Changing learning opportunities and outcomes with varying levels of remote and in-person engineering education outreach

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***Abstract*— Our full paper discusses how the COVID-19 pandemic forced many K-12 schools and educational programs to change course from in-person learning to hybrid and remote learning, requiring students and teachers to adapt rapidly. Based on a project-based learning (PBL) design, our university education outreach program brings air quality sensor technology to rural high school students, allowing them to ask and answer their own research questions. Throughout their participation, K-12 students learn about air quality while designing and carrying out an experiment, and have the opportunity to present their findings at a symposium.**

During the 2018-2019 school year, learning activities took place mostly in person. For 2019-2020, the program began in person, then shifted to remote learning in March 2020 due to COVID-19 related closures. For 2020-2021, the program took place entirely online. We refer to these years as "in-person", "hybrid*", and "remote", respectively. Qualitative and quantitative data were collected from high school students, teachers, and college mentors each year, including interviews, surveys, and analysis of public artifacts.

While learning opportunities differed from year to year, learning outcomes remained relatively stable. While the rapid shift to remote learning during the hybrid* year challenged teachers and students alike, the program ran more smoothly during the fully remote year once everyone was adjusted to the new format. However, students' engagement, excitement, and confidence in engineering was weakest during the remote year. Implications include what combination of educational modes are worth continuing post-pandemic, affording students the best learning opportunities to produce favorable engineering outcomes.

Keywords*— *remote learning, project-based learning, low-cost sensors, air quality education

I. The AQIQ Program

Recent studies have explored the lack of college students enrolling in STEM courses [1] as well as the barriers and lack of exposure in K-12 education that may lead to disinterest in these fields [2]. In response, the Air Quality InQuiry (AQIQ) program brings cutting-edge air quality sensor technology to middle and high school students in suburban-to-rural Colorado. The project-based curriculum, developed for in-person learning, is well-established and hosted on TeachEngineering.org. The program consists of five educational modules, each of which focuses on air quality, the scientific method, and most importantly, hands-on learning. The program participants will be referred to as students, K-12 students, or high school students. The university students who carry out the program will be referred to as mentors.

A. Technology & Tools

The Hannigan Lab at the University of Colorado Boulder has developed portable air quality monitors using sensors which measure a wide variety of pollutants: carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), ozone (O_3), and particulate matter (PM). While these devices, dubbed "pods", were designed for research use, their relatively low cost and ease of use make them ideal for student use and education outreach. To operate the device, students simply plug the pods into a wall outlet or battery, flip on a switch, and the device will begin recording data to an SD card. This easy-to-use tool allows students to collect their own data for the experiments they design themselves.

Since high school students typically lack experience with Excel or data analysis software, a website was developed by the Hannigan lab exclusively for pod data with K-12 students in mind. To retrieve the data, students simply insert the SD card from the pod into the computer, complete a short intake form, and their data is processed for them. Students can then view the data as a time series plot, scatterplot, box-and-whisker plot, or plot multiple pollutants at once. The site also includes conversion factors which automatically generate parts per million (ppm), parts per billion (ppb), or microgram per cubic meter ($\mu g/m^3$) concentrations for each pollutant of interest. While simple data analysis is accessible to all, students are encouraged to advance their skills by downloading the converted data from the website in Excel, Google Sheets, or similar. These supporting mechanisms further empower students to complete their own projects, with guidance from mentors and teachers.

B. *Project-Based Learning Fundamentals*

Project-based learning was created to close gaps between what students learn in school and the skills they will need in the workplace or their adult lives [3]. K-12 students and their teachers generally struggle to master the skills needed to succeed in engineering [2,3]. In PBL, students are supported to work on authentic projects and are actively involved in the development of an idea. PBL has been proven to have better student outcomes than traditional instruction alone [4]. Based on the success of PBL in K-12 settings, the AQIQ program has sought to teach students valuable hands-on scientific and engineering skills, increasing engagement and depth of learning [5].

C. *PBL in the AQIQ Program*

The AQIQ program is broken into five distinct lessons. The first module serves as an introduction to air quality and the pods. Students learn the basics about pollutants of interest, the importance of air quality from environmental and health perspectives, and begin experimenting with the pods within classroom settings. These activities typically entail lighting a candle or testing the air quality content of items throughout the room (e.g., dry erase markers for VOCs or chalk dust for PM). During the pandemic, students were also encouraged to test out the air quality differences when breathing into the pod with and without a mask on. The second module teaches students about combustion by testing tailpipe emissions from different cars in the parking lot.

Once the students are familiar with the pods and have a broad understanding of air quality, the final three modules prepare them for their own projects. Module 3 helps students brainstorm a project pertaining to air quality in their everyday lives. Working on their own or with peers in a small group, students plan out the experiment, receive feedback from their mentors, and are then left to collect data on their own. In module 4, which focuses on data analysis, mentors demonstrate how to use the AQIQ website for plotting. The final module aids students in designing a poster to present their research at an end-of-year symposium. Typically, this is a large event, complete with refreshments and presentations from air quality researchers from the university. Although the program typically followed this general format, the three years chronicled in this work demonstrate how the COVID-19 pandemic re-shaped the experiences of our most recent classes.

II. Remote Learning

A. *The Rise of Remote Learning in K-12 Settings*

Prior to the COVID-19 pandemic, remote learning in K-12 settings was relatively uncommon; more studies have been published on the topic in the past year than in all previous years combined. While numerous studies have chronicled the rise of remote learning in traditional educational settings, little data is available on project-based learning and extracurriculars in the age of COVID-19. The current lack of related literature suggests supplementary science programs may have been abandoned in the past year to focus on more urgent challenges, or to prevent students from gathering.

A small number of studies detail how hands-on classes adapted to remote learning. One science class asked students to carry out a small-scale community outreach project as a class assignment during the pandemic, which consisted primarily of flyers, presentations, and simple at-home activities to help the public understand more about the COVID-19 virus [6]. While this assignment was not as involved as the AQIQ program, students nonetheless appreciated the opportunity to connect with and educate others within the community during a very isolating and stressful time [6]. While several studies have chronicled project-based learning in a remote setting, most seem to have been among college students, who are more technologically advanced and were able to use simulation software in place of some traditional elements [7,8]. Juxtaposed with our program, we conjecture that high school students may lack the level of autonomy and technical knowledge displayed in literature by college students.

B. *AQIQ's Transition to Remote Learning*

The 2018-2019 school year represents the most typical year of the program: mentors first visited the classroom in November to introduce themselves and the program to the students. The bulk of the program took place during the spring semester. In January, mentors visited for a week to teach the first three lessons: introduction to air quality, introduction to combustion, and experimental design. The students then had approximately a month to conduct their experiments using the air quality monitors. The mentors then returned in February to teach data analysis, and then again in March to educate students on communicating their findings to the public.

Most symposiums took place in April and were sizable events. A few of the newer schools in the program elected to hold their symposiums during class time, with students either presenting a digital poster on a projector screen or showing off a physical poster to the rest of their classmates. However, most schools held their symposiums after school hours, or excused students from their other classes if they were held during the day. During each event, students' posters were printed out and hung up in a school gym, cafeteria, or other large gathering space. One symposium in spring 2019 was hosted at a local university. Parents and other community members were invited to join alongside university representatives to chat with students about their posters. Judging rubrics devised by the program director were filled out on paper, and the students with the highest scores were invited to attend the university's Senior Design Expo later that spring. The symposiums were the main event of the program; with refreshments and large audiences, students and mentors alike looked forward to them as they solidified the hard work students had put in throughout the year.

The 2019-2020 school year began as usual, with mentors visiting schools and teaching the curriculum in person. By March 2020, only one out of six high schools participating in the AQIQ program had already completed their projects for the year and held their symposium in person. When statewide lockdown orders were issued later that month, students and mentors alike were sent home, with most schools relying on video conferencing to complete their coursework for the year. The sudden shift to remote learning proved difficult for teachers and mentors alike. We refer to this year as hybrid* rather than hybrid; while the first half took place in person, the second half took place online.

The biggest physical challenge facing the program during the hybrid* year was data collection; many students had not yet had the opportunity to use the pods when stay at home orders took effect, and faced difficulties sharing the pods while in different locations. Little was known about the dangers of surface contact with COVID-19 at that point in time, making students and their parents more hesitant to exchange equipment that other households had already used. Teachers and mentors remedied this by offering to collect data on their students' behalf, but many did not finish the program nonetheless.

While two high schools held their symposium remotely via Zoom, internet connectivity issues, difficulty arranging students in breakout rooms, decreased student engagement, and a lack of refreshments made the event unrecognizable from the symposiums of years' past. More projects were done individually as opposed to small groups due to the difficulty of gathering during the pandemic. Students showed their posters by sharing their screens in Zoom breakout rooms. Because the posters were designed for in-person presentations, presenters had to zoom in to each section for ease of reading.

The remaining four high school symposiums were cancelled, with many students' projects falling by the wayside as they struggled to adjust to at-home learning. One of these schools finished their final posters, but opted out of the final symposium due to scheduling conflicts.

The following year, our research team took the previous years' data and observations into account when planning for a fully remote year. In the fall of 2020, most high school students served by the program returned to the classroom, while only a small fraction remained at home for remote learning. However, with social distancing and other COVID-related guidelines in place at all schools, college mentors were not allowed to visit the schools to teach in person. This created an interesting phenomenon in the 2021 program: most students attended school in person, with the AQIQ mentors being the only remote aspect. This shifted many responsibilities previously taken on by the mentor to the classroom teacher, who could facilitate experiments in person while the mentors instructed virtually. Every participating school completed the program this year. Most student symposiums took place during class time, with their AQIQ mentors and other university delegates joining in via videoconference. Most of the technical issues that had plagued the previous year were resolved through increased familiarity with online platforms and students being back in the classroom.

III. Methods

This investigation incorporates three years of data collection from university students, high school students, teachers, and community members. Data for the first year was collected by the course instructors. In the second year, a partnership was developed between the college of engineering and school of education, with educational researchers designing and conducting data collection for the subsequent years.

Here, we employ a sequential explanatory mixed-method design. Survey questions were employed to investigate the quantitative impact that the course has on engineering and science learning. Qualitative observations, focus groups, and interviews were conducted to provide a richer exploration of student development [9]. Mixed methods were chosen to offer both quantitative and qualitative assessment and reasoning for the same conceptual phenomenon [10], improving the validity of our findings [11].

A. Study Participants

Participants in this study were self-selected 38 university students, 31 high school students, 7 high school teachers, and 7 community members. See Table I for a complete list of participants, relevant data, and survey response rates.

B. Mentor Surveys

Throughout the 3 years of this investigation, pre- and post-surveys were selected as a method for determining quantitative gains on targeted skills and attitudes among mentors. Through Likert-type self-ratings, mentors were asked to report their technical skills (i.e., *Knowledge of Air Quality Science*) and professional skills (i.e., *Communication* and *Mentoring*). On the post-test, more questions were added for mentors to rate the usefulness of the curriculum and whether they would recommend the course to others or have an interest in future K-12 work. Although the current data set is too small for testing of statistical significance, net differences were calculated.

C. High School Student Surveys

In the hybrid* year, students from two rural high schools were asked to complete pre- and post-course surveys. We asked about students' interests in science and engineering inside and outside of school; their identifications and positionings in these disciplines; as well as the personal, professional, and societal relevance of these disciplines in their lives.

D. Interviews

One-on-one semi structured interviews were conducted with high school teachers and community members (in-person and remote years), as well as high school students (hybrid* year). Grounded Theory methods were employed to provide an iterative and inductive qualitative data collection, coding, and analysis process [12]. For the remote year, the researchers interviewed mentors in a focus group setting, and completed an interview with one high school teacher.

E. *Field Notes & Classroom Observations*

Education researchers collected fieldnotes and classroom observation notes throughout site visits, including the university classes, high school classroom visits with the mentors, and final symposiums. Across the three years, a total of 36 field and classroom observation notes were generated, from both in-person and remote visits.

F. *Public Artifacts*

Across the three years, course instructors and education researchers collected a total of 225 posters and PowerPoint presentations (remote year) from high school students. Oriented by the Next Generation Science Standards for high school students [13], the first two authors developed a coding scheme to rank students' 1) *Air Quality Understanding*, 2) application of the *Scientific Method*, and 3) use of *Engineering Practices and Skills*. Each of these coding schemes consists of 2 clarifying questions. For example, criteria 1 was judged based on the clarifying questions: "Does the poster explain the significance of the project?" and, " Does the poster explain why the selected pollutants are important for the project?". Coding values included No (0), Somewhat (1), and Yes (2). As a result, for each coding scheme, a poster could score a minimum of 0 and a maximum of 4. Regarding intercoder reliability, the two authors coded 5% of the total number of posters and reached 73% agreement. The first author then conducted coding for the remaining posters.

I. RESULTS

A. *Qualitative Outcomes of In-Person Learning*

Mentors were motivated to register for the class in 2018 based on teaching opportunities, and felt good about sharing their engineering skills and college experiences with their high school counterparts. They saw themselves as role models and cherished their experiences educating in the community. The opportunity to travel as part of the program was also a plus. Mentors at one school noted that the students who were typically disengaged during class became very invested in project-based learning. The end-of-year symposiums demonstrated the strength of the mentor-student relationships, with mentors responding to students' projects in an enthusiastic and caring manner. Mentors' biggest takeaway was their increased confidence in teaching in a K-12 setting. The changes in responses from mentors' pre-and-post surveys for all three years can be found in Table II.

A high school teacher noted that students enjoyed learning by doing rather than taking notes or reading from a book. This teacher and superintendent concurred that it was great to see their students working excitedly. Every student that began with the program saw it to completion; with most progress accomplished while mentors were visiting. Teachers and community members also noted how students' confidence in air quality and the scientific process had grown throughout the project.

TABLE I. STUDY PARTICIPANTS, DATA COLLECTION METHODS, SAMPLE SIZES, & REPONSE RATES BY YEAR

Year	*Participants*	*Method*	*Sample Size*	*Response Rate*
2018-19 (in-person)	Mentors (15)	Pre-Survey	8	53%
		Post-Survey	12	80%
	High school teachers (4)	Interview	3	75%
	Community members (7)	Interview	7	100%
2019-20 (hybrid*)	Mentors (11)	Pre-Survey	11	100%
		Post-Survey	7	63%
	High school students (31)	Pre-Survey	29	94%
		Post-Survey	25	81%
		Interview	4	13%
2020-21 (remote)	Mentors (15)	Pre-Survey	10	67%
		Post-Survey	12	80%
		Focus group	12	80%
	High school teachers (3)	Interview	1	33%

For most students, it was their first opportunity to participate authentically in the scientific process by contributing data and presenting their findings to the public. The program markedly improved students' abilities in designing and implementing scientific experiments, and helped them understand the relevance of air quality in everyday life. The pre-and-post surveys distributed to students the following year quantifies these same impressions and demonstrate how student takeaways changed as educational modes shifted.

B. *Qualitative Outcomes of Hybrid* Learning (2019-2020)*

Since the hybrid* year began as usual, mentors reported in pre-course survey the usual motivations for signing up for the course: wanting to engage community members in engineering education and gaining teaching experience in K-12 settings. Several also noted interest in teaching as a future career. Since mentors made several in-person visits to the schools, relationships between mentors and students developed as per usual, and students had ample opportunities to engage with their mentors about air quality and college early in the school year. Overall, the mentors still saw themselves as role models despite not being able to complete the program as planned. In the post-survey, mentors reported they would have liked more in-class time with their students, especially since the usual in-person pattern of the course was disrupted by pandemic-related closures.

From interviews, mentors, students, and teachers across the board felt challenged by the sudden switch to remote learning in March 2020. Teachers struggled to support students' AQIQ projects while scrambling to teach their own curricula, and many students were unable to collect data on their own due to lockdown orders and COVID-related concerns about sharing materials. Many mentors struggled to get in touch with their teachers, and coordinating online visits became increasingly difficult. This difficult was also reflected in students' interview responses.

TABLE II. NET GAINS & LOSSES IN STUDENTS' PRE-AND-POST SURVEY RESPONSES IN THE 2019-2020 YEAR

Metrics		***In-Person***	***Hybrid****
Interest in:	Science IN school?	-0.13	-0.14
	Science OUTSIDE of school?	-0.13	-0.12
	Engineering IN school?	-0.34	0.29
	Engineering OUTSIDE of school?	-0.13	-0.06
Personal Relevance	I see how science relates to my life	0.07	0.29
	Much of what I learn in science classes is useful in my everyday life	0.53	0.17
	Science helps me to make sensible decisions	0.4	0.28
	Science helps me to make decisions that could affect my body	0.2	0.14
Societal Relevance	Learning science will affect the way I vote in elections	0.26	0.32
	Science helps in understanding today's world	-0.07	-0.03
	Caring about people and our world is part of making a scientific choice	-0.2	0.15
	Science is useful in solving problems	-1.67	-1.25
Positioning	I am just not good at science	0.74	0.86
	I am pretty good at science	-0.27	-0.42
Confidence	I feel confident using engineering equipment to monitor air quality	0.27	-0.19
	I feel confident conducting scientific research	0.2	-0.04

C. *Quantitative Outcomes of Hybrid* Learning (2019-2020)*

Students' survey responses during the hybrid* year corroborate the observational outcomes reported anecdotally by program staff and researchers. As shown in Table II, students who completed the program remotely after the onset of the pandemic felt more strongly that *science related to their lives* and were eager to *learn engineering in school* after the global rise of air quality conversations in spring 2020. Their in-person counterparts, who finished their projects prior to the COVID-19 outbreak in the U.S., did not experience this. Hybrid* students reported decreases in both *confidence*-related categories, while in-person students saw increases in both metrics. This pattern matches the difficulties reported out by teachers and mentors alike, who saw students scramble to complete the projects on their own with limited guidance and resources once lockdown orders took effect. In-person students likely felt more capable due to greater support while in the classroom as they were never left to struggle on their own. Other metrics, such as students' *interest in science both inside and outside of school,* remained constant despite the change in instruction.

Some student-reported outcomes held true for both modes of learning in 2020. Both sets of students felt that *learning science helped them to make sensible decisions* and would *affect the way they would vote in elections*. However, not all outcomes were as positive. Regardless of the educational mode, students thought science was less *useful in solving probl*ems at the end of the program than at the beginning. Likewise, both groups of students felt more strongly that they *were not good at science* by the end of the year. Although negative, both outcomes could reflect that AQIQ was students' first real hands-on scientific experience; experiments often take unexpected turns, and even well-planned procedures are typically repeated numerous times to achieve a reliable result. It is plausible that students may have been disillusioned with the process despite being enamored by the real-world applicability. Several categories in students' pre-and-post survey responses suffered from inconsistencies, highlighting how it can be difficult for students to accurately assess themselves.

D. *Qualitative Outcomes of Remote Learning (2020-2021)*

As professors and the teaching assistant reflected on the college course in 2021, they agreed that mentors appeared to have put in the same amount of effort, if not more, as mentors in previous years despite not getting to travel to schools. Relationships among mentors and students were not as close-knit as in years prior due to the lack of face-to-face and one-on-one interactions. These reflections suggest that high school students may have missed out on developing a relationship with a role model. The instructors likewise acknowledged mentors' feelings of missing out on relationships with the students. Despite the imperfect circumstances, it appears the isolation many mentors were experiencing at this time due to social distancing may have propelled them to go above and beyond despite never meeting their students in person.

Only one teacher was available for a formal interview during the remote year. They noted how the relationships between mentors and students were lacking compared to years past without opportunities to interact in person. They also elaborated that their students were "acquaintances" of STEM rather than "STEM people"; while students showed a level of interest in certain engineering topics, they were "far from taking these interests to the next level." They also mentioned a need for greater consistency from year-to-year, which was made difficult with cycling through different learning regimes the past few years. Despite the difficulties with remote learning, all students completed the program this year, thus the retention rate improved dramatically from the previous year.

TABLE III. NET GAINS & LOSSES IN MENTORS' PRE-AND-POST SURVEY RESPONSES BY YEAR

Metrics		***'18-'19***	***'19-'20***	***'20-'21***
Knowledge of:	Air Quality Science	0.07	0.95	0.48
	Energy Systems	-0.05	0.31	0.41
	Environmental Monitoring Technology	0.19	0.16	0.48
	Applications of Science	0.07	0.68	0.44
	Engineering as a Career	-0.22	0.14	0.70
Skills:	Teaching	0.18	0.93	0.14
	Presentation	0.04	0.57	0.39
	Mentoring K-12 Students	0.46	0.07	0.70
	Communication	-0.11	0.45	0.07
	Teamwork	0.17	0.37	-0.10
	Project Management	0.07	0.11	0.49

E. *Comparison of Mentors' Outcomes Across All Three Years*

Changes in mentors' survey responses across all three years are presented in Table III. Note that sample sizes were too small for a statistical analysis, so we will focus on net gains and losses. Interestingly, we see the weakest improvements overall during the in-person year. However, four mentors who did not complete the pre-survey participated in the post assessment; missing this initial data from a third of respondents may explain why the standard educational mode yielded the weakest results. Since the mentors were the high school students' main source of information, mentors' skills and confidence in key areas could be reflective of learning opportunities available to the high schoolers.

Gains and losses between the hybrid* and remote years varied considerably, suggesting that different aspects of the curriculum may have shone through with different instructional modes. As shown in Table III, mentors self-reported considerable gains in *Environmental Monitoring Technology* during the remote year, as they were perhaps more eager to collect data and participate in project-based learning when the rest of their classes were online and likely less engaging than in years past. Substantial gains were also seen in *Engineering as a Career*. Unsurprisingly, most other knowledge-based aspects (*Air Quality Science and Applications of Science*) suffered during remote instruction as compared to the previous year. Note that mentors' entire training still took place in-person in the hybrid* year, along with some of their teaching experience before shifting to remote.

Predictably, when rating their skills in K-12 classrooms, mentors' pre-and-post survey gains suffered in categories like *Teaching, Communication, and Teamwork* during the remote year as compared to the hybrid* year. However, other outcomes were conflicting, with *Mentoring Skills* improving dramatically. This might suggest that mentors in the latter year might have had less prior mentoring experience to begin with, or that they were determined to see themselves as role models despite the circumstances.

F. *Comparison of High School Students' Learning Outcomes Across All Three Years*

Based on the posters and PowerPoint presentations collected as public artifacts, students' comprehension of the material varied slightly across years and educational modes (see Table IV). Since the sample sizes are not conducive to an analysis of statistical significance, again we will focus on net gains and losses.

The results of the 2019 symposiums are used as a benchmark to understand how typical outcomes changed during hybrid* and remote learning. Posters among students from the same school tended to have the same shortcomings, such as an irrelevant selection of pollutants or an incomplete explanation as to why the chosen pollutants were studied. This suggests that teachers or mentors at those schools struggled to explain or execute certain topic areas in the classroom. It is worth noting that only one school completed its symposium before the pandemic. Thus, gains and losses compared to the year prior may only have been exhibited at that school and do not necessarily reflect changes in the program as a whole. Additionally, the only two schools that completed projects after the lockdown implemented AQIQ in their Advanced Placement or International Baccalaureate classes. The higher achievement level among these students generally could be why these programs were able to continue while the remainder fell by the wayside. Overall, results for this year and instructional mode are likely biased due to students' innitial abilities or positioning rather than improvements in the program itself. Interviews and observational evidence suggest that this chaotic time did not foster the strongest learning environment despite these promising results.

TABLE IV. POSTER SCORES (0-4) FOR EACH EDUCATIONAL CATEGORY ACROSS YEARS AND EDUCATIONAL MODES.

Year / Educational Mode	***N***	***Air Quality Understanding***	***Scientific Method***	***Engineering Practices & Skills***
2018-19 / In-Person	70	2.00	1.86	2.37
2019-20 / In-Person	19	2.26	1.53	2.32
2019-20 / Hybrid*	53	2.11	2.13	2.52
2020-21 / Remote	79	1.99	2.38	2.49

Comparing the in-person year to the remote year, results were maintained in *Air Quality Understanding*, improved modestly in *Engineering Practices & Skills*, and improved by over half a point in *Scientific Method*. These gains could be in part to the increased number of visits at each school during the remote year. Since mentors did not have to physically travel, many were able to "pop in" to high school classrooms more frequently via video conferencing. The relevance of air quality due to COVID-19, or the excitement of a hands-on project during an otherwise lackluster time in most students' lives during the pandemic may have been behind these improvements in educational outcomes.

G. *Contributing Factors in Changing Learning Outcomes Across All Three Years*

Several other factors observed across the three years of the study may have contributed to the net gain in learning outcomes from 2019 to 2021. One confounding factor that stands out is the inclusion of ozone in the curriculum. Ozone is a secondary pollutant formed by chemical reactions in the atmosphere over time, while the rest of the air quality sensors measure primary pollutants, meaning those that are emitted directly from sources such as cars or fires [14]. We believe students struggled to understand this distinction, leading to incorrect usage of the sensor. In 2019, of the 17 groups that studied ozone, only one used it in the correct context, 9 projects were only tangentially related to the pollutant, and 7 projects that included ozone had no relevance to the pollutant whatsoever. Due to this discrepancy, we removed the ozone sensors from the pods the following year, although information about ozone remained on the data analysis website for users other than the AQIQ program to reference. Despite the sensor being removed in 2020, 10 projects still listed ozone as a pollutant of interest or attempted to plot ozone data, but only at certain schools. This suggests that mentors or teachers at certain schools may have had a limited understanding of which sensors were which in the pods, and either incorrectly guided students towards including them or did not check in with students thoroughly throughout the project. The rapid shift to remote learning forced many students to complete the projects at home on their own, which may explain some of the confusion. By 2021, however, only two projects attempted to collect data with the non-existent ozone sensor, and both occurred at the same school, further suggesting that teachers or mentors may have led them astray. Furthermore, the incorrect usage of ozone data did decrease from year to year and could partially explain the higher average scores from 2019 to 2021.

Across all three years, students also struggled to understand the differences between carbon dioxide and carbon monoxide. This is likely due to the similar names and chemical structures of the two, which students not well versed in chemistry may have struggled to differentiate between. For instance, students incorrectly stated that CO_2 is poisonous to humans, which is only true of CO (5 in 2019, 5 in 2020, 4 in 2021). Likewise, in combustion-related projects, groups failed to understand that CO_2 emissions reflect complete combustion, while CO emissions reflect incomplete combustion and suggest that an engine or other burning process was less efficient (9, 11, 13 respectively). Note that not all pods contained CO monitors in the first year of the analysis, and the data analysis website did not reliably allow students to plot CO for much of the following two years. Thus, the difficulty of discerning CO concentrations may have also led students to analyze CO_2 where CO would have been more appropriate. Recent updates to the pods and website should ameliorate this additional confusion in the coming years.

Posters without explanations of the results or chosen pollutants were omitted from this comparison, as it is unclear whether those students understood the differences between the two. Since this misunderstanding about pollutants was observed every year, this is likely a shortcoming of the curriculum itself and not the educational mode. Based on this, we can improve the curriculum around these pollutants in future years to mitigate this issue.

II. Discussion

Prior to the pandemic, most student progress took place during the five in-person visits throughout the year. It often seemed that students and teachers alike would forget about the program once the mentors left the room; little headway was made in between lessons, with the mentors driving the projects forward during each of their visits. There was also little contact between teachers and mentors between visits, and hardly any communication between mentors and students directly aside from the school visits. During the pandemic, the ability of mentors to "pop in" via video conference more frequently did help move students' projects forward outside of the scheduled lessons. However, with mentors visible to the entire class in front of a screen rather than physically walking around the classroom to speak with individual students, the relationships between mentors and students were markedly different than in previous years. Many mentors recalled that they never learned the names of their students, and students never conversed with their mentors about the college experience in a casual setting, which had been a staple of the program in years prior. With mentors more accessible broadly but less familiar to the students individually, much of the curriculum work previously delegated to the mentors fell to the teachers.

As expected, learning opportunities suffered during the rapid shift to remote learning; students had difficulties getting to use the pods, and many students did not complete posters subsequently. This also affected students' confidence in their scientific abilities. Studies have shown that high school students' mental health suffered at the onset of the COVID-19 pandemic [15], possibly turning the AQIQ projects into another stressor rather than an enjoyable experience for some students. Since teachers were struggling to adapt their regular curricula in a short period of time, our supplementary program fell by the wayside. Increased support from the high school teachers may be chiefly responsible for many of the improvements seen in students' comprehension during the remote year. For instance, during the in-person and early parts of the hybrid* year, teachers used to simply observe while mentors carried out experiments in the classroom. During the remote learning year, teachers often had to lead the in-class experiments themselves while the mentors merely provided guidance via video conference. Likewise, with less interpersonal contact between mentors and students, high schoolers relied on their teachers more for support than in previous years. Students of teachers that went above and beyond tended to have the strongest final posters, while teachers that maintained a similar level of involvement to prior years created weaker posters. Although teachers were not necessarily well-versed in engineering topics, they proved to be a valuable resource to their students, distilling guidance from the mentors more frequently than in previous years.

Our year of fully remote data is unique in that the students themselves were in person, with their mentors being the only remote aspect. This greatly lessened the burden of project-based learning. Students carried out their experiments in groups in and outside the classroom, and were able to share equipment with relative ease. The ability of students to meet with each other in person greatly contributed to the success of the remote learning year, as evidenced by improvements in learning outcomes.

One of the most pressing limitations of our study are the small sample sizes for students, mentors, and teachers surveyed or interviewed. None of our sample sizes were large enough for statistical significance to be tabulated; net gains and losses in survey responses should be considered only in the larger context of observational data. Pre-and-post surveys may have also suffered from response bias, since high achieving students are more likely to have completed them after the course ended, while other students would be less likely to take on this additional assignment [16]. Students and mentors alike may also have experienced the Dunning-Kruger effect, assuming they knew plenty about air quality prior to the course, and only recognizing how little they knew after being introduced to specific topics [17]. Nevertheless, we do not intend for any one result here to be considered alone, but rather this collection of surveys, artifacts, and interviews to characterize the three distinct learning modes in totality.

III. CONCLUSIONS

While the shift to remote learning was unprecedented, small changes to the program and practice during the 2020 spring semester made a huge difference in returning the program to its former success during the second year of the COVID-19 pandemic. By leaning heavily on the classroom teachers, mentors were still able to get the core content across to their students, although the interpersonal relationships between the students and mentors were diminished. We are eager for the program to continue in-person, but will allow mentors to complete one classroom visit remotely in the 2021-2022 school year. This will be a favorable adaptation for our program as inclement winter weather sometimes required mentors to cancel or postpone their lesson plans. We will also encourage mentors to "pop into" their high school classrooms remotely outside of their scheduled visits to answer questions. This way, students and teachers would still receive additional support from their mentors without missing out on the all-important in-person visits, keeping student-mentor relationships strong. We will look forward to maintaining learning outcomes while improving engagement in years to come with the lessons learned in the past three years of the program.

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