Teaching Science in the Virtual Environment: The Case of Excellence Academy during the Pandemic

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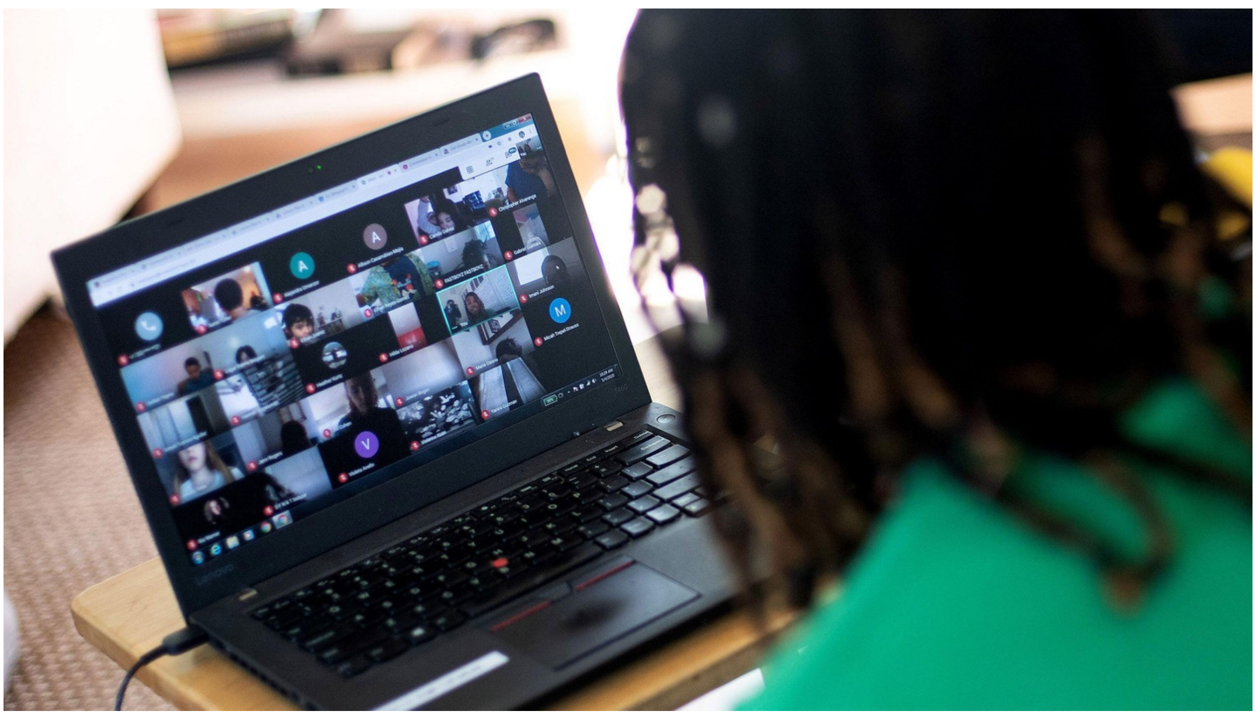

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The global pandemic forced many schools to shut their doors and shift their learning to online platforms. This shift created significant challenges for the administrators and teachers as they navigated the new learning environment. The science teachers at Excellence Academy had a special challenge of finding the best way to adapt their hands on, inquiry-based curriculum focused on the scientific and engineering practices of the Next Generation Science Standards to the virtual learning environment. This project sought to evaluate the effectiveness of the teachers' instructional strategies and the impact of the virtual learning on the student academic outcomes and their interest in science and engineering.

Using Anderson's (2003) model of online learning interactions, this project addressed the following four questions:

- What are the student perceptions of the most effective teacher-student, student-student, and student-content instructional practices that the teachers used in the virtual environment?
- What are the student perceptions of the effectiveness of teaching the scientific and engineering practices of the NGSS in the virtual environment?
- How did learning science in the virtual environment impact the academic outcomes of the higher and lower achieving students, and are there noteworthy differences between the teachers' sections?
- How does learning science in a virtual environment influence student interest in learning more about science and engineering and pursuing these subjects at university and in a career?

After collecting student surveys from both before and after the Fall semester, as well as student science scores from ninth-grade and their tenth-grade final assessments, the data analysis revealed four main findings:

- According to the students, teacher feedback was the most effective teaching strategy, and observing teacher experiments and 'Pivot Labs' were the most effective ways of conducting virtual labs.
- There were no significant differences in the student perceptions of the effectiveness of the assignments and activities engaging the different scientific and engineering practices.
- Overall, student academic outcomes during virtual learning did not differ significantly from their ninth-grade outcomes. Notably, the students in the lowest quartile did better relative to the other students and the students in the highest quartile did worse, with students in one teacher's section showing a small improvement relative to the other three teachers' students.
- Student interest in learning more about science increased during the semester, but not their interest in pursuing science and engineering in college and in a career. There were small differences in interest between males and females, Asian students, and black students.

Overall, these findings show that the teachers were quite successful at adapting their curriculum to the online environment. The students found their instructional strategies to be effective, they continued to learn as expected, and their interest in science increased even while learning online.

From these findings I offer Excellence Academy four main recommendations:

- Structure online instruction to privilege continual teacher feedback on student work, based on the work of Hattie & Tamperley (2007).
- Discontinue student at home experiments in favor of observing teacher experiments and expand the use of 'pivot labs' to recreate inquiry-based lessons that engage the students in the scientific and engineering practices.
- Provide extra-credit activities, summer enrichment units and other means to address the learning deficits of the students.
- Promote student interest in science and engineering careers through more assignments that apply science knowledge to real-life problems, and by creating student STEM communities of practice, and hosting STEM professionals on campus.

The limitations of the small, non-random sample size and the lack of more extensive data weaken the power of the research conclusions. However, this study motivates further research on the impact of school closures on student learning, on how best to reproduce science labs in virtual classes, and how best to promote STEM careers to virtual students.

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The onset of the global pandemic in March 2020 created unique challenges for K-12 schools. Strict public health restrictions caused most schools to close their doors and move learning to online platforms. Administrators and teachers had to make quick decisions on a whole host of different online options: synchronous or asynchronous learning, change schedule or keep the same schedule, adapt curricula or make new units, abandon content assessments or allow open notes tests. The list of choices goes on and on (ASCD, 2020). Teachers and students navigated the complexities of the shift to online learning with varying degrees of success. The essential question on most educators' minds was: What are the best ways to teach, and what are the best ways for students to learn, in a virtual environment?

Excellence Academy was one of the many schools in the United States that shifted to online learning during the pandemic. Excellence Academy is an independent, co-educational K-12 school in the Midwest. Although not perfectly representative of the wider population, its students are ethnically and socio-economically diverse. The teachers and administrators met the challenges of online learning by shifting their schedule and using their LMS, Canvas, more extensively. They opted for synchronous learning and used Zoom as their video classroom. They adapted old units and created new ones. They learned new teaching techniques, utilized new learning apps, and did their best to instruct the virtual students. All the while they were not quite sure which decisions worked well and which did not. This was especially true of the school's science department.

Excellence Academy is known for its rigorous STEM curriculum. This school distinguished itself before the pandemic by its aggressive adoption of the *Next Generation*

Science Standards (NGSS). The National Research Council published the NGSS in 2013 after many years of work. The goal of the new standards is to shift the focus of K-12 science education away from extensive content coverage and memorization toward having the students become *doers of science* (Miller et al., 2018). The NGSS offer a framework for science education with three dimensions: disciplinary core ideas in four areas, crosscutting concepts that unify all scientific disciplines, and the scientific and engineering practices (National Research Council, 2012).

In the summer of 2019 the tenth-grade science teachers at Excellence Academy implemented a new curriculum which privileged students learning the scientific and engineering practices (SEPs) of the NGSS. With the closing of schools during the pandemic, these teachers faced a particularly tough challenge. How could they teach the SEPs when the students could not be in the laboratory conducting experiments, gathering data, analyzing evidence, using models to explain findings, and in general 'doing' science? These teachers embarked on a journey of discovery themselves, adapting their curriculum as best they could to the virtual environment. After a semester and a half of teaching online, they wanted to evaluate their efforts.

The purpose of this capstone project is to evaluate the strategies and practices that the tenth-grade science teachers at Excellence Academy used to teach their NGSS-aligned science curriculum during the virtual learning Fall semester of 2020. This project combines two areas of inquiry: online learning and NGSS-aligned science education. The sample population is all of the students enrolled in the regular tenth-grade science course at Excellence Academy. The goal of the project is to offer the science teachers and administrators at the school robust feedback about the effectiveness of their teaching, the quality of student learning, and the impact of virtual learning on the students' interest in

STEM. From this feedback I hope to offer helpful recommendations for how to improve online science instruction in order to enhance student outcomes.

ORGANIZATIONAL CONTEXT

Excellence Academy[1] is an independent, co-educational, K-12 school in the Midwest of the United States. It began when two separate independent schools merged in 1992. It is situated in a suburban area of a major metropolitan city. The total student population is roughly 1,240, with about 635 in the high school. The school's brand has three key characteristics. The school Mission Statement highlights two of these. It reads, "Our school cherishes academic rigor, encourages and praises meaningful individual achievement, and fosters virtue. Our independent education prepares young people for higher learning and for lives of purpose and service." Academic rigor and college preparation, and fostering virtue and service are two key features of this education. The third main characteristic is the school's commitment to fostering an inclusive community of students from many diverse backgrounds.

The first main characteristic of the school is its academic rigor and excellent college preparation. The teachers are well-educated, with over 71% with advanced degrees and an average of 17 years teaching experience. The curriculum is ambitious, with a large number of electives, so that the students can follow their academic interests. The class sizes are small, between 12-18 students, so teachers offer more personalized instruction. One can see the results of this rigor in the standardized test scores. In 2020 the student SAT Composite Mean was 1347, and the Median ACT Composite was 30. There were also 17 National Merit Semifinalists. Another example of academic strength is the number of Advanced Placement courses the school offers. In 2020 334 students took 757 AP exams

[1] This school has preferred to remain anonymous for the purpose of this study. The information provided on this organization comes from the school's mission statement and official documents. For the sake of privacy, I do not provide the links to these sources.

in 28 different subjects, with 84% receiving a score of 3 or higher. This type of academic preparation leads to impressive college matriculation results. The school boasts that it prepares students very well for higher learning. More than 99% of graduates go on to college, and many enroll in some of the most prestigious universities in the nation, including Harvard, Washington University, NYU, and Notre Dame.

The second main characteristic of the school is the fostering of virtue and service. The school states that its community culture forms students to become ethical persons by emphasizing the virtues of respect, honesty, and integrity. The school provides opportunities for students to serve one another and local communities, so that students learn compassion and to be responsible for others. The school also tries to foster a level of civic engagement. The Mission Statement says that it challenges students “to stand for what is right and good.” Through co-curricular activities and clubs, students learn to become responsible citizens, able to be leaders in society who promote what is right and good for all.

The third main characteristic of the school is its diverse and inclusive community. The demographic of the student body includes roughly equal numbers of males and females and 35% students of color. Geographically, it is truly a regional school, accepting students from 105 different previous public, private, religious, and independent schools and more than 70 zip codes. With a tuition of over $25,000 per year for the high school grades, there is a challenge of a lack of socio-economic diversity. The school responds to this challenge by offering financial aid to about 25% of families, with the average grant for the high schoolers being $19,000. This rounds out the socio-economic diversity among the students. From this diversity, the school works hard to cultivate inclusion, so that everyone, not matter what profile, feels welcomed and valued. In its commentary on the Mission Statement the school explains, “We cultivate a learning environment in which all students, faculty, staff and parents are valued, affirmed and included as equal members of the community, embracing and celebrating race, color, religion, family structure, national or ethnic origin, socioeconomic background, sexual orientation and gender identity."

AREA OF INQUIRY

The Excellence Academy high school science department stands out in its region for developing its science curriculum aligned to the *Next Generation Science Standards* (NGSS). At the conclusion of many years of development, in 2012 the National Research Council published *A Framework for K-12 Science Education,* which in turn led to the *Next Generation Science Standards* (NGSS Lead States, 2013). These ambitious standards shift the focus of science education away from learning detailed content knowledge toward engaging in the practices of science and engineering and developing a deep understanding of the central concepts of science. It describes the fundamental goal of science education as 'three-dimensional learning' (3-D). The three dimensions are: understanding the *disciplinary core ideas*, understanding the *crosscutting concepts*, and becoming skilled in the *scientific and engineering practices* (NGSS Lead States, 2013). Disciplinary core ideas detail the fundamental principles, laws, and properties that are at the heart of each branch of science. So, the core concepts of the physical sciences include atomic structure, and the properties of protons and electrons. There are seven cross-cutting concepts that inform explanations in all domains of science: *Patterns; Cause and Effect; Scale, Proportion, and Quantity; Systems and System Models; Energy and Matter; Structure and Function; Stability and Change*. The eight scientific and engineering practices (SEPs) define the activities and skills of scientific inquiry: asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, obtaining, evaluating, and communicating information (National Research Council, 2012). The standards are organized into four disciplines: Physical Sciences; Life Sciences; Earth and Space Sciences; and Engineering, Technology, and Applications of Science. At each grade level there are student *Performance Expectations* that are a synthesis of the three dimensions, and thus are the major benchmarks of '3-D learning.' Students are supposed to deepen their understanding of the core ideas and cross-cutting concepts while engaging in the scientific practices. Since 2013, twenty states and the District of Columbia have adopted the standards, and twenty-four states have developed their own standards based on the *NGSS*. However, as with all standards, the challenge for teachers and schools is to translate the lofty goals into actual units and lessons in order for the students to achieve the learning outcomes.

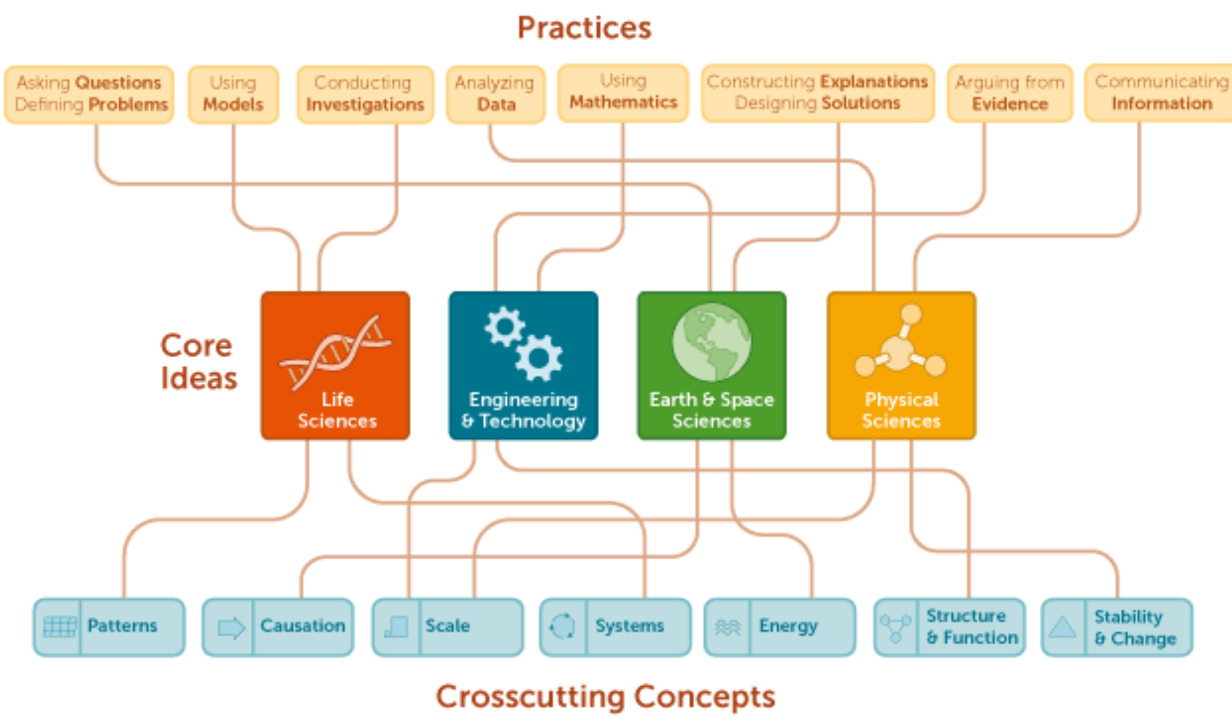

Figure 1: The Three Dimensions of the NGSS

After the publication of the NGSS, the Excellence Academy science department acted. First, they redesigned the curriculum for ninth and tenth grade into two new courses: *Chemical and Physical Systems* in ninth grade and *Bio-Chemistry Applications* in tenth grade. More recently, in the summer of 2019, the tenth-grade teachers revised the curriculum again in order to privilege the goal of teaching students the SEPs. This revised course makes the assessment of these practices 50% of the final grade, and adds three major projects, one at the end of each trimester, in order for the students to integrate their content knowledge through their engagement in the SEPs. In 2020, after the first year of implementation, the science teachers wanted to evaluate whether their redesign had, in fact, been successful at teaching the students to achieve the performance expectations of the NGSS. However, that hope proved to be unattainable.

In March of 2020, as the pandemic hit the country, the Academy closed the school to in-person instruction and shifted to online platforms. As in most schools, the teachers searched for the best ways to teach students in the new virtual learning environment. The tenth-grade science teachers had a particularly difficult challenge. Moving to online learning prevented the teachers from using labs and inquiry-based instruction. How were they supposed to teach the scientific and engineering practices if the students could not be in the labs for experiments and could not do the final projects? Given these limitations, what were the best ways to teach science on a virtual platform? This is the problem of practice that is the focus of this capstone project.

The tenth-grade science teachers went through a learning process in the Fall semester of 2020. They were determined to teach the students the SEPs of the NGSS and cover the major content of their curriculum. They adapted their curriculum and instructional practices to the Zoom classroom. Refusing to cancel labs, the teachers adopted three main practices to the virtual platform: they performed experiments for students to observe and take notes on; they gave students experiments to do at home, either as actual experiments or as imitations; and they used a software program called 'Pivot Interactives', where students engage with interactive videos as a type of lab. Unable to create inquiry-based learning sequences typical of NGSS aligned units, the teachers shifted to more class discussions and group work. Unwilling to abandon the teaching of the scientific practices, the teachers still used and adapted classroom activities and assignments that had the students developing five of the practices: asking questions and defining problems; developing and using models; analyzing and interpreting data; using mathematical and computational thinking; and engaging in argument from evidence (NGSS Lead States, 2013). Finally, teachers used feedback on assignments to help students see their errors and coach them on how to improve.

LITERATURE REVIEW

This problem of practice intersects with two areas of research: K-12 online learning and NGSS science education. Within these two fields of inquiry, there are several questions specific to the context of the science teachers at Excellence Academy. The first and most obvious question is: How has the shift from in-person schooling to virtual learning during the pandemic affected students? The second question is: How effective has online learning been for K-12 students in general? The third question is: What do we know about the best ways to teach in an online platform? Finally, What are the most effective instructional strategies for teaching science curriculum that is aligned to the NGSS? I will review the literature to answer these four questions.

The Effects of School Closures on Students during the Pandemic

It has been difficult to assess the impact of school closures on students, but the evidence suggests a negative impact on student learning. First and foremost, online schooling during the quarantine has caused decreased student attendance (Tadayon, 2020). Experts argue that the quality of instruction has also decreased, as teachers try to adapt their content to online platforms instead of designing online courses (Hodges et al., 2020). With the shifting of many benchmark assessments due to the lockdown, it is difficult to quantify the loss of learning due to the closing of schools. Experts argue that the quality of learning decreased during the lockdown (Drane, Vernon, & O'Shea, 2020). Many scholars suggest that online learning disproportionately affected students from low-income homes, because they lacked access to high-speed internet and appropriate electronic devices that are essential to the success of such learning (Masters et al., 2020).

One study from the Center for Research on Education Outcomes (CREDO, 2020) tried to estimate the loss of learning that took place during the lockdown, using proxies and estimates from the data of previous years. Researchers analyzed the data from 19 states and found that the average losses in reading ranged from slightly less than -0.1 standard deviations to -0.316 for reading, and from between -0.235 to -0.402 for math. The researchers conclude that the impact of the learning losses on student achievement could take years to overcome. CREDO argues that schools and teachers need to develop new approaches to teaching in the COVID-restricted conditions of schooling.

Another outcome from school lockdowns is the evidence of negative psychological effects of students being isolated in their homes for a long time. Connectedness to school is protective against many negative psychological outcomes (Resnick, et al., 1997). So, it is not surprising that early studies on the impact of the COVID-19 quarantine on students have shown increased rates of social anxiety (Zheng et al., 2020) and depression (Tang et al., 2020). Long periods of coronavirus quarantine have been associated with negative psychological effects such as post-traumatic stress symptoms, confusion, and anger (Brooks et al., 2020). Experts expect a surge in mental health problems for minors as a result of the pandemic (Marques et al., 2020; Courtney et al., 2020).

The Effectiveness of Online Learning

Research on the learning outcomes of students enrolled in virtual courses compared to students in traditional, in-person settings varies depending on the age of the students. The research on K-12 virtual learning is not abundant. The Department of Education (Means et al., 2009) conducted a meta-analysis of studies between 1994 and 2008 on the impact of online learning compared to face-to-face instruction and found only five studies of K-12 students that used experimental or quasi-experimental designs. Of those five studies, three found effects favoring blended learning, the combination of online and in-person instruction, one had a significant negative effect in favor of face-to-face instruction, and the other did not attain statistical significance. All of the other studies they analyzed were from undergraduate, graduate and professional programs. Of those studies, the main finding was that students who took all or part of their class online performed better, on average, than those who took the same course through traditional instruction. The average effect size was +0.24 *SD*, statistically significant at $p < .01$ level. Instruction combining online and face-to-face elements, the so-called blended learning, had a larger effect than either all in-person, +0.35 *SD*, $p < .001$, or all online, at +0.14 *SD*, $p < .05$. Several more recent studies on K-12 online education have shown negative outcomes relative to traditional school settings.

A more recent literature review (Nortvig et al., 2018) found similar results to this meta-analysis. Studies showed that students in online and blended learning environments had better learning outcomes, on average, than students in traditional classrooms, with the blended learning environment being the structure with the highest outcomes. Again, the studies analyzed were primarily from higher education. The researchers could not find causal reasons for why there was this difference, but rather concluded, “On the whole, our review of studies comparing F2F teaching to online and/or blended learning reveals that no inherent features of any of the three teaching formats produce either better or poorer learning outcomes for students. Rather, what leads to either is not the format itself, but is circumstantial and context-dependent.” (p. 48)

The largest study of K-12 online learning has come from the Center for Research on Education Outcomes (2015) at Stanford. The researchers compared the academic growth of students in online charter schools with their counterparts in traditional in-person schools in

17 different states and the District of Columbia. They used the Virtual Control Record (VCR) method with a matched data set on a large number of indicators, using students in online charter schools as the treatment group and matching students in traditional schools as the control group. Their analysis showed that students in online charter schools had much weaker growth overall. Across all schools, the average academic losses were -0.25 standard deviations for math, and -0.10 for reading than the students in traditional settings. Although there was some variation between racial-ethnic groups, the effect sizes are all consistently negative, with students of higher economic backgrounds doing better than students from poorer backgrounds.

More recent studies of high school online learning have mostly confirmed the results of the CREDO study. Ahn & McEachin (2017) took student-level data for all Ohio students in traditional and e-schools from 2009 to 2013. Using a linear probability model and controlling for multiple factors, they compared student outcomes in traditional schools and e-schools. They found that high school students in e-schools scored -0.23 *SD* and -0.13 *SD*, -0.18, -0.28, -0.37 worse in math, reading, science, social studies, and writing, respectively, than students in traditional public schools. Heppen et al. (2017) conducted a study testing the effectiveness of online remedial Algebra I classes compared to traditional, in-person classes. Partnering with Chicago Public Schools, the researchers randomly assigned half of the 1,224 9th grade students who failed their Algebra I class to an online remedial class, and the other half to a traditional summer course. Students in the online course had significantly lower scores on the posttest relative to their in person counterparts (d = -0.19), as well as on the Algebra IB test at the end of the course (d = -0.16). However, on the PLAN mathematics assessment in their tenth grade year there were no statistically significant differences between the groups. Finally, only 66% of students randomly assigned to the online course recovered the credit, compared to 78% of the students in the traditional setting. The final grades were also different, with only 31% of online students getting A, B, or C, as opposed to 53% of in-person students.

The only major study that has found different results for K-12 online learners is from Hart et al. (2019). These researchers took data from the Florida state database on student outcomes in equivalent in person and online courses. The first comparison they analyze is between the pass rate of 9th and 10th graders in an equivalent course online and in person, and the likelihood of passing a follow-on course in the same subject and likelihood of high school graduation. Controlling for a number of variables, including student demographics and middle school factors, the researchers found that taking a course virtually increases the likelihood of passing it by 12.5 points, or 18%. However, taking a virtual course decreases the likelihood of passing a follow-on course in the same subject by 1.5 points, or 2%, and lowers the likelihood of graduation by 3.4 points or 4%. The second comparison was between equivalent retake courses. The study found that, controlling for multiple factors, students who retake a course virtually are 4.7 points more likely to pass, 1.7 percentage points more likely to take and pass future same-subject courses, and 6.5 points more likely to make it to the final semester of senior year, than peers who retake courses in face-to-face settings. The researchers accept the risk of selection bias and try to control for it, but they did not find significant differences in effects across different groups of students.

Effective Instruction in Online Environments

On the level of the structure of online learning environments, there are several strategies that have proved effective. The Department of Education meta-analysis (Means et al., 2009) found that the more time learners spent on task online, compared to students in person, the greater the benefit. All other learning practice variables that studies analyzed did not affect student learning significantly. The researchers concluded that the benefit of blended instruction is that it required the learners to be on task longer than in a traditional setting, and that is probably why it was shown to be more effective. The Center for Research on Education Outcomes (2015) analyzed a number of different aspects of online learning, finding that *self-paced courses* had a significant positive relationship in reading compared to traditional school courses. For asynchronous instruction, students having access to recordings of lectures had a +0.10 SD effect size in reading growth and having physical math textbooks had a +0.09 SD relation to math growth compared to schools which did not have these things. For synchronous teaching, having audio conferencing had a positive effect on reading and math (0.13 and 0.29 respectively), online chat forum had a negative impact on math growth (-0.54) and instant messaging a negative effect on reading growth (-0.13). On the negative side, online schools that placed more instructional responsibilities on parents were strongly correlated with weaker growth across most settings, and administrators not monitoring interactions between teachers and families online correlated to a large negative impact on math academic growth (Center for Research on Education Outcomes, 2015). Ahn & McEachin (2017) suggest, from their negative online learning results, that online learning requires more student self-regulation and metacognitive skills than traditional schools. These skills can be difficult to acquire and require scaffolding and guidance. This fact may be one reason why online schools may not be as effective for K-12 learners as traditional schools. Mitigating this problem could be a key to increasing the effectiveness of online learning.

Multiple studies identify interactions between students in online courses as an effective instructional strategy. The literature review of Nortvig et al. (2018) found that student-to-student interaction and the building of a learning community were effective strategies for student learning. Gray & DiLoreto (2016) found from their survey data a significant correlation between learner interactions and perceived student learning (0.62). Martin & Bolliger (2018) also identified learner-to-learner interaction as significant, identifying the three most important strategies as icebreaker introductions (*M* = 4.08 out of 5, *SD* = 0.93), student presentations (*M* = 3.89 out of 5, *SD* = 0.93) and students working collaboratively using online communication tools to complete assignments (*M* = 3.94 out of 5, *SD* = 1.07). Lear et al. (2010) propose a theoretical model for how online learning environments can enhance student engagement in order to create a community of learning, and highlight as a key component student-to-student interaction and communication.

Several studies identified the presence and communication of the teacher with the students as another important indicator of effective online learning. Nortvig et al. (2018) saw a pattern in the research that highlighted the educator's presence to the students and the importance of good communication channels with students. King (2014), in her survey of online graduate students, found that the three most important features of the online course structure were instructor feedback on assignments (*M* = 19.12 *on a 20 point scale*, *SD* = 1.608), emails to and from the instructor (*M* = 18.88 out of 20, *SD* = 2.223), and information about assignments (*M* = 18.35, out of 20, *SD* = 1.768), all of which are teacher-student communications. Gray & DiLoreto's (2016) surveys of online students found a significant positive relationship between instructor presence and perceived student learning and student satisfaction. Martin & Bolliger (2018) found that the most important learner-to-instructor engagement strategies were instructors sending posts and regular announcements (*M* = 4.53 out of 5, *SD* = 0.67), instructor posts grading rubrics for all assignments (*M* = 4.41 out of 5, *SD* = 0.79), instructor creates a forum for students to contact instructor (*M* = 4.36 out of 5, *SD* = 0.81), and instructor posts a 'due date checklist' at the end of each instructional unit (*M* = 4.33 out of 5, *SD* = 0.89). Based on their estimates of learning losses, CREDO (2020) recommends that teachers increase diagnostic assessments and frequent progress checks for students during this time, in order to respond to student learning needs.

The final main area of importance for effective online learning is, not surprisingly, the quality of course content. Gray & DiLoreto (2016) found that content that deliberately connects between online and offline activities, and deliberate connections between course content and professional practice-related activities were more effective than those without these features. Martin & Bolliger (2018) had some similar findings. On their surveys, the most highly rated content strategies were: students work on realistic scenarios to apply content (*M* = 4.40/5, *SD* = 0.65), discussions are structured with guiding questions and prompts (*M* = 4.39/5, *SD* = 0.66), and students interact with content in more than one format (*M* = 4.17/5, *SD* = 0.81).

NGSS Science Curriculum and Instruction

Since the publishing of the NGSS, most of the literature on teaching based on the NGSS has focused on teaching the scientific and engineering practices. One study (Brownstein & Horvath, 2016) analyzed a new teacher training and evaluation instrument partially aligned to the NGSS practices, the edTPA. Based on the students survey, the study found that edTPA promoted the teaching of only three of the NGSS practices and nothing else: analyzing and interpreting data, constructing explanations and describing solutions, and obtaining, evaluating and communicating information. A qualitative analysis of elementary school science instruction (Smith & Nadelson, 2017) found that teachers were not even attempting

3-D learning and only implementing three of the SEPs: asking questions, developing and using models, and obtaining, evaluating, and communicating information. A year-long case study of a high school biology Professional Learning Community (Friedrichsen & Barnett, 2018) found that the teachers judged the implementation of the standards as the trade-off of content for skills, and favored the NGSS science practices the most. Again, they did not incorporate the three-dimensional nature of the Performance Expectations.

The other main approach to implementing the NGSS has been inquiry-based curricula. Inquiry-based instructional methods have gained more and more support from teachers and leaders over the last twenty years, as the empirical evidence for its effectiveness has grown (Pedaste et al., 2015). NRC *Framework* almost presupposes that inquiry-based instruction should be the norm in order to teach the students the scientific practices (Council, 2011). Penuel & Reiser (n.d.) argue that the best way to implement the NGSS standards is through problem-based inquiry units. Penuel & Reiser (n.d.) propose a structure whereby units begin with phenomena and problems, and allow the students to drive their own questioning, investigation, and analysis of data (NGSS practices), so that they are able to engage in incremental sense-making. Instead of being the primary instructor, the teacher is a *co-constructor* of meaning with the students in the process, ensuring that the learning sequence is coherent from the student's perspective. In this way, students become genuine practitioners of science, and engage in all eight of the scientific practices over the course of their inquiry. One literature review on the *alignment* of the NGSS to curricula (Fulmer et al., 2018) found that phenomena-based and design problem curricula are one of the major ways that schools are attempting to implement the standards.

There is evidence that such inquiry-based units have been successful at teaching students both the disciplinary core ideas and scientific practices of the NGSS. Although very few studies have investigated the efficacy of new curricula in helping the students achieve the performance expectations of the NGSS (Yoon et al., 2018), the few that we have focus on inquiry-based units. One study (Ward et al., 2016) evaluated the effectiveness of an open-inquiry model of learning called the *Air Toxics Under the Big Sky* program, developed at the University of Montana. After a year-long research project in which 199 eleventh and twelth grade students developed research questions, hypotheses, collected data, drew conclusions, and presented their findings at a symposium, the researchers found that the students in the treatment group scored significantly higher on the content assessment than the control group, showing statistical significance at $p < .001$. A research report (Tyler et al., 2018) on the impact of an inquiry-based curriculum, the K-8 NGSS Early Implementers Initiative, found that teachers and administrators reported strong results in several key areas. The report, which focused on student learning in eight districts in California, found "substantial" increases in engagement, curiosity, agency, and collaboration with peers, as well as an increase in the quality and depth of science learning, even for lower-performing and ESL students. Another large-scale empirical study (Anderson et al., 2018) conducted over 60,000 online student tests in order to determine the effect of the '3-D' learning *Carbon Time* program. Using a pre-test, post-test research model, researchers found that there were significant increases in student proficiency as a result of the program (effect size of +1.85), as well as a closing of the achievement gap between high-scoring and lower-scoring pre-test students. Also of note, teachers who engaged students more in inquiry-based instructional models had higher outcomes than classrooms where students appropriated material in the more traditional way. Along with the data on student outcomes, there are also survey instruments that have been validated to gauge the effectiveness of instructional practices in NGSS curricula (Hayes et al., 2016).

Another major benefit to inquiry-based science learning has been its ability to increase interest in science. There has been a consistent desire among policymakers to increase student interest in science in order to fill in the gap between the number of new jobs in science-related fields and the number of young people going into those fields (Lamb et al., 2012). This is especially true for women and minority students, who are underrepresented in the STEM fields (National Science Foundation, 2019). Researchers have sought to understand how high school science courses may influence this disparity (Aschbacher, Li, & Roth, 2010; Grossman & Porche, 2014), and more generally, why learning science in school does not translate to more students pursuing careers in science. One important indicator in this regard is student interest in science. Researchers have developed and validated survey instruments to test student interest in science and engineering in order to measure the impact of science curricula on science interest (Oh et al., 2013). There is some evidence that NGSS-aligned science courses at the K-8 level increase student interest in science and overall engagement in science courses (Tyler et al., 2018). At the high school level, inquiry-based science learning has increased student interest in science and in pursuing a career in science fields (Ward et al., 2016). Unfortunately, during the pandemic, inquiry-based units have been difficult to maintain, as online students cannot conduct their own experiments and generate their own investigations. One study comparing student experiences in the same inquiry-based biology course from 2019 and then during the pandemic in 2020 found that students in 2020 perceived the online platform as a barrier to their learning and found labs difficult to understand when they could not actually go through the process themselves (Hsu & Rowland-Goldsmith, 2021). These frustrations could decrease interest in science and contribute to thinning the pipeline to STEM careers in the future. The pandemic could inadvertently cause a long-term impact on the size of the STEM workforce.

CONCEPTUAL FRAMEWORK

In order to analyze the efforts of the tenth-grade science teachers during the pandemic, I will use the theoretical framework that Anderson (2003) developed to explain effective online teaching. Anderson places all the activities of online learning under the overarching concept of “interaction.” Anderson defines interaction as, “reciprocal events that require at least two objects and two actions. Interaction occurs when these objects and events mutually influence one another.” (p. 129) Although a broad definition, it can apply both to person-to-person and person-to-technology activities. Anderson argues that interaction is the key to both engagement and to learning. From this definition, Anderson, along with Garrison, develops a taxonomy of six interactions in education of online courses: student-teacher, student-student, student-content, teacher-content, teacher-teacher, content-content. All the effective online instructional strategies identified in the research literature fall into these categories. Under these categories the effective online instructional strategies identified in the researche literature fall. The balance between these types of interaction determines the quality of the online course (see Figure 2).

Anderson explains the nature of each of these interactions in the online setting. Student-teacher interactions are the most obvious type and the key to student learning. Ensuring the quality and frequency of this interaction is a challenge in the online platform. Anderson argues that teachers should design the online course to maximize the impact of interactions with students.

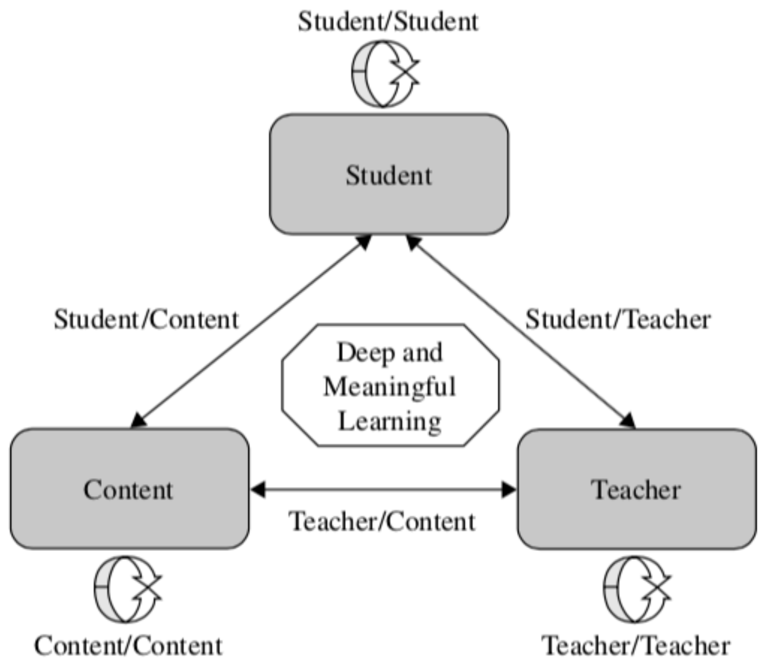

Figure 2: Anderson's Modes of Interaction in Distance Education Model

The research summarized above highlights the importance of student-student interactions. Anderson explains this fact in light of research on social constructivist theory and situated learning (Lave & Wenger, 1991). Studies show that social communication helps concept attainment, motivates students, and helps develop social skills. However, early distance learning models privileged independent learning. According to Anderson, online courses must balance independent learning with meaningful and well-structured student-student interaction. This is consistent with the research summarized above on effective online instruction (Nortvig et al., 2018; Gray & DiLoreto, 2016; Martin & Bolliger, 2018).

Student-content interaction is another obvious feature of all learning. In the online platform there are new modes of this interaction: sound, text, graphics, video, and virtual reality. In online learning there is the media itself (information) and then the technology that mediates the learning. The Internet and new forms of media technology are significantly altering the context of student-content interaction (Anderson, 2003). However, the studies above (CREDO, 2015) found that math textbooks correlated to higher student outcomes. Having non-virtual content may be an effective strategy even for virtual courses.

The other three interactions are of lesser importance to the current study. Teacher-content interaction takes place during the instructional design process. In the virtual environment teachers have many options for the presentation of material. Teacher-teacher interaction in the form of collaboration and teacher learning communities enhance teacher effectiveness in all environments. With new technologies these teacher networks can easily expand. Finally, content-content interactions in the online platform are the computer-generated systems that retrieve and update information.

Anderson acknowledges some of the limitations of his framework, chiefly that it does not consider the different types of people who are doing the interacting. For example, some teachers may be better at communicating with students through video conferencing than others, so the quality of those interactions will be better. Some students may do better in self-paced learning structures than others. Furthermore, how all of these different parts interact with each other in the service of learning is not known. Anderson (2003) explains this point rather concisely, “despite years of study, it is still unclear which students studying what types of content under what conditions and using which instructional design benefit most from synchronous as opposed to asynchronous interaction.” (p. 140) Many questions remain unanswered.

This study will focus on the three main types of interaction, teacher-student, student-student, and student-content. I will assess how effective the instructional practices have been in each of these categories of interaction. For teacher-student and the student-student categories I have chosen to assess the most highly rated instructional practices identified in the research literature. For teacher-student interactions the two strategies are teacher feedback on assignments and teacher explanations. For student-student interactions I chose group work and class discussions. For student-content interactions I selected two instructional practices specific to conducting labs in the virtual environment, teachers conducting labs for students to observe and take notes, and students either mimicking labs at home or conducting experiments at home. Finally, for student-content interactions that involve a fair amount of teacher-content design, tying together the focus in the new tenth grade curriculum on the scientific practices of the NGSS, I will evaluate the student perceptions of the activities of five of the scientific practices that the teachers said they taught in some form during the semester. How the tenth-grade science teachers taught their courses in the online environment during the pandemic to maximize these three types of interaction and how the students benefited from that teaching will be the focus of this study.

RESEARCH QUESTIONS

In order to understand the impact on the students of the shift to online learning during the pandemic, how effective the tenth-grade teachers were at teaching in the new environment, and how the courses impacted student learning and outcomes, this study will focus on the following questions:

1. What are the student perceptions of the most effective teacher-student, student-student, and student-content instructional practices the teachers used in the virtual environment?
2. What are the student perceptions of how effective the teaching of the scientific and engineering practices of the NGSS were in the virtual environment?
3. How did learning science in the virtual environment impact the academic outcomes of the higher- and lower-achieving students, and are there noteworthy differences between the teachers' sections?
4. How does learning science in a virtual environment influence student interest in learning more about science and engineering and pursuing these subjects at university and in a career?

PROJECT DESIGN

This project design attempts to evaluate the impact of virtual learning on student academic outcomes and interest in science as well as isolate the effectiveness of certain instructional strategies. The diagram below provides an outline of the design. The baseline measures are the students' ninth grade final science scores and the students' interest in science and engineering, obtained through a survey administered at the beginning of the Fall semester. The treatment is learning science in the virtual environment in the Fall semester of 2020. Within that treatment I test several specific instructional strategies, organized into three of the main categories of Anderson's (2003) conceptual framework, teacher-student, student-student, and student-content interactions. In response to the research literature on effective online teaching, I chose explanations (Nortvig et al., 2018) and feedback (King, 2014) for the teacher-student interactions and discussions (Gray & DiLoreto, 2016) and group work (Martin & Bolliger, 2018) for the student-student interactions. For the student-content interactions I focused on investigating one of the most difficult challenges to teaching science online, how to incorporate experiments into the course when students are at home and not in the laboratory. For this I chose the two main strategies that the teachers at the Academy used: performing experiments in the school labs for students to observe online and analyze, and having students mimic or perform experiments at home. Finally, given that one of the main ways to evaluate the implementation of the NGSS is to see the extent to which the teachers are having the students engage in the scientific and engineering practices (Brownstein & Horvath, 2016), I chose to investigate the frequency and effectiveness of the five SEPs that the Academy teachers stated they were teaching during the virtual Fall semester: asking questions, arguing from evidence, analyzing data, using models, and mathematical thinking. As outcome measures I administered a survey to the students at the end of the semester that had them rate the effectiveness of the teaching strategies and SEPs, and reassessed their interest in science, and then collected their scores on the final, summative assessment of the semester.

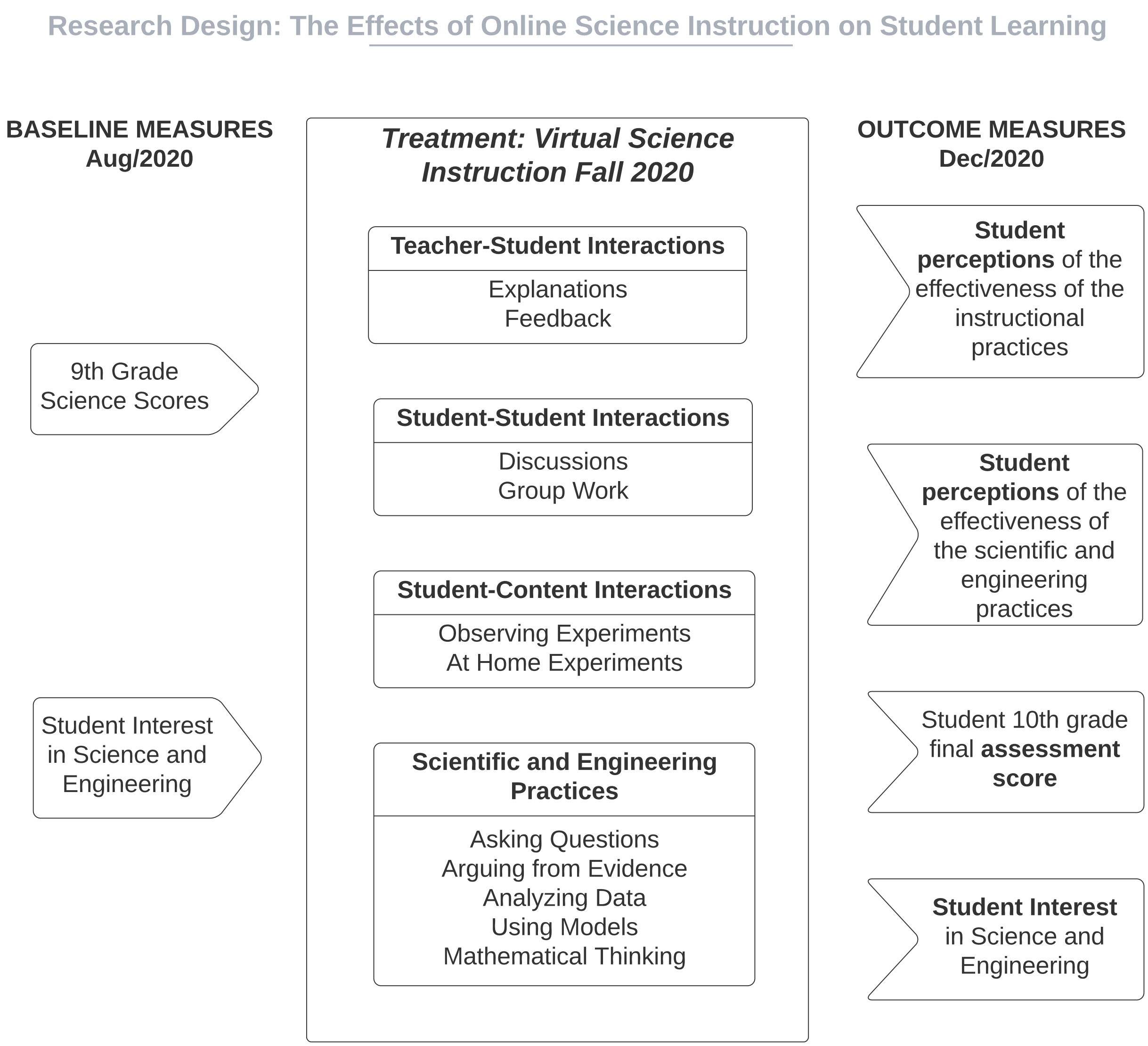

Figure 3: Research Design Model

In order to account for the differences between students, I collected basic demographic information in the survey at the beginning of the semester. There were 106 unique survey responses. The demographic breakdown of the tenth-grade students is fairly uniform across teachers and sections. The overall division by sex is 50 females and 56 males (Figure 4). Of the four main ethnicities, 57% of the students are white, 17% Black/African American, 19% Asian, 4% Hispanic, and 3% other (Figure 5). Teacher A has three sections, Teacher B has two, and Teachers C and D only have one. Analyzed by sex and ethnicity, there are three significant differences between the teachers. First, teachers C and D have a higher ratio of male to female students, approximately 60:40, whereas the other teachers are at 50:50 (Figure 6). Second, teacher C has the most diverse group of students, with over twice as many African American students, 34%, as the other teachers, each of whom having 12-15%, and overall 77% minorities and only 33% white (Figure 7). Third, teachers B and D have the lowest minority representation, with 71% and 66% white, respectively, with teacher A falling between those two and teacher C, with 48% minorities and 52% white (Figure 7).

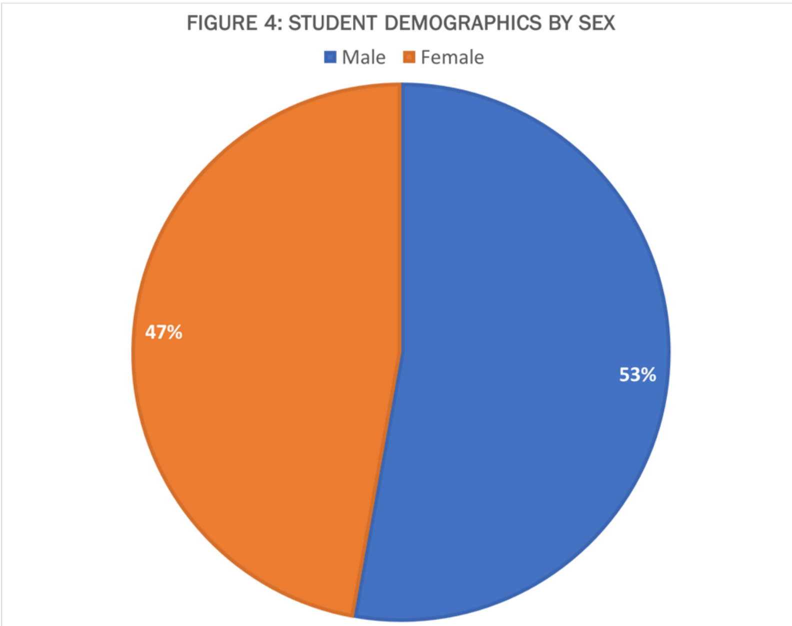

Figure 4: Student Demographics by Sex

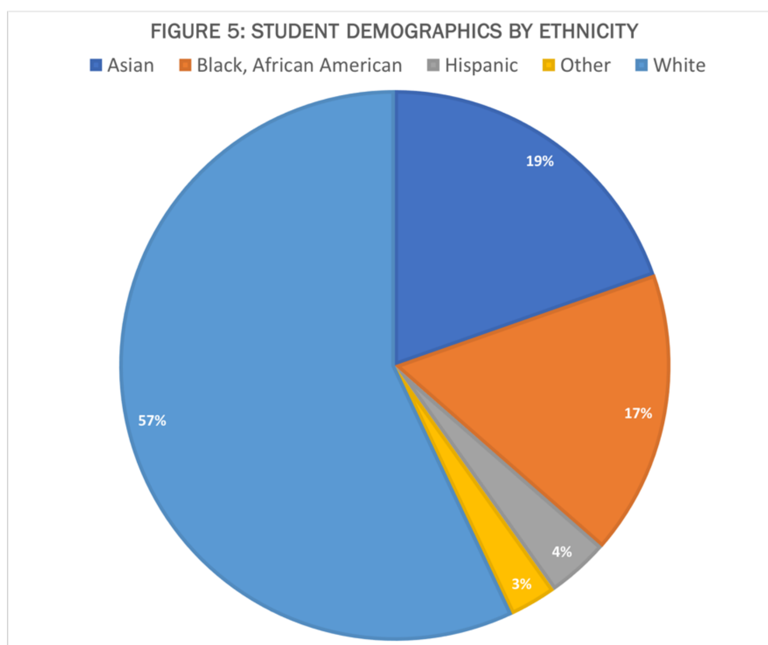

Figure 5: Student Demographics by Ethnicity

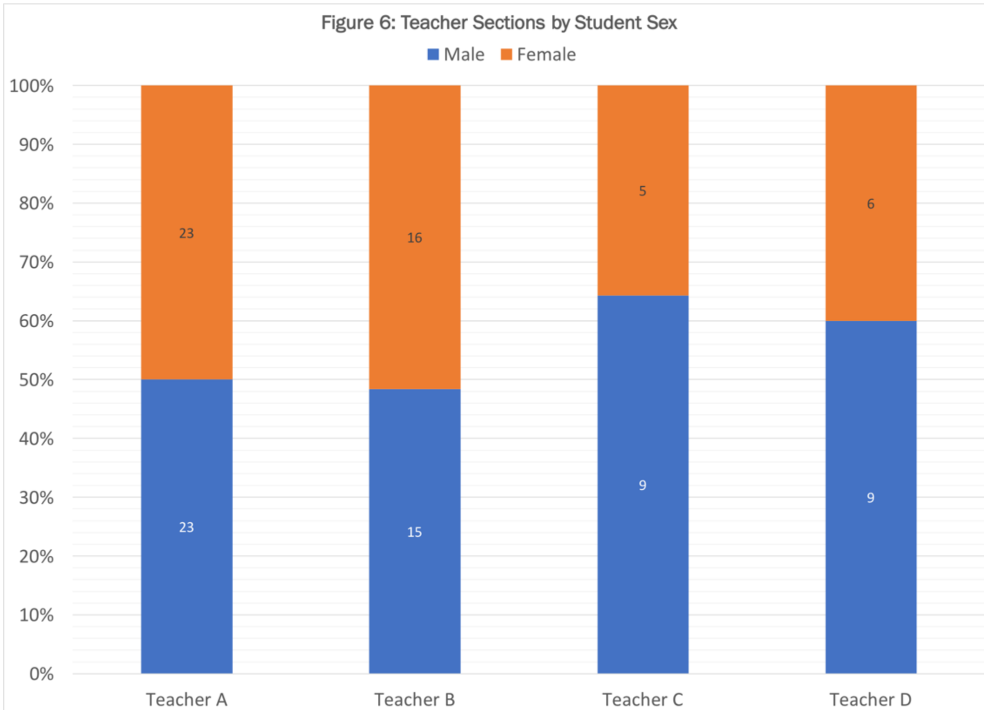

Figure 6: Teacher Sections by Student Sex

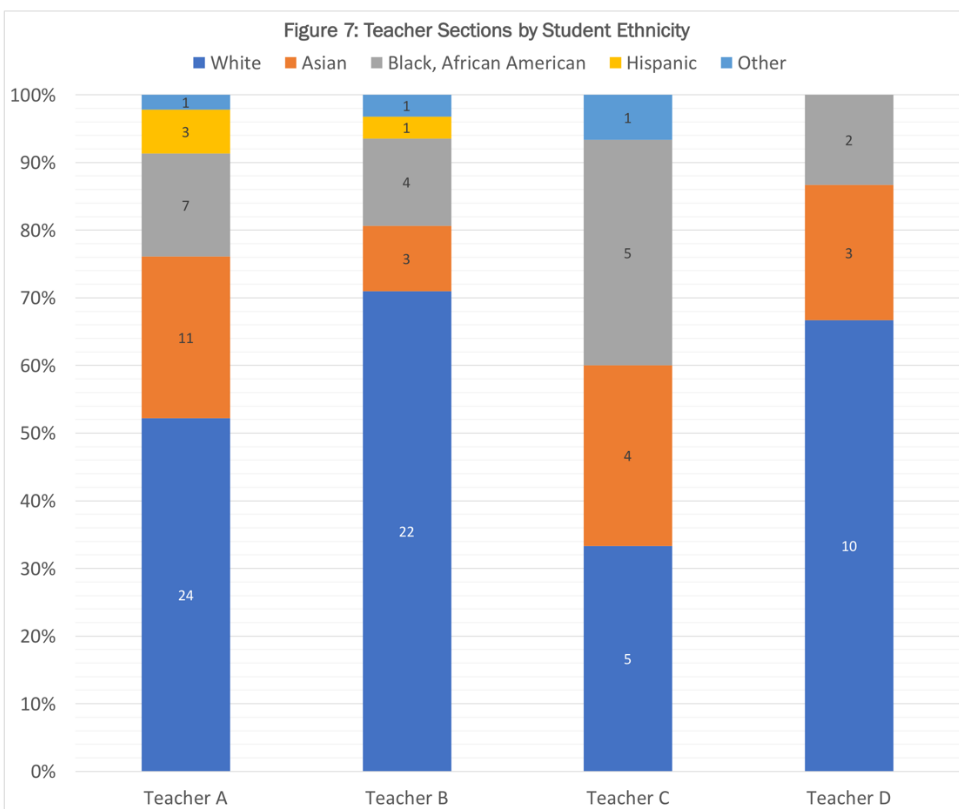

Figure 7: Teacher Sections by Student Ethnicity

To determine the most effective teaching strategies, I surveyed the students at the end of the semester on the frequency and effectiveness of the six chosen teaching strategies. I adapted the survey questions from the instrument that Hayes et al. (2016) developed and validated in their research. It consisted of questions on the frequency of the instructional strategies using a 4-point Likert scale, and then questions on the strategies' effectiveness for learning on a 5-point Likert scale. At the end of the survey there were three open-ended questions on the most effective strategies for teaching science knowledge and skills. I collected 103 surveys, but had to discard 8 as incomplete or duplicate, giving 95 usable answers. I analyzed the student answers through a standard calculation of the mean, standard deviation, standard error and confidence interval for both the frequency and effectiveness questions. I coded the open response questions according to the most common themes that emerged, tabulated the results, and identified representative answers.

To determine the effectiveness of teaching the SEPs online, I again surveyed the students at the end of the semester on the frequency and effectiveness of the activities and assignments engaging them in the five scientific and engineering practices. I again adapted the survey questions from the instrument that Hayes et al. (2016) developed and validated in their research. It consisted of questions on the frequency of the instructional strategies using a 4-point Likert scale, and then questions on the activities' effectiveness for learning on a 5-point Likert scale. In the analysis I calculated the mean, standard deviation, standard error and confidence interval for both the frequency and effectiveness questions.

To determine the impact of virtual learning on student academic outcomes, I analyzed two measures: student ninth grade science final scores and the first trimester final assessment scores. This was not an experimental or even quasi-experimental design, and had no control group. However, I still ran a multiple linear regression with the independent variable of students' ninth grade science scores and the dependent variable of their tenth-grade final assessment scores, using the different teachers as predictor variables. The dataset contained scores from 104 students. Due to the independent collection methods of the surveys and the student scores and the anonymity of both, I could not combine the two datasets and analyze the academic outcomes in light of the survey answers, which included the demographic information of the students. In order to determine whether the virtual environment impacted higher- and lower-achieving students differently, I grouped the students into quartiles based on their ninth-grade scores, calculated their z-scores for their ninth and tenth grade outcomes, and then compared the mean z-scores of each quartile for each score. It was important to determine whether the frequency of the different instructional practices would produce difference in student outcomes by teacher section. I conducted a Bartlett's test of homogeneity of variance between the teachers' frequency scores of the different strategies and then related significant differences back to the coefficients of the multiple linear regression for each teacher.

To determine whether online learning influenced student interest in science, I administered surveys to the students at the beginning and end of the semester and then paired the students' answers. Due to some inconsistencies and incomplete surveys, I was able to gather 77 total paired surveys. For the survey questions I adapted the 'Science Interest Scale' that Oh et al. (2013) developed and validated in their study. The interest survey has six questions, three about science and three about engineering, using a 5-point Likert scale. On the results I conducted a paired t-test on the differences in the pre and post-semester answers, and differentiated them by overall, by sex, and by ethnicity. See the appendix for the instruments.

FINDINGS

Findings for Question 1: According to the students, teacher feedback was the most effective teaching strategy, and observing teacher experiments and 'Pivot Labs' were the most effective ways of conducting virtual labs.

Students reported only small differences in the frequency of the different instructional practices, with a strong consistency across teacher sections. I only collected frequency ratings on the student-student and student-content interactions because of the general prevalence of teacher explanations and feedback in every course (Table 1). Overall the most frequently used strategy was group work (*M*=3.66, *SD*=0.56), and the least used strategy was students conducting experiments at home, 'Vexperiments' (*M*=2.59, *SD*=1.04), with the other two being used more or less the same amount (*M*=3.18). Between the teachers the noticeable differences were teacher D's use of discussions (*M*=3.553, *SD*=0.64) compared to teacher B (*M*=2.93, *SD*=0.93), and teacher A's use of group work (*M*=3.84, *SD*=0.37) over teacher D's (*M*=3.33, *SD*=0.72) (see Figure 8). The other differences in frequency were very small between the teachers.

Table 1: Student Perceptions of the Frequency of Instructional Practices

	Instruction	N	Frequencyscore	sd	se	ci
1	Discussions	95	3.179	0.785	0.081	0.160
4	GroupWork	95	3.663	0.558	0.057	0.114
5	Texperiments	94	3.181	0.567	0.059	0.116
6	Vexperiments	95	2.589	1.037	0.106	0.211

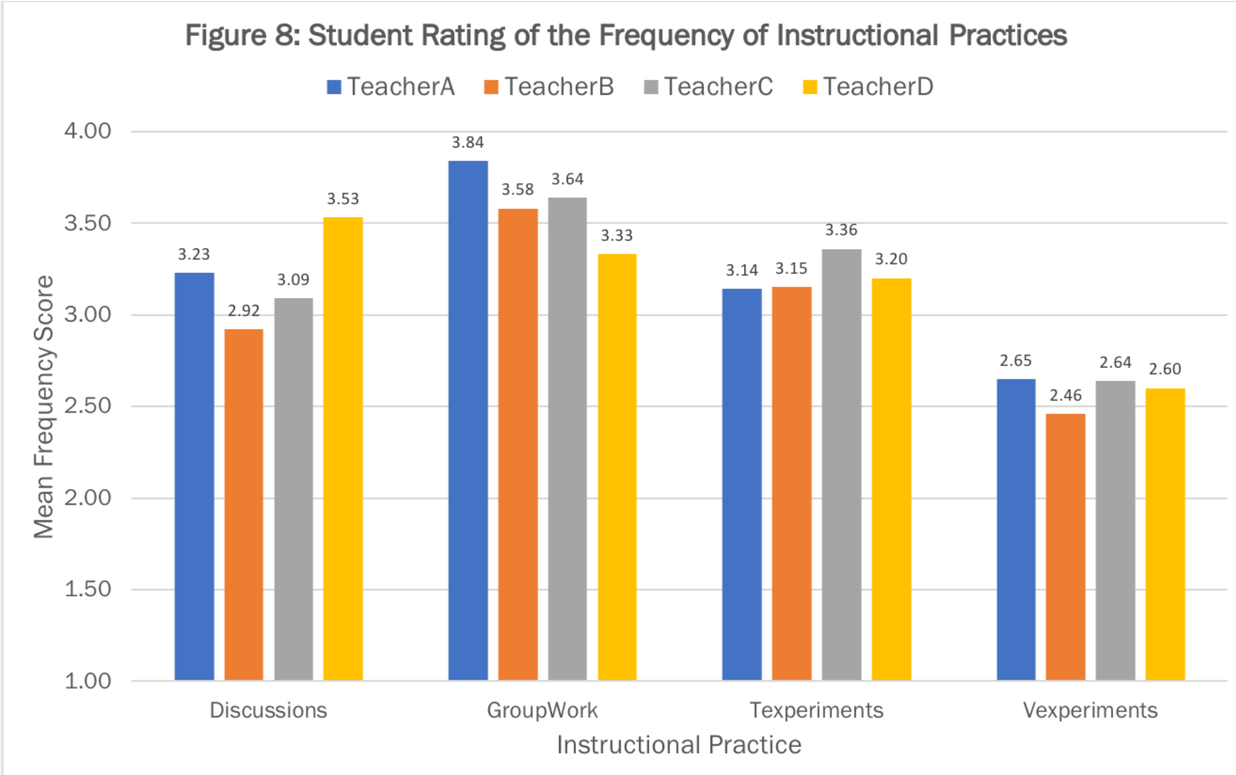

Figure 8: Student Rating of the Frequency of Instructional Practices

The students rated the teacher-student strategies the most effective on the surveys. Teacher feedback on assignments had the highest overall average, (*M*=4.11 out of 5, *SD* = 0.96). This is consistent with other studies of online learning (King, 2014). The next highest rated strategy was teacher explanations (*M*=3.86, *SD* = 0.89). Table 2 shows the full statistical analysis. It seems that the online platform lends itself quite well to direct teacher instruction (see Figure 9).

Table 2: Student Perceptions of the Effectiveness of Instructional Practices

Instruction	N	Effectiveness	sd	se	ci
Discussions	94	3.606	1.128	0.116	0.231
Explanations	95	3.863	0.895	0.092	0.182
Feedback	95	4.105	0.962	0.099	0.196
GroupWork	95	3.779	1.044	0.107	0.213
Texperiments	95	3.611	0.867	0.089	0.177
Vexperiments	95	2.811	1.347	0.138	0.274

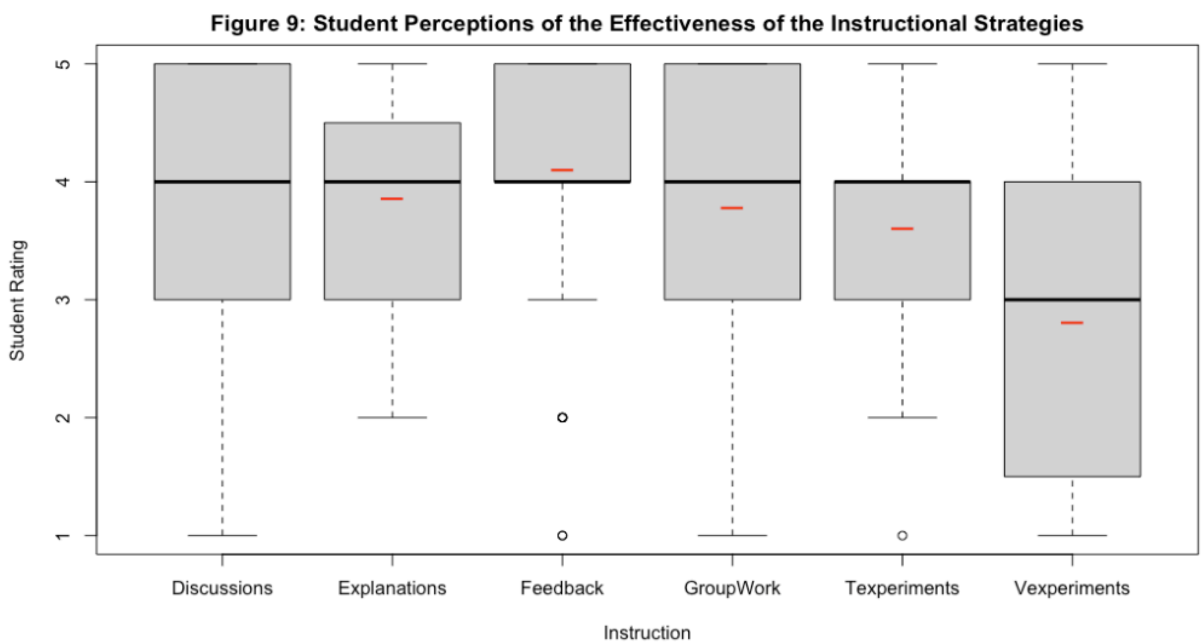

Figure 9: Student Perceptions of the Effectiveness of the Instructional Strategies

The responses to the student-content interaction strategies revealed that experiments at home were not as effective as observing teachers conduct experiments. Students found that performing or mimicking labs at home, ‘Vexperiments’, was the least effective strategy (*M*=2.81, *SD* = 1.35). Students rated observing teachers conducting experiments in the lab, ‘Texperiments’, as 16% more effective (*M*=3.61, *SD* = 0.87). The context of the school laboratory and the expertise of the teacher made a difference to students' perceived learning.

The open response questions show that 'pivot labs' are the most effective virtual labs. Figure 10 shows the coded responses to the open questions on effective strategies. The 'pivot labs' were overall the most effective instructional strategy for teaching science knowledge and skills. Students commented, "I found that pivot labs in class were the most helpful", and "Going into breakout rooms and working on PIVOT labs is a great way to develop certain scientific skills in my opinion." Pivot labs come from an education website that has modules of interactive videos that show students phenomena and problems and then take them through a step by step process of analysis and inference, with questions, feedback, and scaffolded explanations (*Pivot Interactives*, n.d.). The science teachers began using these interactive videos as a substitute to in-person labs. The student responses do not give much information about why these 'labs' were so effective, but perhaps two reasons emerge. First, these videos most closely approached in person labs, and require a fair amount of active analysis, inference, and hypothesis testing. The students work through these at their own pace, with the proper scaffolds, which facilitated learning. As one student put it, "Pivot labs, being able to work on lab work somewhat alone." Second, the interactive platform gives immediate feedback on student answers. As one student explains, "Pivot Labs really help because when you submit an answer it gives you feedback on why it is right or wrong." This tight feedback loop facilitates learning. For virtual science courses pivot labs could be the best way for students to conduct 'labs.'

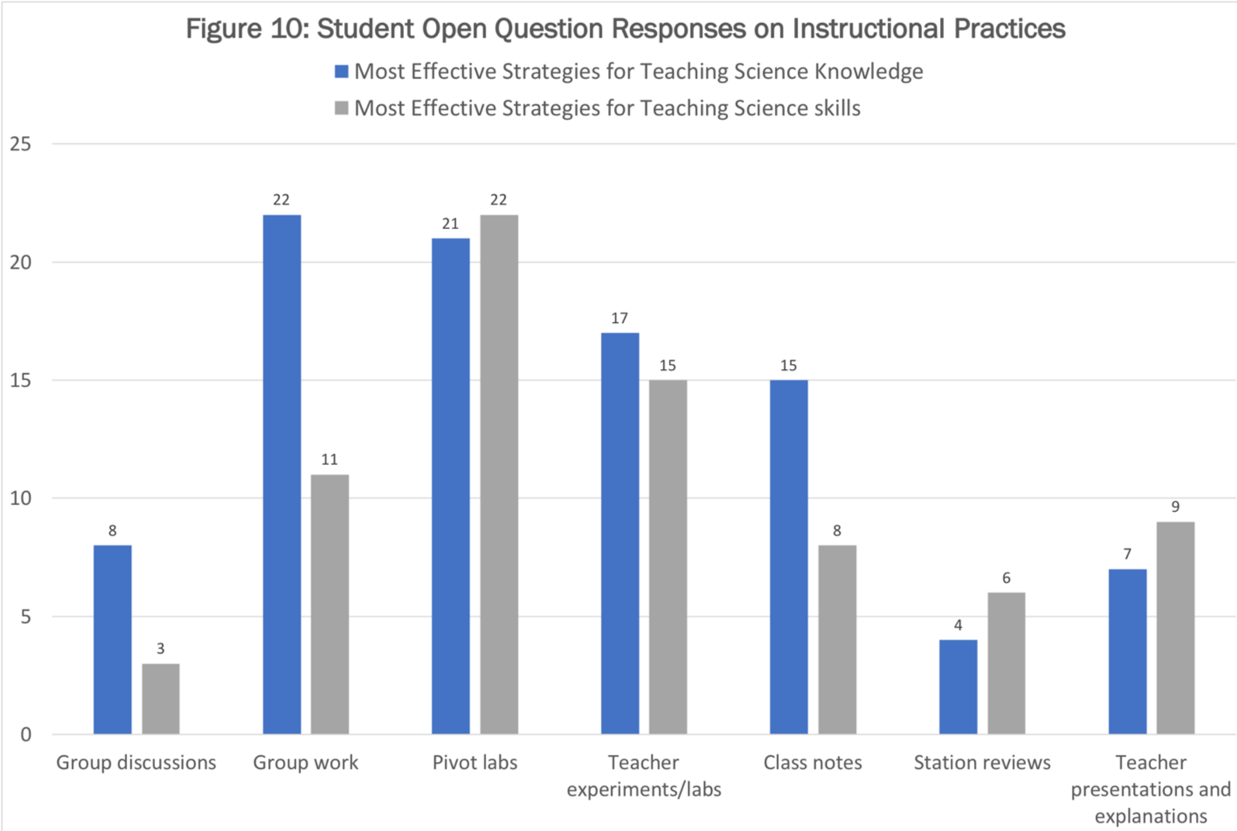

Figure 10: Student Open Question Responses on Instructional Practices

The open response answers also highlight the efficacy of group work and teacher experiments. Many students clearly benefit from the student-to-student interaction. As one states, "The most helpful strategy was the group assignments." Although in the survey group work had the third highest rating (*M* = 3.78, *SD* = 1.04), the open responses show that for 22 students, about 25%, it was the most effective strategy. This is consistent with the research on virtual learning, which has found that students benefit from peer interaction (Nortvig et al., 2018; Martin & Bolliger, 2018; Gray & DiLoreto, 2016). One student explain why this might be the case, "I really enjoyed my partner(s) and I felt very comfortable asking questions that I didn't want to ask the whole class. They made my learning easier." Students learn from each other. The other strategy students consistently identified was observing teachers conducting experiments. For example, "In class experiments that my teacher conducted [were the most effective]", and, "The most effective were definitely the labs and presentations that Mrs.–––- did." These answers give depth to the above analysis. Within the overall mean ratings of the practices there are some students for whom group work is the most effective strategy, and for others it is observing experiments.

Findings for Question 2: There were no significant differences in the student perceptions of the effectiveness of the assignments and activities engaging the five different scientific and engineering practices (SEPs).

Students perceived only small differences in the frequency of engaging in the SEPs, with negligible differences in the ratings of the different teachers. The most frequent practice, mathematical thinking (M = 3.35, SD = 0.71), was only 0.5 higher on a 4-point scale than the lowest rated practice, using models (M = 2.85, SD = 0.70), which is only a 12.5% difference overall (see Table 3). Teacher C had the highest frequency score on four of the five SEPs, yet the difference between that and the lowest frequency score was under 0.5. It would seem that the teachers engaged the students in the SEPs more or less the same amount over the course of the semester, and with a frequency in the same range as the instructional practices (see Figure 11).

Table 3: Student Perceptions of the Frequency of the Activities Engaging the Scientific and Engineering Practices

SEPActivities	N	Oftenscore	sd	se	ci
Analyzingdata	94	3.170	0.598	0.062	0.123
Arguing	95	2.968	0.818	0.084	0.167
AskingQs	95	3.274	0.659	0.068	0.134
MathematicalThinking	95	3.347	0.711	0.073	0.145
UsingModels	95	2.853	0.699	0.072	0.142

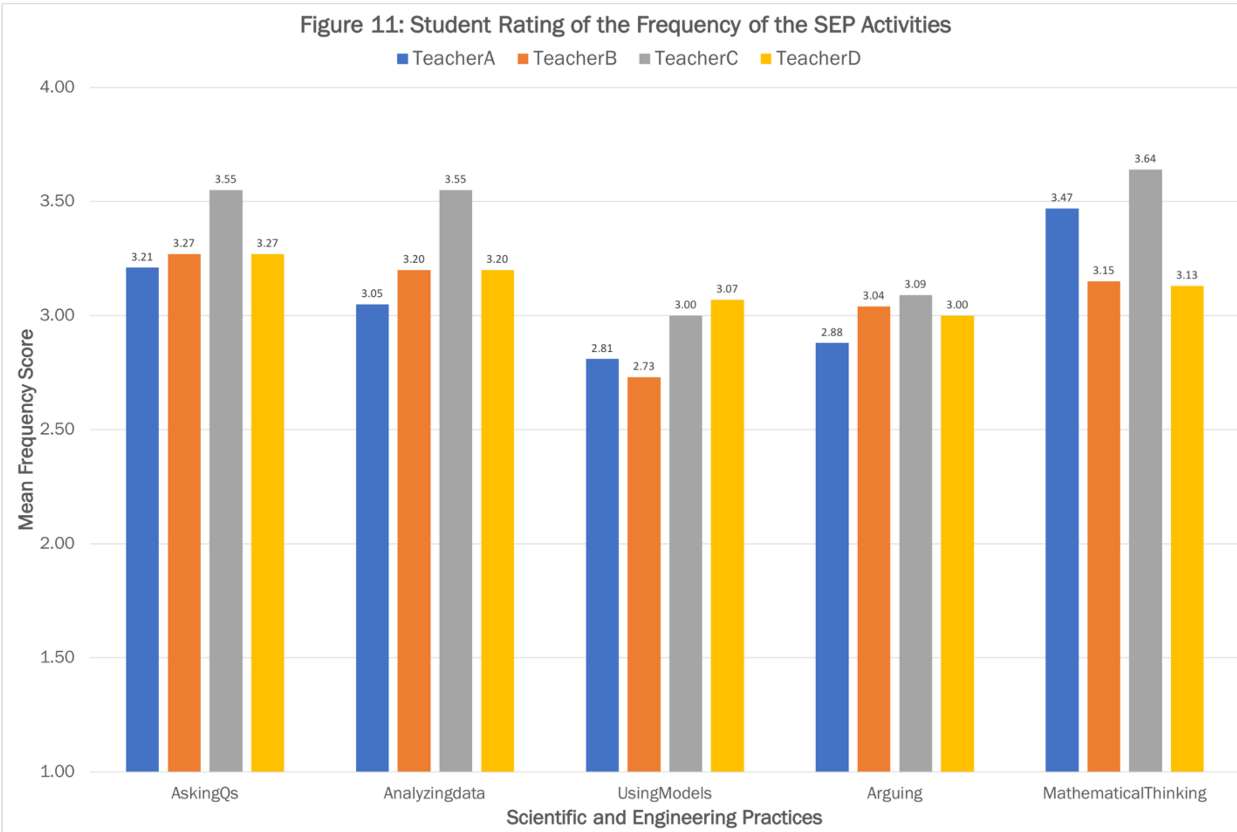

Figure 11: Student Rating of the Frequency of the SEP Activities

The students rated the five SEPs almost the same in effectiveness. All of the SEPs had mean scores between 3.5 and 3.7, with a median of 4 and a standard deviation of around 1, except for the practice of using models (see Table 4, Figure 12). This practice was the lowest rated, but not by much (M = 3.37, SD = 1.05, Median = 3). In the open-response questions one student spoke about mathematical thinking as the most helpful, "The mathematic problems were nice because they helped me make a good connection to what I was learning." In the survey that practice received the highest rating (M = 3.78, SD = 1.02). Yet overall it does not stand out among the other ratings. On the basis of the survey data, there are no strong conclusions about relative value of the different SEPs in teaching science in a virtual environment.

Table 4: Student Perceptions of the Effectiveness of Teaching the Scientific and Engineering Practices

SEPActivities	N	Rating	sd	se	ci
Analyzingdata	95	3.600	1.025	0.105	0.209
Arguing	95	3.526	0.977	0.100	0.199
AskingQs	95	3.737	1.002	0.103	0.204
MathematicalThinking	95	3.768	1.015	0.104	0.207
UsingModels	95	3.368	1.052	0.108	0.214

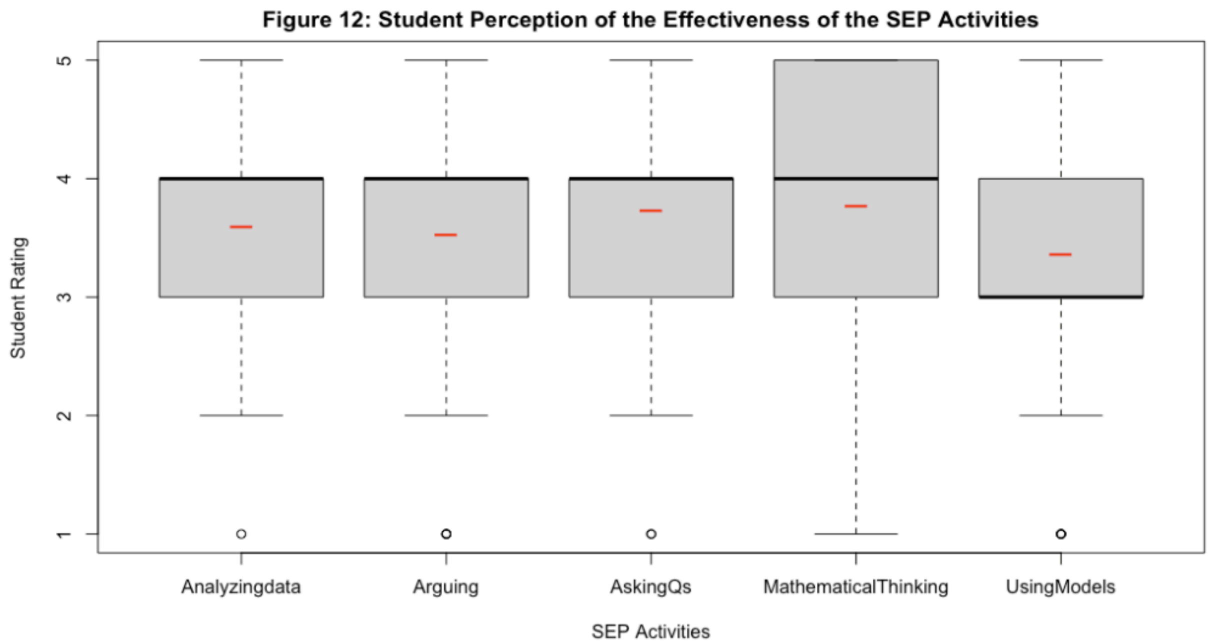

Figure 12: Student Perception of the Effectiveness of the SEP Activities

Findings for Question 3: Overall, student academic outcomes during virtual learning did not differ significantly from their ninth-grade outcomes, but the students in the lowest quartile did better relative to the other students and the students in the highest quartile did worse, with students in one teacher's section showing a small improvement relative to the other three teachers' students.

The multiple linear regression showed that virtual learning did not have a significant impact on student outcomes. I converted all of the student outcome scores to z-scores and then ran the regression with the ninth-grade z-score as the independent variable and the tenth-grade z-score as the dependent, with the teachers as predictor variables (see Table 5). The results show that the ninth-grade score predicts the tenth-grade score at +0.66 ($p < 0.001$, df = 98). Figure 13 shows the strong linear relationship between the two sets of scores.

Table 5: Linear Regression of 9th Grade Score and Teacher as Predictor of 10th Grade Score

Predictors	*Estimates*	*std. Error*	*CI*	*Statistic*	*p*	*df*
(Intercept)	-0.21	0.12	-0.45 – 0.02	-1.83	0.070	98.00
ninthgrade_zscore	0.66	0.08	0.51 – 0.82	8.72	**<0.001**	98.00
teacher [TeacherB]	0.26	0.18	-0.11 – 0.63	1.42	0.160	98.00
teacher [TeacherC]	0.30	0.22	-0.15 – 0.74	1.33	0.188	98.00
teacher [TeacherD]	0.54	0.23	0.08 – 1.00	2.34	**0.021**	98.00
Observations	103					
R^2 / R^2 adjusted	0.455 / 0.433					

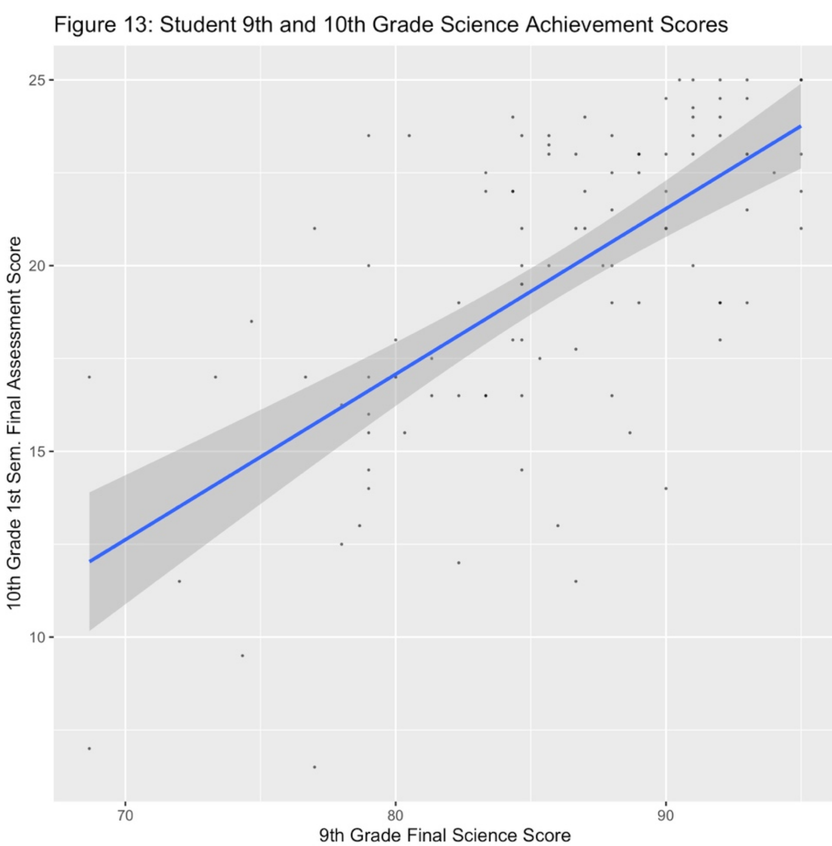

Figure 13: Student 9th and 10th Grade Science Achievement Scores

The analysis of the changes in the z-scores by quartile shows that the virtual learning environment positively affected the lowest achieving students' scores relative to the mean and negatively affected the highest achieving students' scores (see Table 6). A paired t-test showed that the mean z-scores of the lowest quartile increased by 0.43 from their ninth-grade to their tenth-grade science scores (p=0.028), showing that these students improved significantly relative to the other students. The paired t-test also showed that the students in the highest quartile were adversely affected by the virtual environment relative to the other students, with a mean decrease in z-score of -0.42 (p=0.0014). The other two quartiles showed very little variation from ninth to tenth grade.

Table 6: Paired T-Test on 9th and 10th Grade z-scores by Student Quartile

Quartile	estimate	statistic	p.value	parameter	conf.low	conf.high
1st Quartile	0.432	2.326	0.028	25	0.050	0.815
2nd Quartile	0.053	0.293	0.772	25	-0.316	0.422
3rd Quartile	-0.144	-1.061	0.299	25	-0.423	0.135
4th Quartile	-0.420	-3.606	0.001	24	-0.661	-0.180

There are different possible reasons for this variation between the lowest and highest quartiles. One possible reason for this difference for the lowest quartile could be the lower overall grade average on the tenth-grade assessment, only 78.74%, compared to the 9^{th} grade average of 84.89%. Overall, the students did worse, on average, on their tenth-grade exam than in their ninth-grade final score, based on raw percentage. This could explain some of the reason for the 0.43 increase in z-score in the lowest quartile, since the lower mean raises their z-score even if they performed at the same level as in ninth grade. Yet, even if this is the case, the increase still shows that the virtual environment did not affect the lower-achieving students' scores as much as it did for the other students. The highest-achieving students in ninth-grade had the greatest decrease in test scores relative to the other students, suggesting that the virtual environment negatively affected their learning more than it did other students. The reasons for this are not clear from the data. In an informal interview, the lead teacher told me that all four teachers had to reduce the content of the curriculum as they made their way as best they could in teaching virtually for the first time. In the complexity of all of the changes the teachers had to make could explain why the variation occurred.

Turning to the impact the different teachers had on student outcomes, the regression analysis shows that teacher D is a predictor of a higher tenth-grade score compared to the other teachers. Holding all other variables constant, students of teacher D increased their scores by 0.54 standard deviations above the mean from ninth to tenth grade ($p=0.02$). How does one account for this difference? One explanation could have to do with the demographic breakdown of the students in the evaluations. I was not able to control for sex and ethnicity. However, previous information shows that teacher D had a higher proportion of males, white, and Asian students, all of whom typically fare well in science courses. Another possible explanation could be that teacher D uses some instructional practices more or less than other teachers. In an attempt to determine whether the differences between teachers in the frequencies of the instructional practices is large enough to merit attention, I ran Bartlett's homogeneity of variance test on the frequency scores of the instructional practices grouped by teacher (see Table 7). The only differences that were significant were the variance in group work frequency (B-stat = 13.47, $p = 0.0037$) and using models (B-stat = 8.77, $p = 0.032$). Teacher D used group work the least of all the teachers, according to the students. But since the students rated group work as one of the most effective strategies, that does not seem to explain the differences. Teacher D engaged students in using models most of all the teachers, yet the students rated this activity the lowest of all the SEPs. Therefore, that does not seem to explain the difference either.

Perhaps there are other instructional strategies that teacher D used that are not in the survey that account for the relative increase in student scores.

Table 7: Bartlett's Test Comparing the Instructional Practices and SEPs Frequencies by Teacher

Instruction	statistic	p.value	parameter
Discussions	4.100	0.251	3
GroupWork	13.470	0.004	3
Texperiment	6.228	0.101	3
Vexperiment	2.056	0.561	3
Asking Qs	0.243	0.970	3
Analyzing Data	2.123	0.547	3
Using Models	8.774	0.032	3
Arguing from Evidence	4.599	0.204	3
Math Thinking	6.839	0.077	3

Findings for Question 4: Student interest in learning more about science increased during the semester, with Asians showing the largest increase, but not their interest in pursuing science and engineering in college and in a career, except for small increases for black and male students.

There are a number of noteworthy results of the paired t-tests on the interest survey responses (see Table 8). Perhaps against what one would expect, the overall student interest in science, a science career, and studying science in college increased slightly during the semester. The largest effect size was general interest in science, with a mean increase of +0.19 on a 5-point scale, with a p-value of 0.0277.[2] Also of interest is how the interest in a science career and studying science in college both increased by less than half as much as the increase in the general interest in science. This suggests that students are

[2] In all of my statistical analysis I do not use the phrase ‘statistical significance’ and the p-value thresholds of 0.05 and so on. This is in response to the *American Statistical Association* recommendation to refrain from using the p<0.05 threshold as the key value for drawing conclusions from statistical data and to retire the phrase ‘statistical significance’ as misunderstood and misleading (Wasserstein et al., 2019).

not connecting their interest in science with their longer-term plans to pursue scientific study and a scientific career. Finally, interest in engineering did not increase noticeably, with interest in an engineering career and studying engineering in college decreasing very slightly overall. The effect sizes are very small, so one cannot draw strong conclusions. However, when compared to the increase in interest in science, it may suggest that online learning is not conducive to increasing interest in engineering.

There are a number of important differences in the degrees of interest of the females and males. Females and males showed the same size increase in general interest in science, +0.19, but males showed much larger increases on all of the other questions compared to the females, sometimes more than three times as large. Furthermore, females grew in disinterest in engineering over the course of the semester, with the largest estimate value of the whole dataset on the question of the female interest in learning more about engineering for college, with t-stat = -0.39 (p-value of 0.0096). The males increased on that question by estimate +0.19 (p=0.37).

Comparing the results of the ethnic groups also shows some noteworthy differences. All four demographic groups increased their overall interest in science, with the Asians having the largest increase of +0.36 (p=0.083). The Black students showed a healthy increase in interest in science in college, +0.33 (p=0.10), larger than any other group. As with the overall student results, interest in engineering careers and studying engineering in college were slightly negative for all groups, with white students having the largest change at -0.15 for college engineering. Overall, however, the mean differences in interest scores were very small across almost all of the tests, so it is difficult to draw strong conclusions from the results. The incompleteness of the data, with several surveys discarded with incomplete responses, reduced the sample size and thus lowered the statistical power of the data.

Table 8: Student Interest in Science and Engineering Paired T-Test Results

Question	estimate	statistic	p.value	parameter	conf.low	conf.high
All Students						
Interest in Science	0.192	2.244	0.028	77	0.022	0.363
Interest in Science Career	0.077	0.925	0.358	77	-0.089	0.243
Interest in Science in College	0.078	0.773	0.442	76	-0.123	0.279
Interest in Engineering	0.026	0.217	0.829	77	-0.210	0.261
Interest in Engineering Career	-0.039	-0.327	0.744	76	-0.276	0.198
Interest in Engineering in College	-0.115	-0.903	0.369	77	-0.370	0.139
Females						
Interest in Science	0.195	1.668	0.103	40	-0.041	0.432
Interest in Science Career	0.024	0.240	0.812	40	-0.181	0.230
Interest in Science in College	0.049	0.467	0.643	40	-0.162	0.260
Interest in Engineering	-0.049	-0.305	0.762	40	-0.372	0.274
Interest in Engineering Career	-0.171	-1.155	0.255	40	-0.469	0.128
Interest in Engineering in College	-0.390	-2.720	0.010	40	-0.680	-0.100
Males						
Interest in Science	0.194	1.484	0.147	35	-0.072	0.460
Interest in Science Career	0.139	1.000	0.324	35	-0.143	0.421
Interest in Science in College	0.114	0.612	0.545	34	-0.265	0.494
Interest in Engineering	0.139	0.777	0.443	35	-0.224	0.502
Interest in Engineering Career	0.114	0.584	0.563	34	-0.283	0.512
Interest in Engineering in College	0.194	0.909	0.370	35	-0.240	0.629
Asians						
Interest in Science	0.353	1.852	0.083	16	-0.051	0.757
Interest in Science Career	0.176	1.000	0.332	16	-0.198	0.551
Interest in Science in College	-0.250	-1.168	0.261	15	-0.706	0.206
Interest in Engineering	0.059	0.223	0.826	16	-0.501	0.618
Interest in Engineering Career	-0.125	-0.565	0.580	15	-0.597	0.347
Interest in Engineering in College	-0.059	-0.236	0.817	16	-0.588	0.470
Black						
Interest in Science	0.250	1.000	0.339	11	-0.300	0.800
Interest in Science Career	-0.167	-0.804	0.438	11	-0.623	0.289
Interest in Science in College	0.333	1.773	0.104	11	-0.081	0.747
Interest in Engineering	0.167	0.484	0.638	11	-0.592	0.925
Interest in Engineering Career	0.000	0.000	1.000	11	-0.766	0.766
Interest in Engineering in College	-0.083	-0.233	0.820	11	-0.871	0.705
Hispanic						
Interest in Science	0.333	1.000	0.423	2	-1.101	1.768
Interest in Science Career	-0.333	-1.000	0.423	2	-1.768	1.101
Interest in Science in College	0.333	0.500	0.667	2	-2.535	3.202
Interest in Engineering	0.333	1.000	0.423	2	-1.101	1.768
Interest in Engineering Career	0.000	NaN	NaN	2	NaN	NaN
Interest in Engineering in College	0.000	NaN	NaN	2	NaN	NaN
White						
Interest in Science	0.130	1.182	0.244	45	-0.092	0.353
Interest in Science Career	0.130	1.182	0.244	45	-0.092	0.353
Interest in Science in College	0.130	0.948	0.348	45	-0.147	0.408
Interest in Engineering	-0.022	-0.141	0.888	45	-0.332	0.288
Interest in Engineering Career	-0.022	-0.133	0.894	45	-0.350	0.307
Interest in Engineering in College	-0.152	-0.866	0.391	45	-0.506	0.202

RECOMMENDATIONS

Recommendation 1: Structure online instruction to privilege continual teacher feedback on student work through the application of Hattie & Timperley's framework and through corrective activities.

Students rated teacher feedback on assignments as the most effective instructional practice. This is consistent with other literature surveying students about online learning practices (King, 2014; Martin & Bolliger, 2018). Virtual learning does not hinder this practice. Therefore, teachers should leverage this strategy in their online learning. Based on their estimates of learning losses during school shutdowns, CREDO (2020) recommends that teachers increase diagnostic assessments and frequent progress checks for students in order to respond to varied student learning needs during the pandemic. One way to implement this strategy is adopt the framework of Hattie & Timperley (2007). They propose that teachers should focus their feedback on three major questions: Where am I going? How am I going? Where to next? Then to break down the feedback into four levels: the task, the processing, the regulatory, and the self. The teachers can use these questions and levels to target their feedback to hit each area, tailoring the type of feedback that they give depending on the question and the level, as Hattie & Timperley map out. This feedback can be given on assignments, through messages, or in breakout rooms on Zoom or another video platform. When students have yet to reach proficiency in their understanding or skill goals, teachers could differentiate instruction through the use of Guskey's (2007) corrective activities. Corrective activities are qualitatively different from the original instruction and engage students differently in learning. After a major assignment, teachers can identify the students that have not yet grasped a key concept or mastered a particular skill and create corrective activities for them, while giving the other students new work to do.

Recommendation 2: Discontinue student at-home experiments in favor of observing teacher experiments and expand the use of 'pivot labs' to approximate inquiry-based lessons that engage the students in the SEPs.

The student feedback from the surveys revealed that teachers performing experiments for students to observe is more effective than students mimicking experiments at home. Therefore, unless there is good reason to do so, such as for a project or some other extended assessment, teachers should discontinue the practice of having students conduct or mimic experiments at home and rely solely on performing experiments for students to observe virtually. Beyond that, the interactive pivot labs seem to be the best way for students to engage in scientific thinking and laboratory-type work on a virtual platform. Teachers should expand the use of this website to organize its use along the lines of inquiry-based lessons. Inquiry-based learning is the foundation of the NGSS (Council, 2011) and has been shown to be very effective at teaching not only science knowledge but also the SEPs (Pedaste et al., 2015). The interactive videos of the pivot labs have a structure that is very similar to inquiry-based learning progressions; they begin with phenomena, push the students to propose explanations and test their proposals with feedback mechanisms (*Pivot Interactives*, n.d.). Teachers could frame this activity within the learning of the SEPs, give specific instructions on how to develop the scientific skills before the pivot labs, and then have the students evaluate their own thinking afterwards in order to create a self-directed learning progression similar to the structed that Mamun et al. (2020) develop. This could enhance the student learning of the SEPs even when virtual.

Recommendation 3: Provide extra-credit activities, summer enrichment units and other means to address the learning deficits of the students.

Although not the central focus of this study, the findings for question three give a glimpse into the learning deficits of the students. The findings about the variation in student outcomes between the lowest and highest quartile is the most surprising of this study. As strange as the finding itself, it is not clear why the lower-achieving students did better in the virtual environment relative to the other students and the higher-achieving students did worse. Perhaps Anderson's assessment of online learning (2003) proves true in this instance, "despite years of study, it is still unclear which students studying what types of content under what conditions and using which instructional design benefit most from synchronous as opposed to asynchronous interaction." (p. 140) Several factors, including Anderson's finding, the lower average score in tenth-grade compared to tenth-grade, and the report from the lead teacher about the reduced curricular content, indicate that this academic year in the pandemic has led to noticeable variations in student learning. It seems clear that many students did not learn as much or as well as they would have in a normal year. This is consistent with the research on learning losses during the school shutdowns (CREDO, 2020). What can be done about this learning deficit? Excellence Academy and its teachers could offer different ways for students to make up for what they may have lost. For example, teachers could offer students extra-credit projects that fit within the content and skills that the science teachers had to leave out. One such project that the students did last year that the teachers had to drop this year was the building of a fire extinguisher. Teachers could introduce this as an extra-credit assignment and provide resources and after-school tutoring to guide the students. Another possibility is a summer enrichment mini-course.

Students could come into the school in the summer for a two- or three-week, inquiry-based science course. If the school and the teachers do not have the resources, they could find a summer science program that already exists and promote it to the students. Even if imperfect and incomplete, finding ways to fill in the gaps in learning could be one productive way to help the students out of the pandemic.

Recommendation 4: Promote student interest in science and engineering careers through more assignments that apply science knowledge to real-life problems, by creating STEM communities of practice, and hosting STEM professionals on campus.

Although students became more interested in science even on the online platform, there was not a corresponding increase in interest in studying science in college and working in a career in science. This finding was consistent across the demographic groups, with a few notable exceptions. The results for engineering were, not surprisingly, generally negative across the groups except for males. It is a credit to the work of the teachers that students became more interested in science and males more interested in engineering, albeit very slightly, even though they were sitting at home and not engaged in hands-on labs and other activities that they tend to enjoy. If Excellence Academy desires to promote careers in science and engineering, then it must find a way to have students connect their interest in science and engineering to a career in those fields. This is especially true for females, Black students, and Hispanics, who in our culture are often traditionally not seen in those roles. The teachers could offer more assignments that connect student learning with real-life problems, which helps motivate student engagement in STEM (Lee & Campbell, 2020). The teachers could also seek to foster a community of science and engineering practice at the school through a STEM club and other extra-curricular activities (Aschbacher, Li, & Roth, 2010). The school could invite professionals in the STEM fields to speak to the students about their work in order to increase student awareness of the different STEM careers (Byars-Winston, 2014), either periodically or through a career fair structure. Finally, in order to address the disparity between the male, white, and Asian students and the female, African American, and Hispanic students, the school can encourage the teachers to support and encourage these students to pursue STEM fields in college and beyond. This encouragement and support can impact student beliefs about the opportunities available to them in the STEM fields (Grossman & Porche, 2014).

DISCUSSION

The COVID-19 pandemic caused many schools to close their doors and shift their instruction to online learning platforms. This shift created many new challenges for teachers for whom online instruction was new. The tenth-grade science teachers at Excellence Academy faced an even greater challenge as they attempted to adapt their NGSS-aligned science curriculum, which privileged the teaching of the SEPs, to the virtual learning environment. Taken together, the data shows that the teachers did very well to adapt their curriculum to the online platform. The students found the instructional strategies to be effective. Student academic outcomes did not dramatically change online, with lower performing students doing better relative to the other students. Student interest in science increased even when studying online. Well done teachers!

The data also provides the teachers some concrete ways in which they can develop their online instruction. The surveys collected showed that the students judged teacher-student interactions, in particular teacher feedback, as the most effective strategies, and that teachers conducting experiments for students to observe, and the interactive media platform called 'Pivot Labs', were the most effective ways to conduct labs online. The student test scores showed that online learning either had less impact or even a positive relative impact on lower-achieving students, and a greater and more negative relative impact on higher-achieving students. Finally, student interest in learning more about science increased from the beginning to the end of the semester across all groups, with Asians having the largest increase. Interest in studying science in college did not increase significantly across group except for Black students. Interest in pursuing a career in science did not increase either. Interest in engineering at the three levels either showed very little change or decreased slightly across groups, with females showing the largest decrease in interest in pursuing engineering in college. Males showed slight increases across all questions, although not significant at the $p < 0.1$ level.

These findings from the data can help the Excellence Academy teachers and the school improve their practice of teaching science in the virtual environment. Teacher feedback, conducting experiments for students to observe online, and pivot labs are all practices that the teachers can increase and improve for future teaching. Finding ways to fill in the student learning deficits through extra credit and extra-curricular activities is a noble goal. Finally, if the school wants to promote STEM careers, especially to females and minority students, there are ideas and resources available to foster student interest and action along those lines.

This study is limited in many respects. The small, non-random sample size prevents the ability to draw broader conclusions to a different student population. Although some of the findings, such as the effectiveness of teacher feedback and group work, are consistent with the research literature on online learning, other findings, such as the varied impact of virtual learning on the lower- and higher-achieving students, have no parallel in the literature. The limitations of the data prevent further inquiry into the possible causes of these differences. Furthermore, the pandemic posed special challenges to the teachers conducting these classes. They may never be another semester like the Fall of 2020. It is hard to say that the conclusions from this study will pertain to other virtual learning environments that are custom-made and not forced on teachers by a global pandemic.

There are several potential avenues for further research. One topic of great interest is the impact of the school closures during the pandemic on student learning (CREDO, 2020). This extends even to the potential long-term economic effects of student learning deficits

(Hanushek & Woessmann, 2020). This study does not provide sufficient evidence for a rigorous determination of the potential student learning losses during the virtual learning semester. Such a study would have to include a comparison between the students, the curriculum, and the learning outcomes of the students from previous years compared to the Fall of 2020. CREDO (2020) provides a template for such a study which researchers could adapt for studies at schools such as Excellence Academy and others. Another question that this research posed was the best way for science teachers to conduct experiments in a virtual environment. The interactive videos of the pivot labs seem to be a powerful format for approximating real laboratory experiments and inquiry-based learning. More research could be done on the effectiveness of this technological platform in comparison to in-person labs and simple observations of teachers conducting experiments online. How best to recreate lab experiments in a virtual science class is one of the most important questions for virtual science learning. A third line of research relates to the best ways to promote STEM careers in online learning environments. Virtual learning is here to stay, even with the end of the pandemic. What are the best ways to promote student interest in STEM subjects and careers when students are fully virtual? The findings of this study suggest that promoting interest in science is possible even in online courses, but more could be done to discover the key levers to stimulate this interest when students cannot engage in hands-on STEM work. This study also suggests that virtual learning could negatively affect interest in engineering. What could be done to compensate for this problem? These are worthy areas of further research.

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APPENDICES

Excellence Academy 10th Grade Science Student Profile Survey (Aug/2020)

Start of Block: Demographics

Instruction Thank you for taking a few minutes to fill out this survey. The information from this survey will be used as part of a study of the MICDS 10th grade science curriculum. Your answers will not be separable from other students' answers and will be analyzed collectively, not individually. You can answer honestly with the assurance of anonymity.

Gender What is your biological sex (from birth)?

- ○ Male
- ○ Female

Ethnicity2 How would you describe yourself? Please select all that apply.

- ☐ White
- ☐ Black or African American
- ☐ Hispanic, Latino, or Spanish origin
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Native Hawaiian or Pacific Islander
- ☐ Other ____

Page Break

Education What final grade did you receive in your 9th grade science class?

- ◯ A+
- ◯ A
- ◯ A-
- ◯ B+
- ◯ B
- ◯ B-
- ◯ C+
- ◯ C
- ◯ C-
- ◯ D+
- ◯ D
- ◯ D-
- ◯ F

Q13 What final grade did you receive in your 9th grade math class?

- A+
- A
- A-
- B+
- B
- B-
- C+
- C
- C-
- D+
- D
- D-
- F

Q16 Which science class are you taking this year?

- Biochemical Applications with [redacted]
- Biochemical Applications with [redacted]
- Biochemical Applications with [redacted]
- Biochemical Applications with [redacted]
- Biochemical Applications ACCELERATED with [redacted]

Page Break

Marital Status I am interested in taking courses that help me learn more about SCIENCE.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Employment I am interested in working in a career that allows me to use SCIENCE-related skills and knowledge.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q9 I would like to learn SCIENCE-related knowledge and skills because they can be useful to help me be prepared for college.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Page Break

Q10 I am interested in taking courses that help me learn more about ENGINEERING.

- ◯ Strongly agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Strongly disagree

Q11 I am interested in working in a career that allows me to use ENGINEERING-related skills or knowledge.

- ◯ Strongly agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Strongly disagree

Q12 I would like to learn ENGINEERING-related knowledge and skills because they can be useful to help me be prepared for college.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

End of Block: Demographics

Excellence Academy 10th Grade Science End of Semester Survey (Dec/2020)

Start of Block: Demographics

Instruction Thank you for taking a few minutes to fill out this survey. The information from this survey will be used as part of a study of the 10th grade science curriculum. Your answers will not be separable from other students' answers and will be analyzed collectively, not individually. You can answer honestly with the assurance of anonymity.

Page Break

Q20 What is your biological sex?

- ○ Male
- ○ Female

Q21 How would you describe yourself? Please select all that apply.

- ☐ White
- ☐ Black or African American
- ☐ Hispanic, Latino, or Spanish origin
- ☐ Asian
- ☐ Native Hawaiian or Pacific Islander
- ☐ Other ____

Q16 What science 10 class are you taking this year?

- ○ Biochemical Applications with [redacted]
- ○ Biochemical Applications with [redacted]
- ○ Biochemical Applications with [redacted]
- ○ Biochemical Applications with [redacted]
- ○ Biochemical Applications ACCELERATED with [redacted]

Page Break

Marital Status I am interested in taking courses that help me learn more about SCIENCE.

- ◯ Strongly agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Strongly disagree

Employment I am interested in working in a career that allows me to use SCIENCE-related skills and knowledge.

- ◯ Strongly agree
- ◯ Somewhat agree
- ◯ Neither agree nor disagree
- ◯ Somewhat disagree
- ◯ Strongly disagree

Q9 I would like to learn SCIENCE-related knowledge and skills because they can be useful to help me be prepared for college.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Page Break

Q10 I am interested in taking courses that help me learn more about ENGINEERING.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q11 I am interested in working in a career that allows me to use ENGINEERING-related skills or knowledge.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q12 I would like to learn ENGINEERING-related knowledge and skills because they can be useful to help me be prepared for college.

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Page Break

Q28 The teacher's presentations and explanations in class:

- ○ Did not help my learning
- ○ Helped my learning a little
- ○ Helped my learning adequately
- ○ Helped my learning a lot
- ○ Helped my learning a great deal

Q29 The teacher experiment simulations (performing an experiment for the students to observe) occured:

- ○ Never
- ○ Rarely
- ○ Periodically
- ○ Frequently

Q30 The teacher experiment simulations (performing an experiment for the students to observe):

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q31 Student 'virtual' experiments (done at home either for real or mimicking the experiment) occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q32 Student 'virtual' experiments (done at home either for real or mimicking the experiment):

- Did not help my learning
- Helped my learning a little
- Helped my learning adequately
- Helped my learning a lot
- Helped my learning a great deal

Q24 Class discussions occured:

- Never
- Rarely
- Periodically
- Frequently

Q26 Class discussions:

- Did not help my learning
- Helped my learning a little
- Helped my learning adequately
- Helped my learning a lot
- Helped my learning a great deal

Q25 Group work in class occured:

- Never
- Rarely
- Periodically
- Frequently

Q27 Group work in class:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q35 The class assignments and homework that required asking questions and defining problems occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q36 The class assignments and homework that required asking questions and defining problems:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q33 The class assignments and homework that required analyzing and interpreting data occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q22 The class assignments and homework that required analyzing and interpreting data:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q37 The class assignments and homework that required developing and using models occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q39 The class assignments and homework that required developing and using models:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q38 The class assignments and homework that required engaging in argument from evidence occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q40 The class assignments and homework that required engaging in argument from evidence:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q41 The class assignments and homework that required using mathematics and computational thinking occured:

- ◯ Never
- ◯ Rarely
- ◯ Periodically
- ◯ Frequently

Q42 The class assignments and homework that required using mathematics and computational thinking:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Q23 The teacher feedback on assignments:

- ◯ Did not help my learning
- ◯ Helped my learning a little
- ◯ Helped my learning adequately
- ◯ Helped my learning a lot
- ◯ Helped my learning a great deal

Page Break

Q17 What activities during this semester did you find to be the most effective strategies for teaching you the knowledge of science?

____

Q18 What activities during this semester did you find to be the most effective strategies for teaching your the skills of science?

____

Q19 What was your favorite part of the science class this semester?

____

End of Block: Demographics