours to attend, this may not be possible to implement. There was also a wide spectrum of the way teachers view the program, some commenting that although the program was informative, they did not see the need to attend in future years, in that it felt like a one-time experience. Others note they hope to come back year after year in order to try different tracks. These comments have allowed organizers to be more cognizant that for some, REACT is a standalone workshop which means elements, such as track specific activity kits, need not be redesigned every year, however, there is a population of teachers who are attending on a yearly basis and would like to experience new elements of the workshop during each iteration.

There were three pieces of actionable feedback that are currently being used to improve the program. First, it was noted that some of the content was geared toward higher grade levels and to provide tracks corresponding to specific disciplines. For the 2020 REACT program will feature a new “science discovery track” that will focus on grades K-5. Next, there were requests to make the science standards “more explicit”. Finally, it was suggested that more time be given for teacher reflection and networking. Each year since the program’s inception, we have been working to include more downtime in the schedule and increase the opportunity for teachers to connect with one another and reflect on the information they have been exposed to throughout the day.

As shown in fig. 6, the majority of teachers have already used, or are intending to use the activity kit provided. Some have even mentioned using activities from the website that were not part of the track they attended at the workshop but fit their classroom curriculum. There was a wide breadth in the ways teachers implemented their classroom kits. Some teachers mentioned they use the activity as an introduction to a new concept, while others used them as hands on reinforcement of a concept they had already taught in a traditional fashion. Teachers who used the kits mentioned that they encouraged them to try new teaching strategies in their classrooms and implement more project-based learning. Many also note that their students enjoyed the lesson and were able to form connections between what students are learning and how it is used by professional engineers.

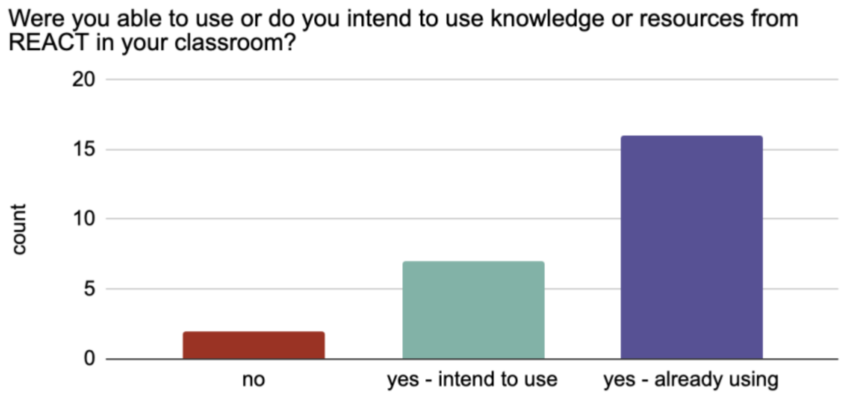


**Figure 6:** Usefulness of activity kits, as measured by number of teachers who use, intend to use, or have not used and do not intend to use.

Teachers who have not used their kits cited several reasons for not doing so. First, several teachers are not teaching STEM courses this academic year, but may use the kit in the future if they return to a STEM classroom or modify their kits to bring design elements into non-STEM courses. One teacher responded that they have multiple sections and do not have enough materials for all of their students. Finally, as mentioned previously, some teachers noted that the kit is too advanced for their grade level, which we hope to solve with the formation of the science discovery track.

Many teachers noted that REACT has impacted their classroom beyond the activity kits. Many mentioned that the tours and research talks provided new examples from the real world to explain "what engineering is" to their students. Many teachers noted that they use the website resources, such as the graduate research talks, to share what they learned at REACT with their students directly. Finally, many teachers note that the workshop has helped them gain a better idea of the career path and job possibilities of an engineer. One teacher suggested that the organizers try to incorporate more undergraduate engineering students so that teachers can learn about the transition from high school to college and how they can better prepare their students.

## V. Future work

We find that subject specific content is very effective for grades 6-12, but most K-5 educators are responsible for teaching STEM more broadly. This coming year we will be including a K-5 Scientific Discovery track that aims to provide teachers with a wide view of engineering and provide activities that connect K-5 student curiosity to the foundations of science. Rather than having a field specific "track" that a teacher would follow throughout the entire day, teachers will have the opportunity to see a variety of different research elements. For example, a K-5 discovery teacher may go on the robotics morning tour, but in the afternoon tour the chemical engineering labs rather than sticking with one subject specific path. Additionally, we are working with local K-5 teachers to develop new activities that will encourage students to engage in the world around them and connect their everyday observations to the development of basic science skills.

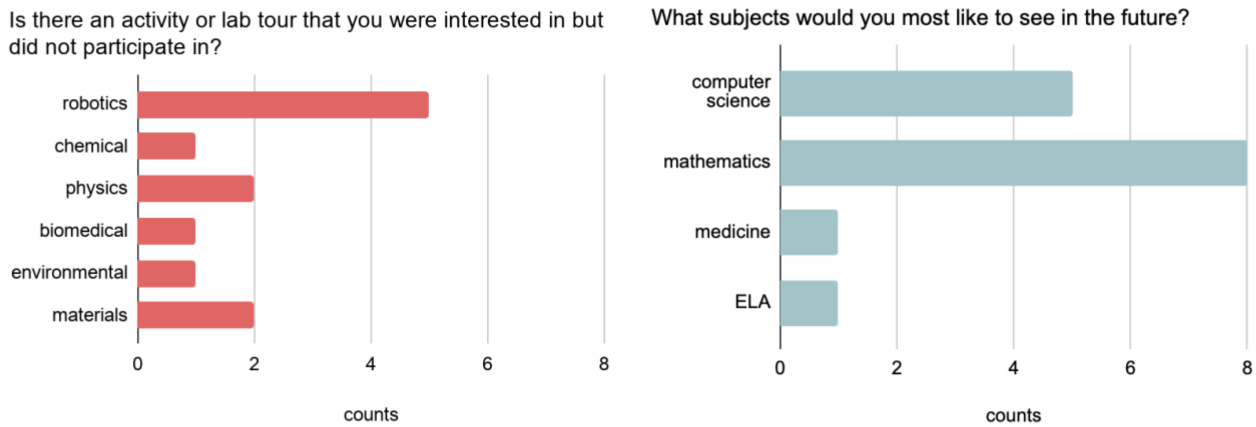


**Figure 7:** Future requests. **Left:** Counts for responses to the question “Is there an activity or lab tour that you were interested in but did not participate in?” **Right:** Counts for teachers’ requests for subjects to be covered in future REACT tracks, where ELA is English Language Arts.

To inform decisions around which subject tracks to include and add in future years, we asked participants about subject-specific preferences. We asked them which tracks they were interested in but not placed in, as well as which subjects they would like to see included in future years, the responses to which are shown in Fig. 7. Because of this feedback, we are currently exploring options for incorporating mathematics more explicitly, as well as introducing a computer science and engineering track for future years.

The next major step for REACT to improve breadth of impact is expanding to other universities. Because REACT is currently limited to teachers within the state, we feel the best way to reach other states is by sharing our model with other research institutions around the country. We are currently working with a research group at Cornell University to implement a similar annual workshop that will serve their region.

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