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ONLINE FIRST

Research in Science Education

ISSN 0157-244X

Res Sci Educ
DOI 10.1007/s11165-020-09964-4

Springer

Research in Science Education
https://doi.org/10.1007/s11165-020-09964-4

Utilization of Remote Access Electron Microscopes to Enhance Technology Education and Foster STEM Interest in Preteen Students

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Accepted: 21 September 2020/Published online: 03 November 2020

Abstract

Remote access technology in STEM education fills dual roles as an educational tool to deliver science education (Educational Technology) and as a means to teach about technology itself (Technology Education). A five-lesson sequence was introduced to 11 and 12-year-old students at an urban school. The lesson sequences were inquiry-based, hands-on, and utilized active learning pedagogies, which have been implemented in STEM classrooms worldwide. Each lesson employed a scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) accessed remotely. Students were assessed using multiple-choice questions to ascertain (1) technology education learning gains: did students gain an understanding of how electron microscopes work? and (2) educational technology learning gains: did students gain a better understanding of lesson content through use of the electron microscope? Likert-item surveys were developed, distributed, and analyzed to established how remote access technology affected student attitudes toward science, college, and technology. Participating students had a positive increase in attitudes toward scientific technology by engaging in the lesson sequences, reported positive attitudes toward remote access experiences, and exhibited learning gains in the science behind the SEM technology they accessed remotely. These findings suggest that remote experiences are a strong form of technology education, but also that future research could explore ways to strengthen remote access as an educational technology (a tool to deliver lesson content), such as one-on-one engagement. This study promotes future research into inquiry-based, hands-on, integrated lessons approach that utilize educational technology learning through remote instruments as a pedagogy to increase students' engagement with and learning of the *T* in STEM.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11165-020-09964-4) contains supplementary material, which is available to authorized users.

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Keywords Educational technology · Technology education · Active learning

Introduction

Technology is both an integral component of other disciplines and a discipline in and of itself. On one hand, technology provides a tool to educate about other disciplines, acting in a supporting role as Educational Technology (Kelley 2010). On the other hand, Technology Education encompasses teaching and learning about technology itself (Sherman et al. 2010). Integrated curricula can easily overlook Technology Education as one of the pillars of STEM and relegate technology to the supporting role of Educational Technology only. An opportunity to increase student achievement and interest may be neglected in this process (NYSED 2006). The International Technology Education Association (ITEA) published the *Standards for Technology Literacy: Content for the Study of Technology* (ITEA 2007). The *Standards* state that technology should be taught in stand-alone courses as well as "integrated into the rest of the curriculum." Curricula and teaching styles are at the center of pedagogical research amidst ongoing concern over worldwide student participation in STEM (U.S. Department of Education 2016; Du Plessis 2018; De Loof et al. 2019). Educators seek to promote interest and confidence of all students, especially students from ethnicities with persistent underrepresentation in college STEM programs (Wong 2016). Many steps have been taken to affect changes, such as the implementation of Technology Education in primary and secondary school (Rennie 2001) in conjunction with increased use of active learning pedagogy, a more student-centered form of teaching (Parappilly et al. 2019), which is at the heart of the *Framework for K-12 Science Education* (National Research Council 2011; NGSS Lead States 2013).

Designing and implementing student-centered curriculum that adheres to active learning principles is a unique challenge for educators. Curricula that is integrated, project-based, hands-on, and contains real-world applications (Kennedy and Odell 2014; Vossen et al. 2019) may serve not only to deliver instruction but also to diversify thinking, such as developing complex systems thinking in younger students (Ben-Zvi and Orion 2005 and Lee et al. 2009). Research has found that integrative curriculum promotes student interaction and increases science literacy (Cajas 2001). While these finding are promising and changes to science education are intended to address valid concerns, there is conjecture on implementation and effectiveness (Eisenhart et al. 2015). Arguments suggest that active learning lacks retrospection and cross-cutting of core ideas has no scholarly basis, with this dimension of the *Framework* appearing inconsistently across grades (Osborne et al. 2018). Inconsistency and contradictory discourse threaten to undermine potential impact (Rodriguez 2015). Thus, pedagogical research must establish best practices within active learning and indeed continually evaluate student-centered teaching strategies. Adding a technology component to active learning curriculum has the potential to be integrative and cross-disciplinary, but without research, it is unclear what role specific technologies might take.

When considering a new technology for use in pre-college STEM education, it is paramount to recognize the role individual technologies play. Research shows technology is a tool to engage students in inquiry-style learning (Williams et al. 2017), and indeed, technological tools may shape student thinking (Chao et al. 2017). Remotely accessible instrumentation is an emerging educational tool that uses the internet to access advanced technology, such as a scanning electron microscope (SEM). Instrumentation is accessed and controlled through an internet browser or downloadable application, allowing otherwise inaccessible technology to become available to students in their classrooms. Remote access opens an opportunity for students to participate in live imaging with electron microscopes, data collection using spectroscopic techniques, or analyzing data alongside a research scientist. As images and data are obtained, students discuss the technology/experiment over live video streaming with a scientist assisting in the remote session. Student engagement can take on a new dimension given this opportunity (Harlow and Nilsen 2011). Students report more positive views of science after remote experiences (Rodriguez et al. 2018a). Yet, remote access pedagogy is a technology in the classroom that has not been well-defined. One could ask, what exactly are students learning when they use remotely accessible technology? A focus of research has been on assessing the value of remote access technology as a tool to deliver science content (Jones et al. 2003; Muñoz and López 2014) or to enhance student understanding of disciplinary core ideas (Flynn et al. 2007). Students reported using remote access technology felt like a "real scientific experience" (Sauter et al. 2013). Early positive investigations led to development of curriculum integrating remote access technology into primary and secondary schools, as well as into undergraduate college science lessons (Ashcroft et al. and Rodriguez et al. 2018a, b). In general, the focus on remote access technology has been on its role as an Educational Technology, to be used as an aid in increasing student attitudes and learning of the content of their science lessons. The efficacy of remote access technology as a form of Technology Education is less known.

Despite educational reforms in the last 20 years, studies reveal an overall decline in STEM interest (Kelley and Knowles 2016) with the most negative effects occurring among students identified as being underrepresented from lower socioeconomic status backgrounds (Cooper et al. 2018). Schools often operate on low budgets within larger social structures of oppression (Eisenhart et al. 2015.) It has been shown that underrepresented students' interest in science or engineering careers falls progressively as they proceed into their pre-college education (Else-Quest et al. 2013) and their academic preparation lags behind when examining ACT College Readiness Benchmarks (ACT 2016). Remote access technology is accessible and affordable for low-income schools, which often serve underrepresented communities (Ashcroft 2017) Developing pedagogy around remote access technology, investigating whether it functions equally well as Educational Technology or Technology Education and whether it increases student interest and performance in STEM, is paramount to assessing its value as a component in technology-based teaching.

Study Methodology

Background

Remote access technology coupled with active learning pedagogy was investigated in a middle school (students age eleven to twelve) with 99% underrepresented student population. Hands-on activities and activities that engage technology have elicited higher interest and engagement from students (Swarat et al. 2012 and Ben-Zvi and Orion 2005), leading to improved student performance and content understanding compared with traditional teaching method (Harris et al. 2015; Taraban et al. 2007). Innovative pedagogy with real-world applications is also found to promote student success (Engberg and Wolnack 2013). In accordance with the wealth of research on active learning, a curriculum was developed specifically pairing remote access technology with hands-on, lab-based experimentation.

This study investigates *learning* and *attitudes* attributable to the pedagogy. Student success in STEM is correlated to student confidence, engagement, and attitudes (Rodriguez et al. 2018a). Across underserved groups, students with positive attitudes and early exposure to complex science problems and technology represented a stronger predictor than grades in students pursuing a STEM career (Hinojosa et al. 2016; Kurz et al. 2015). Additionally, attitudes resulting from ethnic perceptions of science and scientists influence career identities (Wong 2015). The importance of student attitude as an influencer of student engagement with STEM after secondary school is why our study focuses on attitudinal effects of the pedagogy.

Research Questions

Investigation of learning and attitudes were divided into two distinct research questions as related to middle school students age eleven to twelve from a low socioeconomic demographic:

1. Does remote access technology, coupled with active learning, influence student attitudes toward Science, College, and/or Technology?
2. Does remote access technology, coupled with active learning, fulfill the role of Technology Education?

This inquiry allows for separating and analyzing various aspects of pedagogy. It considers the need for pedagogy that increases student attitudes toward science and college, explores student attitudes toward scientific technology, and seeks to identify the role of remote access technology within integrated STEM education.

Participants and Aspire Pacific Academy

Participants were predominately Latinx from a seventh-grade classroom at Aspire Pacific Academy (APA). APA is a public charter school for grades 6–12 in downtown Los Angeles. A total of 33 students participated in the study with 29 completing the pre- and post-survey, 100% participating in 3 or more lessons, and 20 completing the sequence in its entirety (5 lessons). Previously, a study was performed with predominately sixth to eight grade students using remote access a single time using the geology lab with 837 students at seven different schools in 21 separate classes that demonstrated a 92% engagement with the remote experience and a 2.5-fold favorable increase in student perception of science coursework (Rodriguez et al. 2018a). In addition, remote laboratory experiences have been shown as an effective practice in secondary science education (Tho and Yeung 2018). The APA study evolves the past study to determine specific learning gains using more in-depth and year-long remote lessons. One obstacle to this study is the accessibility and willingness for teachers to allow multiple remote experiences in their classrooms. Most teachers asked to participate would not give up class time. APA offered administrative support and teacher willingness to allow five class days to administer remote labs. Because this was a pilot study for an integrated curriculum (a lesson sequence designed to complement middle school/high school science coursework), it was essential that the five lessons were spread throughout the year.

RAIN

Remotely Accessibly Instruments in Nanotechnology (RAIN) is a network of twenty-four universities and community colleges that provide free access to advanced technologies, such as a scanning electron microscope. A classroom computer and internet connection are the sole requirements required to use RAIN. During a RAIN session, research scientists or technicians are made available at no cost to participating schools. Sessions are scheduled through the RAIN website at nano4me.org/remoteaccess. Connection to RAIN is accomplished using free software Zoom. To date, 355 RAIN sessions have been performed to 6743 students, including eight sessions outside the USA. The remote capabilities and over the internet connections overcome geographic obstacles for participation in advanced instrumentation activities. Post RAIN surveys asked educators if they would recommend RAIN to a colleague. Every respondent said yes, demonstrating the positive impression teachers had on the impact on their students.

During lessons at APA, students remotely accessed an SEM with EDS capabilities. SEM provided interactive microscale imagery (Fig. 1a, b), whereas EDS performed elemental analysis of imaged sample (Fig. 1c). Students viewed live SEM imagery as a large group via projector (Fig. 1d). They could change magnification and resolution of image by verbally requesting adjustments or ask questions that prompted the RAIN scientist to change image. Students only directly controlled the SEM during the final active learning activity, where they imaged samples they brought from home.

Curriculum

A single lesson occurred within a 90-min class period. Each lesson had a similar structure: (i) PowerPoint introduction to lesson's theme/context; (ii) experiment-based, hands-on exploration/observation; (iii) live SEM imaging and EDS; (iv) scientific conclusions/connections. Additionally, lessons were integrated, multidisciplinary and framed in a "real world" context. Current issues in space exploration was a common theme within each lesson, as well as connections among earth sciences, environmental issues, and students' experiences. The five lessons were Introduction to Quantum Theory Scale of the Universe (Ashcroft et al. 2018b), Geology (Rodriguez et al. 2018b), Oxygen (Ashcroft et al. 2018a), Water (NASA n.d.-a), and a Mystery of Life Astrobiology (NASA n.d.-b) lab. Quantum science lesson introduced students to the

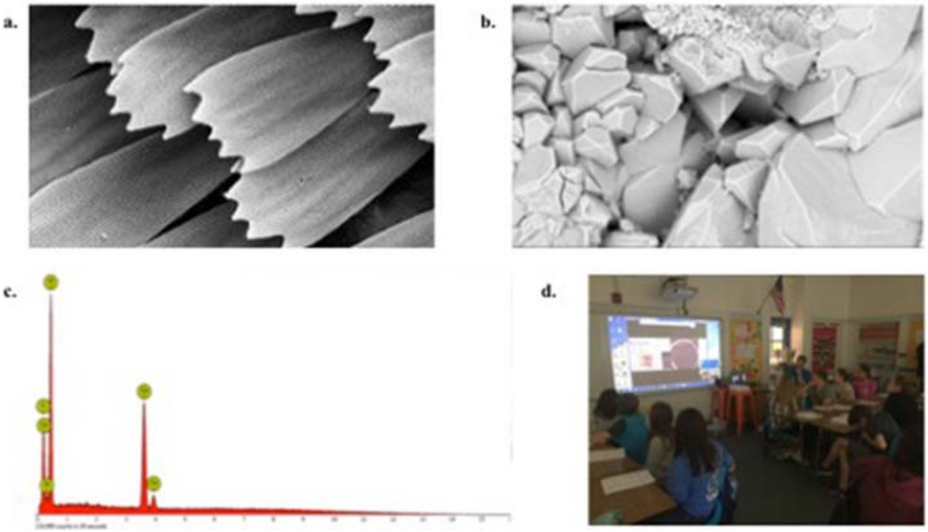

Fig. 1 **a** SEM image of butterfly wing. **b** SEM image of limestone. **c** EDS elemental analysis of limestone. **d** Students at Aspire Pacific Academy using RAIN

scales of the universe concluding with an SEM interactive image guessing game. Geology lesson utilized EDS alongside chemical and physical tests to determine identity of unknown mineral samples. Oxygen lesson asked students to analyze percent oxygen in a room through oxidation of steel wool (iron) while visualizing changes in chemical structure before and after oxidation with SEM, followed by analyzing elemental composition of iron oxide with EDS (Experiment in supplemental materials). Water lesson was a NASA-designed filtration challenge modified to visualize impurities in water samples before and after filtration using SEM. For the final astrobiology lesson, students evaluated signs of life in common objects. They were asked to bring any sample of their choice to image using the remote control of SEM. In this case, the actual astrobiology lab did not have a direct SEM component. Instead, SEM was used more actively by students directly controlling the SEM and imaging their own samples.

Lessons were designed to be cost effective, low complexity with minimal exposure to harmful materials. Each activity can be performed in any level of K-12 class and can be modified to the standards associated with each grade level. Access to the RAIN Network is free, thus allowing for the widespread adoption of the activities presented in this paper or for novel activities to be created by educators in any STEM discipline. The experimental labs presented could stand on their own, but were modified so significant conclusions could not be drawn without the SEM. For example, in geology lab, identity of an unknown mineral was investigated by students. Traditional lab-based tests such as acid, flame, density, hardness, and streak could give students clues to identify the unknown mineral. However, the lab was designed so that the final conclusion of "limestone" could only be determined after performing elemental analysis (EDS) and identifying elemental composition of the mineral. Similarly, "cleanliness" of water was investigated using chemical tests before and after filtration during the water lab. Then, SEM imagery obtained remotely revealed impurities in water that could not be identified by the filters and chemical tests.

Data Collection/Analysis

Data was collected through participant surveys (supplemental materials) developed in collaboration with professors of science education, primary and secondary school science teachers, and RAIN Network providers. Student identifiers were anonymized with data from individual students tracked through alphanumeric codes. The study progressed as follows: pre-survey was administered before commencing first lab; lesson survey followed each lesson (with lessons spaced approximately 6 weeks apart); post-survey was administered at completion of final lesson. Demographic questions were posed at the end of pre-survey so as not to influence student response.

Surveys contained a mix of multiple-choice and Likert items. Multiple-choice questions were fact-based, used as a metric to track student learning. Likert items (on a five-point scale) gauged student attitudes. Data collected tracked changes/differences within a single sample group; accordingly, dependent sample statistical tests were used to evaluate data. Differences in multiple-choice scores were compared using matched-pair t tests. Likert item data were analyzed using Wilcoxon matched-pairs signed-rank test. For Likert data, median, rather than mean, as a measure of central tendency was used due to the ordinal nature of Likert items.

A description of each instrument follows:

Pre-Survey A total of sixteen Likert items ascertained students' (i) attitudes toward science, (ii) attitudes toward college, (iii) attitudes toward technology. Six multiple-choice questions asked about remote access technology (specifically, the SEM and EDS) and science concepts contained in lesson sequence. Students were not expected to have encountered these concepts prior to pre-survey. Therefore, a significant increase in correct multiple-choice responses at time of post-survey would be an indicator of learning gains.

Post-Survey The post-survey contained identical multiple-choice questions and Likert items to the pre-survey. The post-survey had five additional Likert items related to student attitudes toward their remote access experience, which would not have been relevant to ask before commencement of lesson sequence.

Lesson Surveys Each lesson concluded with multiple-choice questions that were aligned with core science concepts, methods, or real-life context/application. These questions furthermore were classified as being related to Educational Technology, Technology Education, or Active Learning. Active Learning was used as a baseline to compare students' Educational Technology and Technology Education responses. Educational Technology questions specifically related to learning the content of the science lesson using RAIN; Technology Education questions related to learning about technology using RAIN. An example of each is shown below:

> **Active Learning:** The formation of iron oxide on the Mars surface makes it what color? (*answer: red*)
> **Educational Technology:** What was one of the elements revealed in the Elemental Analysis? (*answer: oxygen*)
> **Technology Education:** What could you find out about common household items by using Electron Dispersive Spectroscopy (EDS)? (*answer: find out what elements the item is composed of*)

Lesson Evaluations Students were asked to evaluate the lessons they participated in using a Likert-style questionnaire. Research suggests that students may be essential regulators of their own curricula (Morales-Doyle 2017). We sought to identify correlations between student evaluations and the content, design, or student's academic performance within each lesson.

Results

Demographic Data and Sample Size

A total of 33 students participated in this study. All students participated in at least 3 lessons. Of these, 29 students completed the pre-survey and post-survey. A total of 20 students completed all 5 lessons. The class had a slight male majority; 81% of the students selected ethnicity as "Hispanic/Latino"; 47% of students were unaware of parents' education level; 22% had parents who were high school graduates or had attended some college; and 28% reported at least one parent who was a college graduate.

Due to $n = 29$ for the pre/post-survey sample, we used a Wilcoxon matched-pairs signed-rank test (a nonparametric test) to evaluate the Likert-style data. This approach is appropriate both for the type of data (ordinal, dependent) and the $n = 29$ sample size (Woolson 2008). We used a matched-pair t test (a parametric test for dependent data) for the multiple-choice responses; these results may be considered a good approximation given the $n = 29$ sample size (Kim 2015).

Pre/Post-Survey

Multiple-choice questions 1–3, 5, and 6 were about the technology (and the science behind the technology) encountered during remote access sessions. Pre- and post-responses ($n = 29$) were compared with a matched-pair t test (Table 1). The mean score increased from 0.38 (before lesson sequence) to 0.50 (after lesson sequence). Under the assumption that scores could have increased or decreased (i.e., a two-tailed test), the resulting p value was 0.05 (95% confidence interval). A one-tailed test, assuming it is reasonable to expect that students will perform better after participating in the lesson sequence, had a p value of 0.025 (99% confidence interval). Under both assumptions, statistically significant difference in the means leads us to conclude that learning gains occurred.

Likert items were analyzed to compare student attitudes toward science, college, and technology. A Wilcoxon matched-pairs signed-rank test was performed on each Likert item to determine if there was a significant change in median score. In this test, each student is compared with themselves, and changed scores are compared in a ranked analysis. We used an 85% confidence level (alpha = 0.15, see Table 2 for p values). For all questions, a left-tailed test, which predicts a decrease in the median, gave no significant results. A two-tailed test, assuming neither increase nor decrease, resulted in a single Likert item from the Technology category showing an increase in median score. A right-tailed test, which predicts an increase in the median, resulted in 3 out of 5 questions in the Technology category rejecting the null hypothesis in favor of an increased median score. The results of this comparison suggest that attitudes toward Science and College were not, in a statistical sense, significantly affected by the lesson sequence, but that a positive change occurred in the students' attitudes toward Technology.

Post-Survey: Remote Access

There were 5 Likert-style items on the post-survey that were not on the pre-survey. These items directly queried the students' experience of remote access. There were 30 students who completed this assessment of remote access. A frequency table displays students' feelings about different aspects of their experience with remote access (Table 3). For 5 out of 5 items, over half the responses were positive ("strongly agree" or "somewhat agree") and the median

Table 1 Matched-pair t test analysis pre- and post-responses

Matched pair t test	Pre-survey	Post-survey
Mean	0.38	0.50
Variance	0.044	0.090
Observations	29	29
Hypothesized mean difference	0	
Degrees of freedom	28	
t Stat	−2.04	
$P(T \leq t)$ one-tail	0.025	
t Critical one-tail	1.70	
$P(T \leq t)$ two-tail	0.050	
t Critical two-tail	2.05	

Table 2 Wilcoxon matched-pairs signed-rank test on Likert data

Wilcoxon matched-pairs signed-rank test (pre/post-survey)		Two-tailed test		Left-tailed test		Right-tailed test	
$n = 29$		H0: $M = 0$		H0: $M = 0$		H0: $M = 0$	
		H1: $M \neq 0$		H1: $M < 0$		H1: $M > 0$	
		alpha: 0.15		alpha: 0.15		alpha: 0.15	
		p value	H	*p* value	H	*p* value	H
Attitudes toward technology							
Q8	Nanotechnology has led to discoveries in chemistry and engineering.	1.00	0	0.56	0	0.50	0
Q17	Nanotechnology offers many insights that other scientific tools do not offer.	0.13	1	0.94	0	0.07	1
Q19	Nanotechnology has impacts on ordinary people's lives.	0.23	0	0.89	0	0.12	1
Q24	I know how to use remote access to operate scientific equipment.	0.50	0	0.76	0	0.26	0
Q25	I know how to access scientific tools on the internet.	0.24	0	0.89	0	0.12	1
Attitudes toward college							
Q10	I want to go to college.	0.54	0	0.73	0	0.27	0
Q11	Going to college is possible for me.	0.29	0	0.87	0	0.15	0
Q12	I'm not good enough at science to go for a college degree in a STEM field.	0.38	0	0.20	0	0.82	0
Q13	There are many obstacles to going to college.	0.97	0	0.49	0	0.55	0
Attitudes toward science							
Q14	I can overcome challenges in my education.	0.21	0	0.91	0	0.10	1
Q16	I can use science to answer questions I have about the world.	1.00	0	0.51	0	0.51	0
Q17	I enjoy learning about science.	0.96	0	0.55	0	0.48	0
Q26	I can conduct a scientific investigation.	0.65	0	0.33	0	0.68	0
Q27	I feel comfortable speaking to professionals working in STEM fields.	0.40	0	0.21	0	0.81	0

score was "somewhat agree." For 3 out of 5 items, over 1/3 of students gave remote access a maximum score of "strongly agree": (i) Remote access learning labs increased my interest in going to college; (ii) I hope to use remote access in future classes; (iii) I would recommend remote access to other students. Out of 150 total Likert responses, 61% were positive, 21% were neutral ("neither agree nor disagree"), and 19% were negative ("somewhat disagree" or "strongly disagree").

Table 3 Frequency table student experiences with remote access

Frequency table for Likert items regarding student attitudes toward remote access technology (post-survey)

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree	No response	Total
Q15: Remote Access learning labs increased my interest in going to college.	10	6	9	2	3	0	30
Q20: I think remote access helped me learn the content of the learning labs.	7	13	7	0	3	0	30
Q21: Using a Scanning Electron Microscope increased my enjoyment of science.	8	11	4	3	4	0	30
Q22: I hope to use remote access technology in future classes.	12	5	6	3	4	0	30
Q23: I would recommend remote access to other students.	12	7	5	2	4	0	30
Total	49	42	31	10	18	0	150
Percent	32.7%	28.0%	20.7%	6.7%	12.0%	0%	100%

Lesson Surveys

Table 4 displays the response rates for the multiple-choice questions the students answered at the end of each lesson. This table shows the responses of all participants on a question-by-question basis. However, to identify statistical parameters of the distributions (such as differences in average score between categories), only data from students that completed all 5 labs were used (i.e., a matched-pair *t* test would lack meaning for a student who did not attend a given lab). Only 20 students completed all five labs; therefore, the multiple-choice data from the lesson surveys were nonparametric. We present this data in summary form in Table 5 with the following analysis: over the lesson sequence, multiple-choice questions referred to the science behind the remote access instrumentation (Technology Education, 4 items), the use of remote access technology to achieve educational aims of the lessons (Education Technology, 4 items), and the parts of the lesson that did not utilize remote access technology (Active Learning, 12 items).

We included data only from those students who completed all five labs ($n = 20$). This ensures that each category contains a single score from each student. We found that the median score was higher for Technology Education (0.63) than Education Technology (0.50). Additionally, the most common score (mode) in Technology Education was 0.75 (matching Active Learning), compared with a mode of 0.50 in Education Technology (Table 5). The box-and-whiskers plot in Fig. 2 helps visualize the distribution of the data. Active Learning, a known educational method, provides a sense of baseline (median = 0.54).

Table 4 Response rate on multiple-choice questions (lesson sequence, by category)

Category	Lesson	Correct responses	Total responses	Percent correct (%)
Technology Education (4)				
What would be something we could measure by looking through the SEM?	Quantum	20	29	69
When using the SEM, we are seeing the activity of what type of particle?	Quantum	16	29	55
What fields of science would use an SEM with EDS to find the elemental composition of a mineral?	Geology	12	31	39
What could you find out about common household items by using EDS?	Astrobiology	21	31	68
Education Technology (4)				
What was one of the elements revealed in the Elemental Analysis?	Geology	22	31	71
The presence of which elements definitively determined the identity of the unknown sample?	Geology	20	31	65
Elemental analysis from SEM/EDS revealed that ______ was an element that not in the clean steel sample but was in the oxidized sample.	Oxygen	3	23	13
Based on today's lab and the SEM images of water from different environments, which statement is most likely to be true?	Water	13	31	42
Active Learning (12)				
When the energy from light hits an atom, what happens to the electrons?	Quantum	22	29	76
Your eyes see different wavelengths as _____.	Quantum	13	29	45
Which test revealed the presence of carbonate in the sample?	Geology	12	31	39
As iron oxide formed, what happened to the overall amount of matter within the test tube?	Oxygen	8	23	35
The formation of iron oxide on the Mars surface makes it what color?	Oxygen	11	23	48
What materials were used for this lab?	Oxygen	18	23	78
What happens to a salt (and ionic compound) when it is dissolved in water?	Water	18	31	58
If astronauts were to find clear water on Mars, would it be safe to drink it?	Water	22	31	71
What was the purpose of using different types of materials for your water filter?	Water	10	31	32
Which of the following is NOT a criteria for life?	Astrobiology	14	31	45
Which of the following is an example of a living organism?	Astrobiology	25	31	81
Why did we add water to our samples?	Astrobiology	24	31	77

Lesson Evaluations

Data from the Likert items, intended to give the students an opportunity to provide feedback on their experience of the lessons, showed no statistically significant differences between the labs. Thus, we omit an analysis on a lab-by-lab basis. Table 6 is a frequency table of responses showing Likert item responses over the entirety of the lesson sequence. A total of 63% of all responses were positive evaluations of the lessons ("somewhat agree" or "strongly agree"); 43% were the maximum score of "strongly agree" (note: a reverse scale was used for "negative" questions such as Q6: "I was confused by this lab.")

Table 5 Distribution of multiple-choice responses (lesson sequence, by category)

For $n = 20$ students who completed all 5 lessons	Technology Education questions	Education Technology questions	Active Learning questions
Mean	0.56	0.49	0.53
Std. dev.	0.34	0.26	0.23
Mode	0.75	0.50	0.75
Minimum	0.00	0.00	0.00
1st quartile	0.25	0.25	0.42
Median	0.63	0.50	0.54
3rd quartile	0.75	0.75	0.75
Maximum	1.00	1.00	0.83

Discussion

The pre/post-survey offers preliminary results in support of the hypothesis that remote access technology, coupled with active learning, is a pedagogical tool for Technology Education. The multiple-choice responses showed unequivocal learning gains on the science behind technology and the SEM. All students participated in at least 3 lessons, suggesting that exposure to a diversity of science lessons, each with a component that involved interaction with the SEM, contributed to students gaining information about the technology that they were using.

The Likert item analysis of the pre/post-survey supports the hypothesis that student attitudes toward Technology was impacted by the lesson sequence. The most statistically robust change in student attitudes occurred for Q17: "Nanotechnology offers many insights that other scientific tools don't offer." (Table 2) Significant increases also occurred for the following items: Q19: "Nanotechnology has impacts on ordinary people's lives." Q25: "I know how to access scientific tools on the internet." We did not find student attitudes toward College or Science shift in a statistically significant way, as previous research has found (Ashcroft et al. 2018a). This may be in part because students in 7th grade have already, from

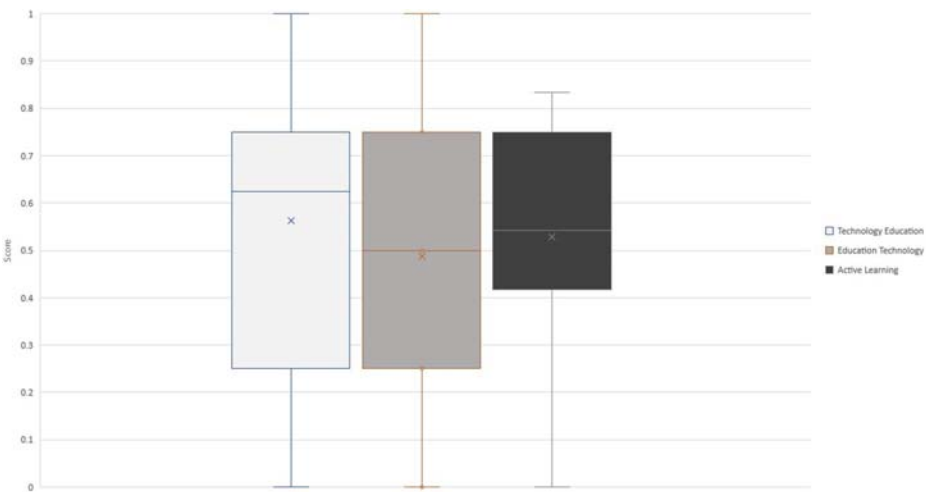

Fig. 2 Box and whisker distribution plot, multiple-choice questions on lesson surveys ($n = 20$)

the onset of their education, been exposed to STEM curricula. However, the students had never encountered advanced scientific instrumentation—thus the "newness" of the scanning electron microscope may have had a greater impact on the students. The increased confidence in the Likert item responses suggests that remote access instrumentation coupled with active learning increased positive attitudes toward scientific technology at an early age—supporting future student success in STEM (Hinojosa et al. 2016; Kennedy et al. 2018). It is relevant to point out that exposure in a hands-on, scientific context likely contributed to the shift in attitudes. Almost every kid knows how to use a cell phone, tablet, or computer. To interface with the SEM, students were required to develop a deeper knowledge of the *science behind the technology*. Similar to how computer programing and robotics move students from the passive role of "user" to the active role of "creator" (Simpson et al. 2020), the students were asked to pull back the curtain on technology in order to utilize it for scientific experimentation.

Lesson survey Likert item responses were 63% positive—suggesting that the majority of experiences were engaged, satisfied with the content, and confident that they had learned something new (Table 6). Research connects active learning and engagement as an indicator of learning (Swarat et al. 2012; Ben-Zvi and Orion 2005), so these student assessments may be a positive indicator for active learning coupled with remote access instrumentation as a learning tool. Feelings that the lesson contents were inaccessible, i.e., not having to do with real life, persisted (with 43% negative responses, see Q5 in Table 6) despite efforts in the lesson design to engage both real-world environmental issues and current issues in space exploration. This was the most apparent barrier to engagement we found in the students' own evaluations of the curriculum.

The post-survey Likert items that queried the students' experience of remote access (Table 3) likewise had a 61% positive response. This finding is in alignment with current research on remote access technology (Rodriguez et al. 2018b). Thirty students completed this post-survey assessment of their overall experience using the RAIN SEM. The highest frequency of "strongly agree" (40%) occurred for items Q22:"I hope to use remote access in future classes" and Q23: "I would recommend remote access to other students." The lowest frequency of "strongly agree" (23%) occurred with Q20: "I think remote access helped me learn the content of the learning labs." Comparing these response rates, we see a drop of nearly

Table 6 Frequency table of Likert item responses (lesson sequence)

	Likert item score						
	5	4	3	2	1	No response	Total
Q1 The lab was taught in a way that was clear and easy to understand.	68	31	19	9	18	0	145
Q2 I had all the supplies I needed to do the lab.	81	24	16	10	14	0	145
Q3 I feel confident that I learned something new in this lab.	75	33	17	4	15	1	145
Q4 The lab was fun.	72	35	14	5	19	0	145
Q5 The lab seems to have nothing to do with real life. *(reverse scale)*	46	19	37	17	26	0	145
Q6 I was confused by this lab. *(reverse scale)*	48	25	40	21	11	0	145
Q7 I want to learn more about the subject in this lab.	51	35	35	4	20	0	145
Total	441	202	178	70	123	1	1015
Percent	43.4%	19.9%	17.5%	6.9%	12.1%	0.1%	100%

one-half occurred for the students' own assessment of the value of the remote access instrumentation in learning the lesson content.

The multiple-choice section of the lesson surveys, in light of the pre/post-survey results, suggests that the remote access instrumentation might have played two distinct roles. Keeping in mind that the sample data in Table 5 and Fig. 2 are from the subset of students who completed all 5 lessons, we do not make any conclusions about the parameters of the distributions (such as a significant difference between means). In its role as Education Technology, remote access instrumentation did not appear to be a major improvement over Active Learning (consider the lower median score of Education Technology). This would be contrary to previous research on remote access instrumentation (Jones et al. 2003), and due to the small sample size, this cannot be stated here conclusively. We note that the much higher median score for Technology Education is on par with Active Learning. The high scores and tighter distribution for Active Learning aligns with established research on student motivation through active learning experiences (Owens et al. 2020). Considering the changed student attitudes toward technology (pre/post-survey, Table 2) and Technology Education learning gains (pre/post survey, Table 1), this warrants further research into remote access as a pedagogy for Technology Education. The students' own perceptions that remote access may not have helped them learn the content of the lessons prompts further questions: Does the use of remote access technology teach *the science of technology* more effectively than the content of science lessons? Or is it on an equal footing *augmenting* science lessons in an unforeseen way? These are questions that can be answered by further research, in particular studies with large sample size and a more developed metric for learning gains in educational technology versus technology education.

From a pedagogical point of view, technology in the classroom should assist student learning (act as good Education Technology). If, as this data suggests, the use of the RAIN SEM did a better job at teaching the science of technology than the science in the lesson plan, we must consider factors in this study that might have contributed to this outcome. For example, prior research has linked learning with remote access (Flynn et al. 2007; Muñoz and López 2014), but implementation is a key component of effectiveness (Lowe et al. 2012). It is also important to be aware of the halo effect in which students are more effusive in their assessment of a lab experience due to the use of more interesting, advanced technology, in this case the scanning electron microscope (Kehinde et al. 2011). In this study, students performed the labs in small groups of two to four but used the RAIN technology all together as a large group; it is possible that this interface supported learning gains in Technology Education but neglected to support the students' learning of lesson content. This prompts the question as to how remote access technology could better support student learning. One approach would be to tailor remote experiences for small groups or individuals—a more student-centered approach (Colbert and Arboleda 2016). Research has related student perceptions of identity, motivation, and "realness" of remote access as a factor of remote learning environments (Childers and Jones 2017). Further research may consider the "intimacy" of interactions with remote access a factor in student learning.

Conclusion

Barrier of cost is a serious roadblock for advanced technological access in classrooms worldwide. The low cost of RAIN is an opportunity to bring advanced technologies like

SEM into all classrooms, making long-term interactions achievable. Yet, the significance and role of remote access instrumentation such as RAIN should not be taken for granted. In this study, a group of young students used RAIN to access an SEM to augment active learning science lessons. The SEM was integrated into the lessons so that the experiments relied upon both an active component (some physical and/or chemical experiment in the classroom) and the use of SEM and elemental analysis (EDS). The students' experience led to increased understanding of the role of scientific instrumentation and the science behind SEM. Learning gains related to Technology Education and attitudes toward technology shifted in a statistically significant positive direction. Separating the remote access component from experiment-based, hands-on, integrated lessons holds no promise that these results would hold. In fact, a well-established pedagogy of hands-on learning supports the likelihood that it was this integrated approach that allowed for remote access technology to more fully inform students' experience of the *T* in STEM. If further multi-year studies on remote access technology coupled with learning labs confirm this role of Technology Education, previously ignored or considered secondary, to be a primary role, it would influence curricula design significantly. On one hand, it would mean changing the focus of lessons to include deeper learning about the science of technology, which this research suggests, is a natural consequence of this pedagogy. On the other hand, researchers may want to direct extra attention toward discovering ways to boost remote access technology's efficacy as an educational tool as well.

Acknowledgments The authors would like to thank the assisting RAIN technicians. RAIN is a network supported by National Science Foundation grant DUE 1204279. We would also like to thank Diana Campos and her sixth-grade class at Aspire Public Schools. Jennifer Portillo and Esteban Bautista assisted in curriculum development with help from the NASA Educator Professional Development Collaborative.

Funding Vanessa Wolf is supported by BUILD PODER, funded by National Institute of General Medical Sciences of the National Institutes of Health under award number RL5GM118975. Ashley Min is supported by the Early Career Undergraduate Research Experience (eCURe), funded by National Science Foundation Advanced Technology Education grant DUE 1601813. Jared Ashcroft and Brandon Rodriguez are supported through the Micro Nano Technology Education Center (MNT-EC), funded by the National Science Foundation Advanced Technological Education grant DUE 2000281.

Compliance with Ethical Standards Compliance with ethical standards includes no noneducational research involving human participants or lab animals, and informed consent was obtained from all individual participants.

Conflict of Interest The authors declare that they have no conflict of interest.

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