Lighthaus NIH FastTrack SBIR Randomized Control Trial Report

Submitted to: Lighthaus

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Executive Summary

WestEd conducted a randomized control study for Lighthaus Inc. from September to December 2022 to test the feasibility and impact of the Nano Virtual Reality (VR) experience in authentic educational settings. Thirteen high school biology teachers at Los Angeles Unified School District (LAUSD) participated, with all teachers successfully completing most study activities. A total of 516 consented students participated in the study across thirteen biology classes. Teachers were randomly assigned into one of two conditions – the Treatment group ($n_{Teachers}$ = 7) used Nano: Cell to help teach cell biology content, and the Control group ($n_{Teachers}$ = 6) taught business as usual instruction of cell biology content. Treatment teachers were asked to integrate Nano: Cell into their classrooms for a minimum of six class periods. Treatment teachers and students were able to successfully use Nano and its resources with few challenges. The Nano lessons covered protein synthesis including transcription and translation.

The study found that:

- Teachers reported that students were highly engaged in the lessons and classroom during VR lessons, and that student engagement persisted even after the initial novelty of VR wore off.
- Nano was especially helpful with enhancing the "hands on" aspects of learning about cell biology, allowing students to see concrete examples of processes and structures that they would not normally have the chance to see.
- Teachers and students felt that Nano increases students' knowledge of cell biology and protein synthesis, but as a supplement not as a standalone curriculum.
- Both Treatment and Control students showed statistically significant learning gains on the pre and post content assessments. There was no significant difference between groups when looking at outcome measure regressed by condition with pre assessment score as a covariate and using teachers as clusters.
- Treatment students showed near statistically significant increases in science attitudes, suggesting that use of Nano: Cell may positively impact students' interest in and enjoyment of science.
- Treatment students enjoyed using Nano: Cell and found it easy to use the VR controls. Treatment students also found Nano: Cell most helpful for visualizing cell biology concepts, and specifically spoke about how it supported their understanding of transcription and translation.
- While VR in the classroom is feasible, additional development and supports may be needed to fully realize the promise of learning with VR. Districts, schools, teachers and students need additional resources and systems to support using VR in the classroom.

Study Overview

WestEd conducted a randomized control study for Lighthaus Inc. from September to December 2022 to test the feasibility and impact of the Nano Virtual Reality (VR) experience in an authentic educational setting. WestEd, an education research agency, conducted evaluation activities and formative testing of the Nano curriculum and experience under the Lighthaus NIH FastTrack SBIR grant.

Research Questions

The primary research questions that guided the randomized control study are:

1) *Science Learning* – Does Nano: Cell increase students' knowledge of cell biology, DNA, and protein synthesis? Does Nano: Cell support students' development of science practices?
2) *Engagement* – Does Nano: Cell increase students' engagement with STEM learning compared to regular classroom practices? Does it have the potential to support students' interest in STEM?
3) *Classroom Use* – Can teachers and students successfully use the Nano: Cell VR app, the Lighthaus Web Station "Mission Control", and associated teacher resources? Are there barriers to classroom use at scale?
4) *Improvement – How can the student and teacher experiences be improved, and how can they be better integrated into class time and pre-existing curriculum and instruction?*
5) *Potential for Informal and Out-of-School Learning* – Does Nano: Cell show promise as an effective and attractive learning experience outside of regular classroom instruction?

Description of the Study Intervention

Treatment teachers were asked to integrate Nano: Cell into their classrooms for a minimum of six class periods. Teachers taught six Nano: Cell lessons designed to be approximately 50 minutes long each. The lessons covered DNA and proteins, including protein synthesis, transcription, and translation. The lessons were designed for students to work in pairs, with approximately half of the class (10-15 students) or less were in VR at one time while the other half engaged with their partner through the web-based "Mission Control".

Prior to the start of the study, teachers were instructed to spend at least 90 minutes on independent preparation to use Nano: Cell. These preparation activities included reviewing a curriculum document

and using an Oculus Quest 2 headset to go through the VR experience. Teachers also participated in a 2-hour in-person training session with Lighthaus and WestEd staff, and a 30-minute online study orientation. During the in-person training session, Lighthaus staff did a walkthrough of key components of the curriculum and VR experience, including modeling a sample lesson with teachers acting as students using the VR headset.

To gather feedback on the use of Nano: Cell, teachers administered a student pre and post assessment and survey before and after the 6-day Nano experience. Teachers were asked to complete a log after each lesson, and WestEd researchers briefly spoke to each teacher at the end of one of the lesson days, also referred to as a post-lesson debrief. At the conclusion of the study, each teacher was interviewed for one hour to gather formative feedback on the Nano: Cell experience, its perceived impact on student learning, and to provide actionable feedback to Lighthaus for future product revisions.

Participants

Thirteen high school biology teachers in Los Angeles Unified School District (LAUSD) participated in the randomized control study, with all successfully completing most study activities. Teachers were randomly assigned into either the treatment or control conditions from 5 different cluster blocks. Clusters were made based upon the teacher's school, school demographics (% free and reduced lunch students, Title 1 status) and the teacher's prior experience in a VR study. A total of 516 consented students ($N_{ControlStudents}$ = 162, and $N_{TreatmentStudents}$ = 354) participated in the study across fourteen general biology classes and one genetics class. Six teachers also taught honors and/or advanced placement courses. A breakdown of participating classes is included in Appendix A.

Measures

The following measures were used to collect data around student outcomes and use of Nano: Cell during the study.

Student Survey

Students completed pre and post attitudinal surveys around their interests and attitudes towards science and STEM careers at the beginning and at the end of the study. Researchers developed the 20-item survey consisting of five-point Likert items. Items were adapted using three resources: Motivation and Beliefs about the Nature of Scientific Knowledge Within an Immersive Virtual Ecosystems Environment (Chen, Metcalf, & Tutwiler, 2014), Student Attitudes toward STEM: The Development of Upper Elementary School and Middle/High School Student Surveys (Faber et al., 2013).

The adapted survey items included subscales with three items on self-efficacy for science inquiry, four items on science interest, five items on science identity and conception of ability, and eight items on interest in STEM-related careers. Response options on self-efficacy for science inquiry items ranged from "not at all confident" to "very confident," and response options on STEM-related careers ranged from "not at all interested" to "very interested." Science identity and science interest subscales included response options ranging from "strongly disagree" to "strongly agree."

Additionally, on the post-survey, students were asked to rate their level of engagement in Nano: Cell and the ease of use of different platform components. Students completed 19 five-point Likert items on overall enjoyment, ease of use in using Nano: Cell and specific activities in Nano, and helpfulness of Nano in learning specific DNA and protein synthesis concepts. Response options ranging from "strongly disagree" to "strongly agree" for items such as "I enjoyed using Nano: Cell." Content-related items such as "understanding the difference between mRNA, RNA, and tRNA" featured response options ranging from "Not at all helpful" to "Extremely helpful." Ease of use items featured response options from "very difficult" to "very easy." There was also a Yes/No question asking students if they had ever used a virtual reality headset before.

Student Assessment

Students were asked to complete a proximal assessment before and after using Nano: Cell. The researcher-developed assessment consisted of 26 multiple choice items, two one open-ended response items, and one drag-and-drop item for a total of 29 items. The assessment was aligned to California's NGSS standards for the content being covered by Nano on DNA, proteins, and protein synthesis. The assessment contained both researched-developed items and items adapted from Pearson's Student support materials (MCAS), OpenStax textbooks for High School Biology, BSCS Science Learning NGSS aligned assessment item bank, and the New York Regents Examination in Living Environments. The open-ended response items were based on LAUSD district course resources shared with the research. Changes were made to the format of this item in order to translate it from a paper-based assessment to a digital assessment.

Students were asked to respond to items that were content specific, such as questions on the definition and purpose of genes vs DNA; the structure of DNA, mRNA, and proteins; the process of transcription; the process of translation; and overall process of protein synthesis.

As the assessment items had not been validated together as a single assessment, a classical psychometric analysis, based on classical test theory, was run on all completed pre-assessments blind to the student's study condition. There were 433 complete pre-assessments from both treatment and control classes to use in the psychometric analysis. Of the 29 original items, 9 items poorly correlated with the other 20 items, indicating that they added little information to the assessment, or they introduced an undesired second underlying factor to the assessment. After a careful content review of the 9 items, it was determined that removing them from assessment did not change the overall content coverage or difficulty level of the assessment. The remaining 20 items fall into one dominant factor and have a Cronbach's alpha of 0.66. Both the factor analysis and the Cronbach's alpha indicate the assessment is valid and moderately reliable. The 9 items in question were removed from the final assessment scores of students and were not used in the final outcome analysis. The assessment items and how they were displayed to students can be found in Appendix B, including the 9 items that were removed from the impact analysis.

Post-Lesson Debriefs

In lieu of in-person observations, WestEd asked teachers to complete a log for each lesson and conducted post-lesson debriefs after one of the lessons for each teacher. These debriefs consisted of a roughly 10-minute phone call to ask several big-picture questions about the day's lesson, such as how engaged students were and whether the teacher noticed instances of student learning.

Teacher Post-Interview

At the end of the study, each teacher participated in a 1-hour post-interview in which they were asked about the implementation of Nano in their classroom, the content and instruction presented in the system, their overall impressions of Nano, and suggestions for improving the platform.

Student Focus Groups

At the end of the study, a small number of students from three treatment classrooms were invited to participate in a 45-minute focus group during which they were asked about their overall impressions of Nano, their experiences using the platform, and their perceptions of Nano's effect on their learning of science content.

Limitations

Due to the timing of the study nearly all teachers, both treatment and control, were teaching the cell biology content earlier in the school year than they normally would have. Scheduling constraints meant that treatment teachers were asked to teach the content during a 2–3-week period in November, while most control teachers taught the cell biology content in December. Treatment teachers also experienced several technical delays, largely due to a network security challenges with the district which resulted in 1-2 days of lost instructional time. Due to delays three teachers were also forced to pause instruction for one week due to the Thanksgiving break and resumed instruction with stages 5 and 6 after the holiday.

Findings

1) *Science Learning* – Does Nano: Cell increase students' knowledge of cell biology, DNA, and protein synthesis?

Does Nano: Cell support students' development of science practices?

Students completed a content assessment before and after the Nano: Cell intervention. This 29-question assessment included 26 multiple choice items, 2 open ended response items, and one drag-and-drop items. As stated above, after conducting a psychometric item analysis, it was decided that only 20 of the 29 items would be used in the final outcome analysis.

A total of 104 control and 242 treatment students completed both the pre and the post assessment. Those students' scores on the 20 final assessment items are included in further analysis.

Student Content Assessment Analysis

Prior to participating in the Nano: Cell intervention, both groups participated in the pre-assessment during the same two-week window in the school year. This was to ensure that students were at roughly the same point in their learning journey's.

A preliminary baseline analysis of pre-assessment scores shows that both treatment and control students started out with no significant difference in their content knowledge. Table 1a below shows the average pre-assessment scores for both treatment and control groups. The numbers in the table depict a difference of less than one point between the averages and a non-significant p-value of 0.89 and an effect size of -0.030 which satisfies baseline equivalence requirements used by the What Works Clearinghouse (WWC) [0 <= absolute difference, effect size <= 0.05].

Table 1a. Baseline Equivalence Results

	Mean Score	# of Students	Difference	SE	p	effect size
Treatment	9.11	242	-0.11	0.77	0.89	-0.030
Control	9.22	104				

Because students were randomized at the teacher level, a multi-level regression analysis that takes into account the clustered structure of the data (students nested within teacher) in variance estimate was run to check for potential differences between treatment and control post assessment scores. Adjusted means were generated based on the clustered nature of the data. The pre-assessment score was

included as a covariate in the model. The regression analysis found no significant difference between adjusted means of the treatment and control post-assessment scores (see Table 1b).

Table 1b. Regression Analysis Results with Adjusted Means

	Treatment	Control	Difference	SE	p	effect size
Adjusted Mean	11.59	13.31	-1.72	0.92	0.09	-0.390
Standard Deviation	4.52	4.14				
# of Students	242	104				

Note. **the effect size is estimated based on the pooled standard deviation.**

Both groups' increase in scores could be attributed to the fact that teachers were asked to cover course material pertaining to DNA, proteins, and protein synthesis in the time between pre and post assessments. Any increase in score in both the control and treatment group is expected under these conditions, as students had not yet learned the material at pre and had covered material with either business-as-usual materials (control) or using Nano: Cell (treatment) at post.

Though the difference between groups cannot be considered significant with a p-value of 0.09 (significant p-value <= 0.05), an additional differential impact analysis was run to see if individual performance on the pre-assessment may have played a part in student outcomes. Table 1c shows the adjusted means and results of the comparison between treatment and control groups when also grouping students into high performing and low performing groups. Low performing students were those who scored at the 25th percentile or below (7 points or lower) on the pre-assessment, high performing students were those who scored above the 25th percentile on the pre-assessment (a score of 8 or above).

Table 1c. Differential Impact Analysis based on Pre-Assessment Scores

	Treatment	Control	Difference	Contrast	SE	p	effect size
High Performing Adjusted Mean	11.99	13.68	-1.69	-0.11	0.99	0.91	-0.02
# of Students	*164*	*71*					
Low Performing Adjusted Mean	10.74	12.54	-1.80				
# of Students	*78*	*33*					

Note. **the effect size is estimated based on the pooled standard deviation.**

As shown in Table 1c, the difference in score-change between pre and post assessment does not appear to be statistically significantly different and there was no differential impact by performance level at the baseline.

Teacher and Student Feedback on Learning with Nano

In addition to the statistical analysis of student pre and post assessments, teachers and students were asked to provide feedback on the perceived impact of the program during interviews, focus groups and as part of the student post-survey. Teachers in particular were asked to reflect on student understanding of protein synthesis, transcription, translation, other cell biology and DNA concepts, and how Nano compared to their traditional curriculum.

Teachers and students felt that Nano: Cell supported student understanding of cell biology content, specifically noting an increase in student use of scientific vocabulary.

During interviews and debriefs teachers shared that they felt Nano: Cell was helpful in improving student understanding of key concepts, in particular teachers noted student use of academic vocabulary when communicating with their partners and describing the processes taking place in VR.

> *"As they were talking, they were using the academic language so smoothly, so it was really nice to hear them like, "You need to find the tRNA. You need to pair up the base pairs, you need to use your base pairing rules." So it was just really nice to hear them talk biology as if it's the language they're familiar with, which is really nice."*

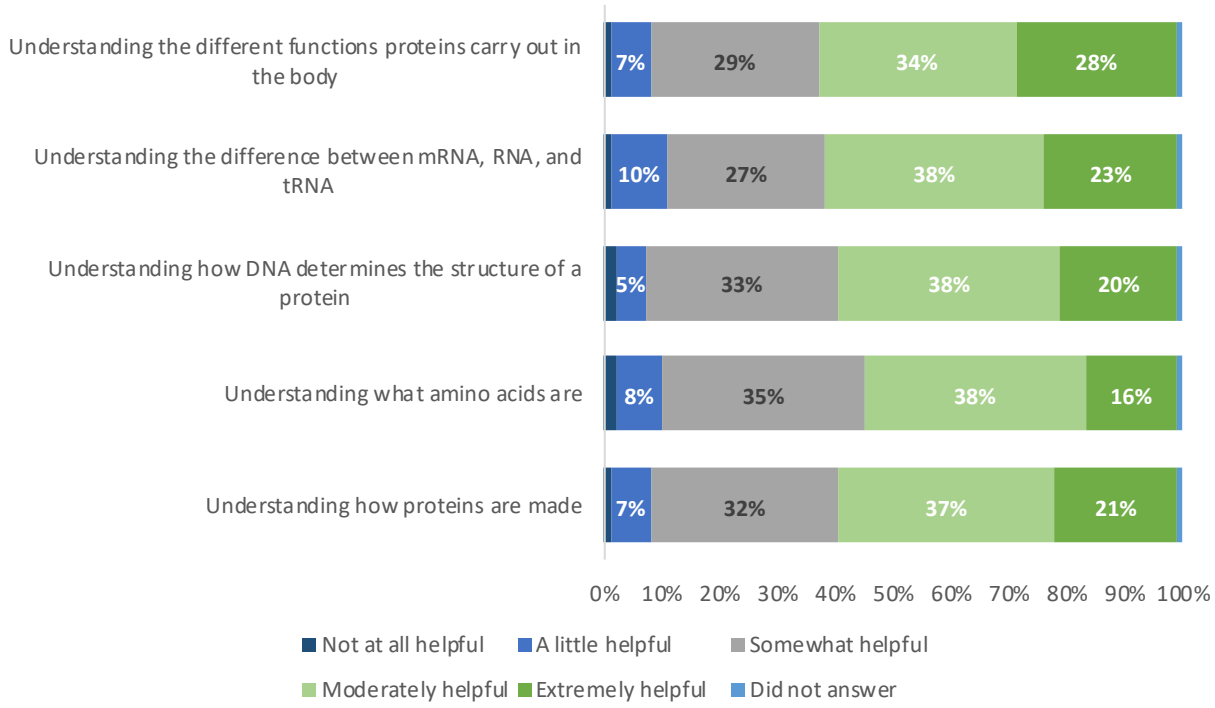
Teachers and students also mentioned learning about the needs and functions of the cell, and were particularly positive in their feedback about learning transcription and translation. According to one teacher:

> *"Having that little decoder on mission control, so that they could help each other, that definitely helped them with Transcription and Translation. I definitely saw a lot more engagement when I teach those topics, because when I teach in the traditional way, it just kind of goes in through one ear out the other, and this way visually they could see what is actually happening."*

Students were generally positive when asked about the extent to which Nano supported their understanding of learning targets.

On the post-assessment students who used VR were asked to rate how well Nano supported their understanding of five learning targets, described below in Figure 1. For each of the learning targets, the majority of respondents (54% or more) felt that Nano helped their understanding at least moderately. Students considered Nano most helpful in supporting their understanding of the different functions proteins carry out in the body (62% moderately or extremely helpful), and understanding the difference between mRNA, RNA, and tRNA (61% moderately or extremely helpful). Students considered Nano least helpful in supporting their understanding of amino acids, with 54% rating Nano as at least moderately helpful. Overall, these findings suggest that Nano helped students at least moderately with a number of learning targets.

Figure 1. Student survey feedback on how well Nano supported their understanding of learning targets (n=274)



Students and teachers felt that the visual component of Nano: Cell supported student understanding of the structures of the cell and protein synthesis.

Both teachers and students spoke positively about the immersive experience of VR and mission control, saying that the visual elements went a long way in supporting student engagement and understanding of various processes and parts of the cell. One teacher shared:

> *"I feel like it's been such an amazing experience for my students to be inside of the cell and experience being surrounded by organelles, it's immersive. It's an immersive experience that I think the kids really genuinely appreciated. Protein synthesis came alive for them… I think that is so important because when kids learn the importance and the purpose of what's going on inside the cell, they're more motivated to learn about the topic. It becomes more real for them. They become more excited about science."*

Students also spoke about their experience, saying that the visual experience helped them understand the steps of protein synthesis more clearly than traditional instruction.

> *"Honestly, it's like a class when you use it. It gives you more details and it's visual learning so like it shows you everything that you have to do, and it shows you step by step by step. So it's more easier to understand and easier to learn."*

Teachers generally thought that the Nano: Cell activities, in particular the Schoology assignments, were aligned with NGSS standards including planning and carrying out investigations and constructing explanations.

When asked about how well Nano: Cell aligns with NGSS standards, teachers were generally positive about the curriculum. Though most felt it did not map closely to every standard and practice, most felt that the activities and assignments in Schoology encouraged NGSS practices such as planning and carrying out investigations, constructing explanations, designing solutions, and communicating information.

> *"I know NGSS and the science and engineering practices, they promote asking questions, they promote coming up with solutions, so I think the Nano VR did really well with having them come up with, oh, what real life applications does this have? There were problems that were appearing in the cell that they were actually able to come up with solutions for and see how those solutions actually unfold in the cell. And I think those are the two aspects that I really enjoyed about how the Nano VR interacted with the NGSS standards."*

2) *Engagement* – Does Nano: Cell increase students' engagement with STEM learning compared to regular classroom practices?

Does Nano have the potential to support students' interest in STEM?

Teachers were asked to describe their perception of student engagement with Nano: Cell during interviews, debriefs, and logs. Students were also asked about their own interest in science and engagement with Nano: Cell during student focus groups.

Overall both teachers and students felt the VR was much more engaging than traditional instruction.

The response to questions about engagement was overwhelmingly positive from both teachers and students. Teachers reported hearing a lot of positive feedback from students during class and noted that students would discuss their use of the VR with their friends outside of class as well. One teacher explained their response saying:

> *"They were very engaged. I actually got lots of positives that, 'Miss, are we doing this tomorrow? It was so cool.' So they were very engaged. They were very, very engaged in*

it. … I heard some positives, which is rare. No matter how hard you try. So it was nice to hear that."

Other teachers echoed this sentiment, noting that students asked to use the VR more often for "Transcription Translation practice" when normally their students would not ask to do more practice work. Several teachers specifically noticed an increased level of engagement as compared to their more traditional teaching methods using textbooks or slides. One teacher noted:

"I definitely saw a lot more engagement when I teach those topics, because when I teach in the traditional way, it just kind of goes in through one ear out the other, and this way visually they could see what is actually happening, so I think that definitely that was a big plus."

Students also expressed enjoyment in using Nano: Cell. They described the lessons as "fun" or "awesome", and one student noted that for them the pace of the lessons was engaging:

"I enjoyed was how fast paced it was. You didn't have to wait a long period to figure something out or you didn't have to wait for something to process. It was all just quickly done. I liked that part."

In general, teachers felt that Nano: Cell does have the potential to support students' interest in STEM, especially as a "hook" to gain their initial interest in STEM.

Teachers reported that though it was difficult to say for sure what a long-term impact of the VR lessons would be on the short timeline of the study, they felt that Nano: Cell did have potential to support students' interest in STEM. Some teachers described the VR as a "hook" to grab student interest that might then lead to more interest in STEM in the long run. When asked if Nano: Cell would have a long-term impact on student interest in STEM one teacher replied saying:

"I can't say for sure because I haven't had any one-on-one conversations, but I'm pretty sure that this will be one of those memorable experiences. One of those things they'll remember they did, versus our normal humdrum day-to-day things, or even my best lab, they probably won't even remember that, but they will remember this activity. Will they remember what they learned? Not sure. But I think with a quick reminder, it'll come back, type of thing."

Teachers did acknowledge that the novelty of the VR lessons was a big part of what made the lessons so engaging, but they thought that even once the novelty wore off, students seemed more invested and interested in learning about the content. One teacher noted that they thought it may have inspired some students to think about careers in video game design and computer programming. Another teacher noticed more engagement on her normal paper assignments that she used on days when they were not using VR:

> *"I think majority of them actually appreciated learning science more. They are positive going into the classroom, they're always excited, 'Miss, are we going to use that VR today?' Because I supplemented with paper assignments sometimes. … So, on the days that we have to do paper assignments, … I feel like they're more confident in answering the questions when we do practice on the protein synthesis chart…They're learning more, they're appreciating learning more, and they're engaged with the activities that we do, with the VR, and then also as I supplemented with other assignments."*

While not all students noticed a difference in the way they think about science when asked in focus groups, some students reported that they felt like the Nano: Cell lessons increased their interest in STEM. One student described their experience saying:

> *"I just found it really interesting the way the cell works and it honestly got me more intrigued in science and things like that. And I kind of want to go in that field because there's just so much to learn about the cell and the body and what it does."*

These findings are also reflected in the student survey questions about science attitudes, interest, and confidence. Before students started their pre and post assessments, they were asked to voluntarily respond to a number of survey questions. All of the survey questions asked students to respond to statements with a choice on a five-point scale. The survey question responses were then grouped by theme to create composite variables.

Table 2a below shows the results for regression analysis on composite variables. The table shows near significant results for the science attitude construct (Sci_Attitude) with a p-value of .05. Other composite variables showed no significant results.

Table 2a. Adjusted Means and T-Test Values for Constructs

	Control	Treatment	Difference	T-test	P-Value
Confidence	5.155	5.207	0.052	0.746	0.469
Attitude	**4.109**	**4.257**	**0.147**	**2.156**	**0.050**
Identity	3.666	3.808	0.143	1.493	0.159
Mindset	6.844	6.861	0.016	0.196	0.848

Note: no constructs showed statistically significant results at the .05 alpha level.

Several individual items showed significant results with respect to treatment group status. This included one item from composite construct one (Sci_Confidence), two from composite construct two (Sci_Attitude), and one item from construct three (Sci_Identity). Table 2b below shows the results for four items which had significant or near significant results. Treatment students showed higher scores on all of these items than did students in the comparison group, while controlling for pre score.

Table 2b. Adjusted Means and T-test Values for Survey Items With Significant Findings

	Control	Treatment	Difference	T-test	P-Value
Explain my reasoning using relevant information. (SQ1_5)	6.391	6.593	0.202	2.599	0.022*
I find science enjoyable. (SQ2_1)	4.675	4.964	0.289	3.952	0.002*
Science is just NOT interesting to me. (SQ2_2.R**)	6.058	6.352	0.294	2.476	0.028*
I consider myself a science person. (SQ3_2)	3.864	4.036	0.173	2.101	0.056†

***indicates statistical significance at the .05 alpha level.**

****items with "R" in the item code name were reverese coded.**

† indicates near statistical significance (< .10)

The findings in the above table are all significant or near significant at the .05 alpha level. Note that 20 analyses in total were run on the survey items and their composite variables. With a Bonferroni adjustment, the adjusted alpha cutoff would be .0025. With this in mind, item SQ2_1 would retain its statistical significance, though *other* items would not be considered significant with this more conservative cutoff. These findings suggest that at the end of the intervention period students who used VR felt greater confidence and more positive towards science.

Gamified learning was engaging and motivating for students.

Students and teacher felt that the game-like aspects of the VR lessons enhanced the engagement for students and increased their motivation to do well. Teachers mentioned that students getting a score at the end, specifically the number of stars, was motivating for their students. They wanted to try again to achieve a higher score and in the process were practicing science concepts. One teacher shared:

> *"I think just there was more engagement, so automatically there was this hook of I want to learn this because it looks like a video game. It's something that I'm used to from home. And once they were playing the video game, they got to see what DNA looks like, what a ribosome looks like, because we've talked about it in class before, but when they're actually in it and actually can see what the job it's doing, and how they're able to*

successfully get points and stuff like that, and pass these levels, I think just the whole aspect of this gamer mindset just made it more intriguing for them."

Other teachers also noted that the specific game-like aspects were familiar to students who play other video games, which made them more engaging. Examples teachers gave were the wristband of nitrogen bases on the students' arm, or the decoder in mission control. Students also made comparisons to video games when trying to express what made the VR fun. More than one student noted that parts of the VR lesson were just like a popular cooking game, while others noted that the timed aspects made the lesson more engaging and challenging:

"Student: The intensity of when we were fighting the virus. It felt like the timer, it was making me sweaty.
Interviewer: You liked having that challenge of the time?
Student: I like that challenge. It would make your brain think fast. Improve your brain skills."

Teachers noticed increased communication, fewer absences, and more attention from students when using VR.

A notable trend across all teacher interviews is that teachers noticed students communicating and collaborating more than they normally do during traditional lessons. Teachers saw this as additional evidence of engagement. As one teacher put it:

"They're all very engaged. I really like that some of them are learning some of the vocabulary for what they are doing. And what I also like is that they're helping each other. So it's just one of me, and so they're able to ask other peers like, 'Okay, I'm in stage three and I'm stuck here. I don't know what to do next.' And then you'll have other groups coming over and helping each other. And so none of them are just waiting for nothing. They're all actively trying to figure it out. They're all actively doing it, and they're actually very engaged."

Multiple teachers also specifically noticed that on days when students were using Nano: Cell, none of the students were on their phones. Their students were engaged for the duration of the class period and were attentive to the lessons without being distracted.

"I didn't have a single student pull out their phone or anything like that. Everyone wanted to be involved. They were like, oh, hurry, so I could get my turn for stage two and all that stuff. Everyone wanted to participate. Everybody was like, oh, wow, how cool, all the graphics and everything. I think visually they really, really loved it and stayed engaged the whole period for sure."

A few teachers interviewed also noticed that their attendance rates were higher than usual during the study period when the students were using Nano: Cell. More than one teacher overheard students mention that they came to class specifically because they knew they would be working on the VR that day.

Some teachers noticed a decrease in student engagement during later stages or after technical glitches.

Some teachers noticed that after the first few lessons, student engagement fell off somewhat. This was especially notable to teachers during lessons five and six. One teacher felt that student interest declined because the lessons were similar in nature:

> *"Some students, because of the repetitive nature of the stages, they felt like, 'Oh, I did this already and I don't need to do it again.' And that's why I want to be able to see what levels that each student has completed to ensure that they've actually completed because I feel like at the end it, the interest kind of dropped off because of the repetitive nature. But I think that it is important to repeat information so that they can truly, truly grasp it and it gets in their long term memory. But these are 14, 15 year old kids."*

Other teachers saw engagement begin to wane due to technical glitches that frustrated students. Some of the glitches were in the actual lessons, while others were due to the Wi-Fi issues in the district or school. Regardless of the reason, the glitches had a negative effect on engagement for some students:

> *"I think it started as, 'Oh my gosh, this is new. I'm excited,' and I think that was the hook that they needed to just kind of stay invested, but I did see a couple students who towards maybe by stage three, some of them were kind of like, I guess, their interest was lessening from the game, … but when I talked to them, it was mainly because of the glitches involved in the game. So, they were kind of just tired of that."*

Technical glitches were especially prevalent in the first days of the lessons, which put a damper on the initial excitement that some students experienced at using the VR.

Some students preferred to remain as mission control or were hesitant to try VR.

Some teachers reported that they had students who were hesitant to try on the VR headsets at first but did end up enjoying the experience after some additional help with how to use the controls. Others did not care for the feeling of the VR, even after trying it, as it made them feel dizzy or sick. In general teachers reported that this represented a small portion of their classes. There were other students however, who simply did not want to do the VR part of the lesson and preferred to stay as mission control. One teacher explained this:

> *"I started noticing that a lot of the males wanted to do the VR. They wanted to be the drone pilot, and sometimes I would even notice like, 'Hey, you guys never even switched.' So that I feel like some students prefer to just be on the computer, so they missed the whole experience from using the VR set, and a lot of times it was my male students who would gravitate towards using the VR set. They would prefer doing that than the mission control. But there became a point where I started noticing some students who weren't*

touching the VR set at all for two stages, and I didn't know if they were still getting the same content."

For this teacher, they felt like it would be ok if there were students who were not as interested in using the VR and wanted to stay as mission control, but it was unclear whether the students would get the same content exposure. For that reason, the teacher was more persistent in trying to get the reluctant students to try the VR than they might otherwise have been.

3) *Classroom Use* – Can teachers and students successfully use the Nano: Cell VR app, the Lighthaus Web Station "Mission Control", and associated teacher resources?

Are there barriers to classroom use at scale? Is Nano cost effective?

Teachers and students were asked to provide feedback on their use of Nano: Cell in the classroom across a variety of areas, including interfacing with the VR technology, curriculum, and classroom management.

Overall, students and teachers were able to successfully use Nano: Cell in the classroom with few challenges.

Teachers and students reported that they were able to successfully use Nano: Cell in their classroom, though they did note that there was a learning curve on the first day, as most of them had not used VR before. However, the learning curve was short lived, and students got used to using the VR relatively quickly. One student noted:

> *"For me, I enjoyed being in the VR and needing to figure out how it was and seeing everything in 3D, that was in the VR. But when it's in the mission control, it was a bit more confusing for me because while I could see everything that was happening, it wasn't how it was in the VR. It was pretty much the same concept, but it was just not in the VR and that was a little confusing for me, but eventually I figured it out."*

This sentiment was echoed by several other students in the focus groups, who also noted that they were confused at first, but that their understanding of how to use the VR and mission control improved over time. Teachers also noted that the students were able to adapt quickly to use of the VR and enjoyed the process even if it took a bit of time to get used to. One teacher summarized the experience saying:

> *"I think it went really well. The students were definitely bought in. It did take a little bit of work to adjust at first, but after that it went pretty well. …. I remember one girl the first day, she was, this was so cool, I'm really glad I was able to do this. So I mean, even though the first day was all about just getting acquainted with the technology, they still thought it was really great."*

There were a few teachers who noted that in a small percent of their students, the VR made them feel nauseous or sick. In general, this was only a small number of students per class. In this study, we had two teachers who had participated in a previous version of Nano, and both expressed that they preferred the Nano: Cell over the genetics unit they had tested previously. One teacher noted:

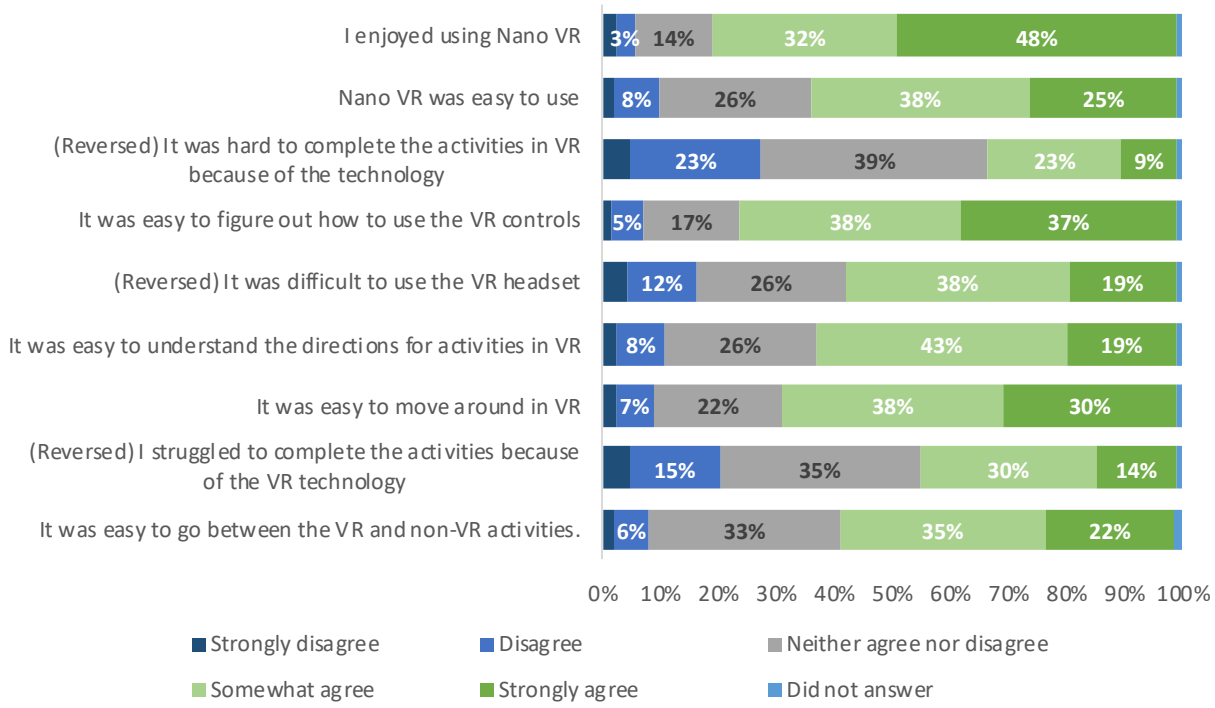
> *"I can compare last time with this time, the topics were different and a lot of other things were. This time I really enjoyed it much, much more, and I think students found it more relevant basically because of two reasons. One, there was actual need for communication between the mission control and the drone pilot whereas the last time when it was not really. The need for WiFi and the connecting of the headsets with the mission control was amazing."*

Both previous participants expressed that they enjoyed the use of the VR more for this subject and felt it was more useful for communicating this subject matter in particular. Other teachers who were trying the VR for the first time echoed these sentiments, and multiple teachers noted that given the opportunity, they would choose to use Nano: Cell again for this content.

> *"If I could do this every year, I think I would for sure. I really liked how the learning was in the hands of the students versus me just sitting up here and lecturing for an hour and a half. I definitely think this was more engaging than any other traditional paper lesson or Google slides. So if I could, I would use this every single year, and then if I could use this for different units in biology, I definitely would too"*

These overall positive experiences are reflected in student survey responses shown in Figures 2 and 3. Most students who used VR agreed that the enjoyed using it (80%), that it was easy to figure out its controls (75%), that it was easy to move around (68%), that it was easy to use (63%), that it was easy to understand the directions (62%), that it was easy to go between VR and non-VR activities (57%), and that it was (NOT) difficult to use the headset (57%).

Figure 2. Student survey feedback on the usability of Nano: Cell (n=274)

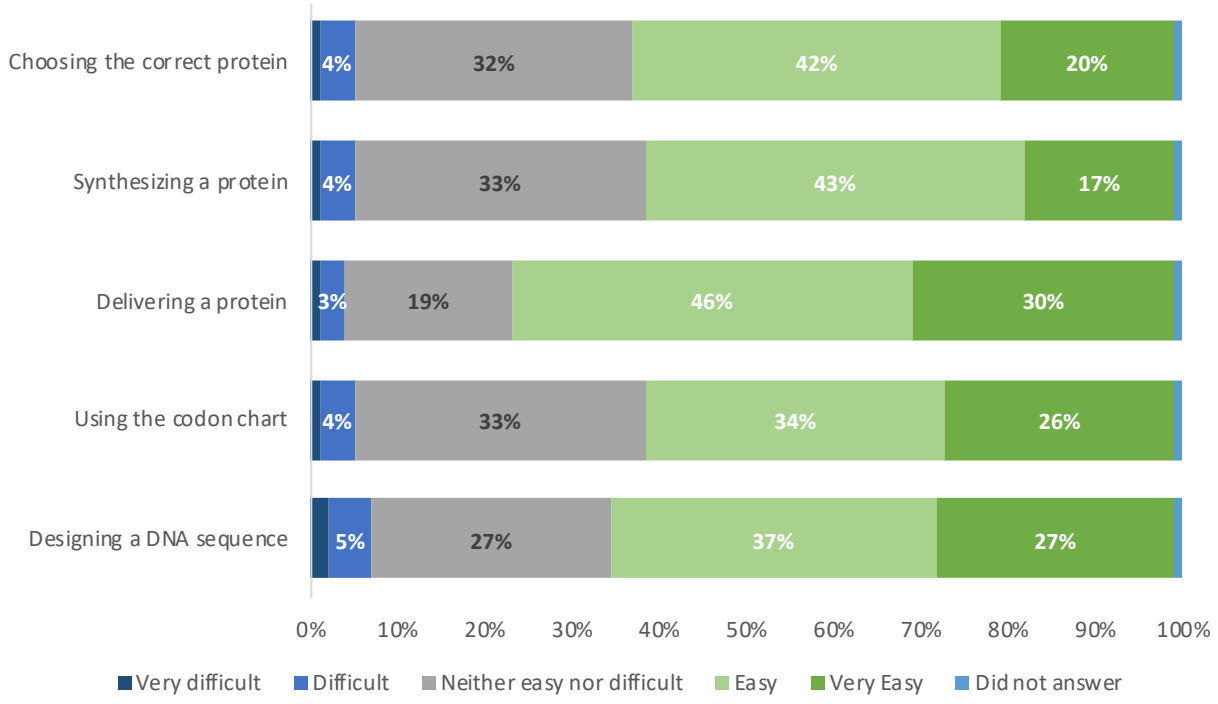


However, less than half of students agreed that they (did NOT) struggle to complete the activities because of the technology (44%) and that it they (did NOT) struggle to complete the activities in VR because of the technology (32%). Independent t-tests were employed to investigate whether student responses to these questions varied depending on whether students had prior experience with virtual reality. The independent t-tests showed no differences in responses between students with and those without prior experience.

These findings suggest that students overall enjoyed the VR experience and that they found it easy to use and understand directions, but that several students encountered technological issues which impeded their ability to complete the activities.

Students were also asked to rate the ease of completing five activities in Nano: Cell. For each activity, the majority of respondents (60% or more) considered the activity to be easy or very easy. The activity considered easiest was delivering a protein, rated as easy by 76% of respondents. The hardest activities were synthesizing a protein and using the codon chart, each rated as easy by 60% of respondents. Together these findings suggest that students overall had a relatively easy experience with various Nano activities.

Figure 3. Student survey feedback on the ease of various Nano activities (n=274)



Teachers reported that students who are learning English and students with and individualized education program (IEP) were able to use Nano: Cell with varying success.

Teachers who had English Language Learners in their classes experienced varying degrees of success with those students using the VR. Multiple teachers noted that their ELL students struggled with the VR because all of the instructions were in English, which made it difficult for them to know what to do in the lessons. According to one teacher:

> *"For the English learners, it was challenging because reading and then following instructions, everything is in English, definitely challenging… For the English learners, it was also difficult to communicate on time with their partner because they're trying to make sense of a lot of things. They're trying to make sense of the words that they're seeing on the screen. Then the drone pilot, what they're listening to. They were definitely working slower. It was more challenging for them than the rest of the students."*

However, one teacher found great success with her ELL students due to the visual nature of the lessons in VR. The visual aspects did not have as much of a language barrier and so students were able to interact with the lessons.

A number of classrooms also included students with IEPs. When asked about how these students fared when engaging with Nano the teachers shared that on the whole these students did not struggle with the VR lessons and may have benefited from the visual and interactive nature of the lessons.

> "*But the students who had IEPs, their accommodations are very common, like individual check-ins and more check-ins than other students and being available to help and all that. I don't think they faced any challenges. I don't think they faced any challenges. In fact, I think it was good for them. It was good for them that they could use the VR headset to learn about otherwise very complicated topic. I think it was actually beneficial for the students with IEPs, at least in my class"*

Other teachers echoed similar experiences, stating that their students with IEPs worked faster than normal, and did not appear to struggle with the VR lessons.

Technical glitches and WiFi issues hindered student use of Nano: Cell and caused implementation delays for teachers.

Teachers noted that there were technical glitches that hindered their implementation of Nano: Cell in the classroom. They found it difficult to troubleshoot the headsets with students since they could not see what students were seeing and most were not comfortable with the technology themselves. One teacher explained how she struggled to troubleshoot saying:

> *"A lot of those, 'Miss, what do I see? I don't see anything.' So I have to attend to students who are asking for help, 'cause in the beginning it could be a lot of them asking, 'Miss, how do you turn it on? How do you do it? I don't see it. I don't see that message that you are saying.''You have confirm the boundary, do you see that?' And, 'No, Miss.' And then I have to try it on too."*

Troubleshooting took a substantial amount of time and effort for teachers, who had to go from group to group especially on day one to try to get students through the first hurdles one at a time. A few teachers had Lighthaus staff in their classroom either virtually or in person and greatly appreciated that additional support. Early technical glitches caused some students to disengage from the activity. One teacher noted this issue saying:

> "*I think there was maybe two or three students that had technical difficulties that really frustrated them. And they just gave up. That's the difference that I saw between the whole class being engaged and then maybe two or three students that just kind of gave up because they couldn't figure it out and they didn't want to. …I think it's tech literacy, I think that is the issue. And they don't want to show their peers that they're not as literate as the others."*

Students brought up the technical glitches in their focus groups as well. They noted a variety of issues with the boundaries being too high, getting stuck behind a wall, or the mission control and headset not connecting to one another. In general students were able to overcome these glitches with troubleshooting or by being patient and trying things more than once, as one student notes:

> *"At first it was a little confusing and there were a few bugs with the VR thing, and it wasn't picking up the little cargo that it needed to. So, I just kept on putting stuff in the Golgi body and then nothing was happening. So, it was a little bit confusing, but once it started working it just made more and more sense as went on."*

One teacher said that they helped frame these glitches by noting that this is what video game testers go through, and that helped the students to be patient when glitches were repeated.

Separate from the headset and program glitches, several teachers ran into major issues with Wi-Fi access and district network security settings. There were several days during the study when the district Wi-Fi was down, and teachers and students were unable to use the lessons as Nano requires an active internet connection for the headset and computers to communicate with each other. This was disruptive for teachers and students who had to delay finishing the lessons and needed to design a new activity for the day. While this was a temporary issue, it may present scalability challenges for districts in areas with less reliable internet service.

Teachers found it challenging to managing student groups, in particular when they had periods of high absences.

One of the main issues that teachers had with Nano: Cell was with the partnering features. Some teachers had issues managing the PINs for students and tracking which student was assigned which PIN. When students were absent, teachers had difficulty figuring out how to pair students with a new partner, or how to create groups of three students working together. When teachers were able to pair up new students, they often ran into other technical issues, as one teacher explains:

> *"For me, challenging was poor student attendance because many students were getting sick. Two partners started, next day one partner didn't show up, so this partner was stuck and then pairing them with another one. Coming back to technology,... If a partner doesn't show up and we were pairing this student with a new partner, then once they connected, in the beginning a lot of them reported that their data wasn't saved, it was gone."*

Other teachers noted that the new partnership would cause the mission control and headsets to have pairing issues. The mission control and headset would not be at the same part in the stage, and they would need to restart to fix the issue. Some teachers also noted that it may be beneficial to not have the same partnerships throughout:

> *"I think I would keep the pairing flexible as well. I can think of, in my one class, there was a pair, they kind of got tired of each other. So, I had to say, 'Okay, you guys could work with somebody else.' So, it was just more management within the classroom that had to change."*

Teachers suggested that having a guide on how to handle student absences, or how to create groups of three as needed would be helpful. The guide could also include troubleshooting steps for syncing issues between new pairings, to make switching partnerships easier if desired.

Managing headset logistics was challenging for teachers.

Several teachers felt that the first day was the most difficult when it came time for students to return their headsets because they had not gotten used to the process yet. As teachers came up with a system for cleaning and storing headsets, they did feel that the process improved. One teacher explained saying:

> *"I would say that the first two days was a bit chaotic. I had all these rules set up. I was like, 'Okay, so you are signing up to work with a partner for the entire lesson and when you bring your VR set up, you have to wipe it down and plug it in and put it in the right place.' … And the last seven minutes of class, the kids are coming up and there's just so many goggles and controllers and there's a long line and the bell's going to ring….So at the end of the day, it was up to me to do that, which was fine. I became faster at doing all of that. And so it was just the first two days where was, it was a bit chaotic, but then I got used to it and it was fine."*

In addition to the process of cleaning and returning the headsets at the end of each day, teachers noted that they did not have space for all the headsets to charge in their classrooms. The charging cords would get tangled and make it difficult for students to find the right charger, or there was no physical space for the headsets to sit while charging. Several teachers suggested that having a cart where the headsets could all charge in the same place would be helpful:

> *"Prior to being one-on-one, we used to have computer carts and so the students would get their computer from a cart and the computer would be plugged in centrally there, but unless you have a system like that, you essentially have to go and plug each one of those in yourself or have a system where students plug them in, but laying around your classroom, I don't know, unless there's like a cart and I know it came in that box, but you couldn't charge while in that box."*

One teacher was equipped with a VR headset cart and expressed fewer logistical issues with equipment.

Teachers also expressed concern that they did not know how long the charge on the headsets would last. Some teachers charged them after every class period because they were unclear on whether the charge would last through two classes in a row. Others noticed that the controller batteries would occasionally die without warning to the students, so they were interrupted in the middle of their work and had to come get batteries from the teacher.

Some teachers struggled with pacing and timing the lessons in their class periods

According to teacher logs, most treatment teachers' class periods lasted 46-60 minutes. For teachers who did not have longer block schedule class periods, fitting lessons into their class periods was sometimes a struggle.

> *"I'm looking at stage three and they're supposed to log in, select a role, and then they're supposed to do levels one through four and then switch and then do levels five and eight and then complete the Schoology activity. I feel like my students can't do all of that in one period. And I don't know if it's just me or my students, we're just slower."*

Other teachers echoed this sentiment, stating that they felt anxious because they were behind schedule. Teachers who had longer classes (75 minutes or more) did not express the same issues with pacing. One teacher who struggled with Wi-Fi issues and had to keep lengthening the time spent on the VR lessons felt like her students lost some of their enthusiasm for the lessons because of the delays. The repeated technical struggles made it harder for students to stay excited about the experience.

4) *Improvement* – How can the student and teacher experiences be improved, and how can they be better integrated into class time and pre-existing curriculum and instruction?

Teachers and students were asked during interviews and focus groups to provide feedback on how Nano: Cell could be improved, including clarifying learning content and refining the user interface.

Teachers suggested providing a printed guide for students to minimize the need for switching between VR and a web page.

Several teachers noticed that students struggled to switch between VR, mission control, and reference materials and resources. This led some teachers to request printed materials in addition to the Google slides that they could give to the students for a quick reference.

> *"I would also prefer, if there's like a printed handout that could, because I can also point them. I know I have the slides and I also made it available to them, the Google slide. So I review that before the lesson. But if there's also a page that we can print and then I can point it out anytime during the session. So something handy or a sheet that they can refer to. Because all this, the materials are online… So they have to go back and forth. Sometimes it would be also better to have something that's, okay, I can just point out, this or that that makes troubleshooting also easy."*

Teachers also noted that having a printed worksheet to have students write down their understanding for the day would help, instead of only having the questions and activities on Schoology.

Teachers found that they needed to frontload the vocabulary and content before sending students in to VR.

The majority of teachers determined that they needed to preteach vocabulary and some of the content for students before having them jump into the VR lessons. The general sentiment from teachers was that after they had reviewed the lessons themselves, they thought that students would be lost or confused in the VR lessons without preparation for the vocabulary they were going to see. One teacher explained saying:

> *"When I looked at the lesson, I'm like, they need some at least those vocabulary …They didn't know about the base pairing rules, transcription base pairing rules, replication base pairing rules so I kind of gave them a crash course Monday and Tuesday, just to front with them with the vocabulary they would need. They did some small lessons related to that, just to get familiar with that and then the cell organelles that would be involved in protein synthesis, just to give them an idea. They did an ed puzzle. So just to give them a background so they would completely not be lost in the VR world"*

Multiple teachers agreed with this feedback and noted that the only modification they made to the lessons was to give a "crash course" in the content prior to starting the lessons with their students. At a minimum almost all teachers introduced the vocabulary that students would see in the VR prior to starting the lessons. Without this introduction teachers felt that students would not be able to understand what they were supposed to do in the VR lessons. This issue could be partially attributed to the fact that many of the study teachers were teaching their genetics unit earlier in the year than they normally would. Most teachers noted that they usually teach cell biology content in the spring rather than the fall. Therefore, it is possible that there would normally be other units that would help introduce or scaffold knowledge for students that would better prepare them for the VR lessons. Some teachers also noted the visuals in the VR lessons looked different than their textbook versions, and so they felt students would need an introduction to know which organelle was which.

Students requested a way to share what each partner is seeing to support communication and collaboration.

Students requested a way for the person in mission control to see what the person in VR was seeing, and vice versa. They suggested a smaller screen in the corner of mission control that would allow them to see what the person in VR was seeing, which would help them communicate better without having to describe what they were seeing to the person who was not in VR.

> *"It would be kind of helpful if in a little bit of the corner for mission control that we could enter and see what the person in VR is seeing."*

Teachers requested a way to see how the students are progressing through the stages such as a teacher dashboard.

Almost all teachers interviewed requested some way to see how the students were progressing through the stages. Teachers noted that there was no way currently to keep track of where students were in the lessons, which hindered time management and the ability to keep all their students at the same or similar pace.

> *"I would like to be able to see in Schoology or the hub where all of my students are; exactly what stage they're in… so that I can manage my time and really get some of the students, if they're behind, really push them to move forward."*

Without any way to see which stage students were on during a given class day, teachers had no way of knowing who was falling behind without walking around and talking to each group. A teacher dashboard would allow for teachers to hold students accountable for completing the VR stages. As currently set up, teachers are unable to confirm that students have completed all the VR lessons.

> *"I wish there was a way for teachers to be able to see exactly what stage and level that each student was in to hold them accountable because I would walk around the room and I'd be like, 'Okay, did you finish level three?' And they'd be like, 'Yeah, yeah.' But I don't know if they really did it because I think sometimes some of the students, they may have not finished the levels. I didn't know if they did."*

If teachers cannot verify that the students completed the VR lessons, it makes it more difficult for them to know what content the students have covered, and what areas are taking longer than others to grasp. Teachers suggested an online dashboard that showed progress in real time as the students were working would be helpful. This would allow them to better manage class time and ensure that all students are completing all aspects of the lessons. One teacher also suggested that it would be beneficial for students to see how far along they were in a lesson as well on a student dashboard, so that they could visualize their progress.

Students requested more control over the narration within the stages.

Many students struggled with the narration within the game. They noted that there was no way for them to control the narration from within the VR. Students sometimes felt that the narration was too loud, and often struggled to balance listening to the narration while being able to communicate with their partner.

> *"The audio was super loud in your ears, and so if your partner was trying to tell you something the sound from the VR would override what they were saying. So then you would miss what was going on in the VR and then you would miss what your partner was saying. So I don't know if we could control when it talks, that would be helpful."*

Students expressed a need to be able to control when the narration happens, to stop and start the narration on demand, and be able to repeat the narration instructions if they needed to hear something again. Multiple students also requested subtitles to help with clarity in the instructions and for those who struggled with the audio. Some students suggested that if they were stuck for long periods of time,

it might be helpful for the narration to automatically offer another instruction, or for there to be a "help" button that students could push to get a prompt on what to do next.

Teachers felt that the training was helpful, but would have benefited from a longer session that focused on instruction rather than the technological elements. They requested more concrete steps outlined for working through the lessons with students, and more time to work through lessons in the training.

Overall teachers found the in-person training to be helpful. They valued the opportunity to try out the VR lessons with others and see what the lessons looked like on the headsets. Many teachers who had not tried out the VR technology before were nervous about being able to teach using it, but having the in-person experience was helpful in alleviating some of that anxiety:

> *"The in-person training helped a lot, because without me having tried it, I would be very nervous and anxious of teaching it. But being able to see how it is, trying it myself, I'm able to let the kids do it and try it. And also the tips on how to manage, especially if it's a big class, it's important to have that system of making sure that they log in. You give them the advice, they log in, they switch partners, and things like that."*

However, most teachers felt like the training did not go far enough for them to feel completely comfortable when it came to facilitating the VR lessons and providing instruction. They felt that the training was too short and focused too much on explaining how to use the tech rather than on instruction. Teachers suggested spending more time on breaking down how to plan for and facilitate lessons, navigating the curriculum, and managing a classroom of students using the tech to learn. One teacher explained saying:

> *"I think maybe having more than one training for teachers, or if it is one training, having it a little bit longer, so we can go through everything, because I don't know, I feel like I like to be really prepared for what I'm getting myself into, especially if I'm going to be facilitating it. So maybe having a longer in-person training where we can go through all six stages, and also see a mockup of what it looks like on the teacher end, like teacher moves. Teacher should be doing this here. Teacher should be doing that, and it doesn't mean that we have to follow that, but at least we have a general guideline of what it should look like, and then maybe we can adapt from our own teaching style from there, but that would've been really helpful for me."*

Multiple teachers echoed the need to see someone model the teacher role for them. They felt that they were able to learn how the VR headsets worked and appreciated the ability to see things from the student perspective, but they were at a loss for what their own role should be and what their instruction might look like. Some teachers tried to practice at home with others in their household, but for those without a willing volunteer, it was difficult to practice, and they were unable to practice the teacher role even with a partner. Several teachers suggested that having a guide or quick start one pager with more concrete steps on what they should be doing to start, manage, and complete each lesson, along with best practices for using VR to teach in their classrooms. One teacher suggested that outside of the context of a study it would be helpful to have a community of teachers where they could share ideas on classroom management and tips for using the VR in their classrooms.

Teachers felt that the content was generally aligned to their instruction, however felt that there were areas of central dogma that were missing and not enough supports in catching and addressing misconceptions. Teachers and students also noted that some of the Schoology quizzes presented concepts as having a single answer, when in fact there are multiple.

One teacher in particular felt that there were areas of the central dogma that were missing from the content. They noted specifically the role of tRNA was missing:

> *"I think the role of the tRNA and the amino acids, the genetic, if there was a way to somehow put that in the VR, because I think that part was very brief so they didn't really get the role of the tRNA and that it carries only one amino acid and how it selects the amino acid. I had to supplement that part for them, go over that part a little bit with them. If we can just add that to the program I think it would be perfect because that's the only part they didn't get through the VR that relates to the central dogma."*

This same teacher felt that there was not a clear way to catch common misconceptions that students might be forming during their use of the curriculum. Other teachers did note that they felt like students might not have fully internalized the science, and focused more on the game aspect:

> *"I feel like they learned very surface level things, but I think they missed a lot of in-depth concepts, concepts that I wish they would've retained a little bit more. It became more of I'm just clicking on the debris. I'm just doing this, because it's what I've been doing and not really I know why I'm doing it, if that makes sense. I feel like that was lost."*

This feeling varied among teachers, with some feeling like the VR helped deepen student thinking, while others thought the game aspects of the VR were more of the focus than the science for their students. Both students and teachers did note that the quizzes were occasionally too rigid in their definition of correct responses. One student noted:

> *"Quizzes were also a little bit confusing because on some of the questions it only had one correct answer when in reality there's a bunch of different ways you could do it. So, it was a little bit confusing, but I think for the most part it was fine."*

Teachers also called out specific examples in the quizzes where they felt there were multiple options that could have been correct responses, but only one was given credit as the "correct" response. They suggested that partial credit might be helpful as well, for students who demonstrate knowledge, but do not necessarily choose the correct response.

5) *Potential for Informal and Out-of-School Learning* – Does Nano: Cell show promise as an effective and attractive learning experience outside of regular classroom instruction?

During interviews teachers were asked to consider whether Nano: Cell could be used successfully outside of a traditional educational setting, such as students working independently at home.

Teachers felt that there was potential for Nano: Cell to be used in informal settings, but with caveats for logistical and equity issues.

When asked about out of school learning opportunities, several teachers responded positively to the idea that Nano: Cell could be used outside of the classroom. However, they also noted that there are some immediate potential issues with that type of use with the lessons as currently designed. The first issue that teachers noted is that it would be difficult for students to use Nano: Cell at home because of the partnering feature. Students might not have an available partner at home to work with and might not have the technology at home to have another partner on a computer to work with, or the necessary Wi-Fi access. The question of tech access also introduces equity issues. One teacher described some possible challenges:

> *"If they are at home, they're going to need a partner. And that could be a challenge finding a partner with two computers. You need to have two computers where one signs in as mission control, one signs is an as a drone pilot. So there's an equity issue too there, right? Because you need to have two people, two computers. That could be a problem."*

Teachers thought that if students were unable to work with a partner, they might lose the communication and collaboration features, which many felt were some of the best aspects of the Nano: Cell program:

> *"It would have to be structured in a way where they can do something solo. But then…part of the thing that I really liked about the paired version was, towards the end, the communication. How the drone pilot had to tell mission control, 'hey, send me this. Hey, send me this. I would like this', type of thing. So there would be less communication in that way."*

Additionally, teachers expressed some concern for students working on Nano: Cell at home where they would not have access to troubleshooting help and guidance from the teachers. Teachers noted that the students would at least need access to the videos, guides, and resources that teachers had in order to troubleshoot, set up their boundary, and other logistical steps. Teachers also noted that without the teacher there to guide students and ensure they are on task, there would be no accountability for doing the activities at home.

> *"Because there would be no way to check on their progress unless you ask them to fill something out or tested them on it. That will detract from the funness of learning by VR. So, you'd have to essentially assign whatever it is, activity as an honor system activity*

and hope that they do it because they're genuinely interested in learning this by way of the VR, not because they have to. But I also see value in, because it's so new, if they had the ability to take it home and keep it safe, they could now immerse their siblings and their parents and pull them into this world of science that maybe gives them a little more insight into what we're doing in our classroom beyond, 'Hey, what'd you do today?'"

Overall, teachers did see potential for Nano: Cell outside of the classroom but noted that there would be several challenges to overcome before it could be used in informal settings.

Conclusions

Although VR is still in early stages of classroom utilization, teachers and students were able to successfully use Nano and its resources with few major challenges. Teachers reported that students were highly engaged in the VR, and student engagement persisted even after the initial novelty of VR wore off. Nano was especially helpful with enhancing the "hands on" aspects of learning about cell biology and protein synthesis, allowing students to see concrete examples of the cell structures and processes that they would not normally have the chance to see. Teachers and students were particularly positive when speaking about being able to visualize transcription and translation.

Teachers and students felt that Nano positively impacted their learning, however there are no statistically significant gains between conditions seen in an analysis of the assessment. While the control group does appear to have a higher average post-assessment score, the difference cannot be conclusively attributed to a number of factors including the fewer parameters placed on control teachers over when they would be teaching the relevant content, technological challenges and lost instructional time in treatment classrooms, and the fact that treatment teachers were relatively inexperienced when it came to facilitating VR lessons. In particular control teachers were asked to teach the content over a period of 2 to 3 weeks between the pre-assessment and the end of the semester (winter break). Both groups were asked to administer the post assessment to students withing 3 days of finishing the relevant content. While most teachers in both groups had to shift around the order of the units they were teaching to meet these parameters, control teachers had more flexibility and extra time to teach content that would usually come before the protein synthesis portion of their curriculum. Treatment students did show near statistically significant increases in science attitudes – suggesting that they were able to connect more positively with the VR learning environment and found science to be more accessible after using VR. Treatment students also enjoyed using Nano VR and found it easy to use the VR controls.

This study shows that while VR in the classroom is feasible, additional development and supports may be needed. Teachers and schools need additional resources and systems to support the technology management, logistics, and space requirements for students using VR in the classroom. Teachers need additional resources to monitor student progress and learning in VR. Teachers need additional training to both learn how to teach with VR learning content and how to manage the additional technology in the classroom. And finally, additional VR learning content, developed from a sound research basis, is needed for teachers, schools, and districts to invest in VR technology for learning.

Lastly, limitations on findings from the summative study should be noted. The initial launch of the study recruitment and teacher onboarding was delayed several weeks due to necessary updates to the VR application and collaborations with the district network security department. The study window also meant that teachers were covering cell biology content that they would typically not teach until the spring term, which may have impacted student knowledge and performance on the pre and post

assessments. Teachers also reported higher than usual absences, in part due to the ongoing COVID-19 pandemic. These delays, coupled with WIFI challenges at the district level, meant that study participants were often running into scheduling challenges with school holidays and end of term finals. This may have resulted in study participants experiencing greater overall fatigue near the end of the study activities.

Further studies on the use of VR technology in the classroom are warranted to see how teachers with additional training or experience with VR, additional supports, or fewer study constraints can teach using VR learning content.

Appendix A. Participant Information

Table 3. Participating Teachers and their Classes

Group	Teacher	# of participating Classes	# of participating Honors or AP Classes	# of Consented Students
Control				
	Teacher N20204	1	1	30
	Teacher N20406	2	0	18
	Teacher N30208	2	2	25
	Teacher N40109	1	1	21
	Teacher N40311	1	0	9
	Teacher N50113	3	0	59
Total				162
Treatment				
	Teacher N10101	3	0	65
	Teacher N20103	2	2	58
	Teacher N20305	2	0	37
	Teacher N30107	2	0	53
	Teacher N40210	3	2	63
	Teacher N40412	1	0	19
	Teacher N50214	3	2	59
Total				354
Total (Treatment & Control)				516

Note. **All participaating schools in LAUSD are Title I schools. Only 1 school had fewer then 85% of their students qualify for Free or Reduced Lunch**

Table 4. Student Assessment Participation Numbers

Group	Teacher	# of Consented Students	Number of Students Participating in Assessments			
			Pre (*started*/**finished**)	Post (*started*/**finished**)	Matched Started both	Matched Finished both
Control						
	Teacher N20204	30	*29* **29**	*27* **27**	26	26
	Teacher N20406	18	*15* **14**	*10* **10**	10	9
	Teacher N30208	25	*22* **22**	*21* **21**	18	18
	Teacher N40109	21	*15* **14**	*17* **17**	12	12
	Teacher N40311	9	*7* **7**	*8* **8**	7	7
	Teacher N50113	59	*39* **37**	*46* **45**	34	32
Total		162	*127* **123**	*129* **128**	107	104
Treatment						
	Teacher N10101	65	*58* **57**	*57* **57**	54	53
	Teacher N20103	58	*51* **50**	*54* **54**	50	49
	Teacher N20305	37	*31* **31**	*26* **26**	24	24
	Teacher N30107	53	*45* **45**	*41* **40**	35	34
	Teacher N40210	63	*56* **56**	*27* **23**	26	23
	Teacher N40412	19	*18* **17**	*16* **16**	16	15
	Teacher N50214	59	*56* **56**	*46* **45**	45	44
Total		354	*315* **312**	*267* **261**	250	242
Total (Treatment & Control)		516	*442* **435**	*396* **389**	357	346

Appendix B. Student Assessment

Assessment Questions and how they were displayed to students

Assessment Overview

- Each Block in this table represents a single page of the only Assessment. Students could only see the items or text on the page of the survey they were currently viewing. They could not preview questions in advance or view questions they had already passed.
- All Assessment questions required a response before students could continue onto the next page of the assessment.
- The text in light grey was not visible to students. It denotes the page breaks in the assessment. Bolded variable names were also not visible to students.
- The correct response to each question is **bolded and highlighted in yellow.**
- Questions that were removed from the final impact analysis are highlighted in green

Start of Block: NIH_Assessment_Questions

assess_text1
The next section will check your understanding of DNA, Proteins, and Protein Synthesis.

We will ask you to answer 29 questions about DNA, Proteins, and Protein Synthesis. Your answers will be kept confidential and will have no effect on your grades in class.

As you advance through the following pages, you will not be able to go back and change your answers on previous pages.
Please read each question carefully and do your best to answer all the questions as best as you can.

Page Break

AQ1

1. Which of the following molecules does not contain genetic information?

- DNA (1)
- mRNA (2)
- **Protein (3)**
- RNA (4)

AQ2

2. Proteins are complex molecules needed for the growth and repair of cells. What is TRUE about where these proteins in multicellular organisms come from?

- These proteins are built by specialized cells for all other cells in the organism to use (1)
- **These proteins are built by each cell for its own use (2)**
- These proteins are not built by the cells; instead, they are taken in from the cell's environment (3)
- These proteins are not built by the cell or taken in from the outside; these proteins are already in the cell (4)

AQ3

3. Which defines a codon?

- A protein that begins transcription by breaking apart H bonds (1)
- A free-floating base that attaches to an open DNA strand (2)
- **The sequence of three bases on mRNA that specify one amino acid (3)**
- The strong bond between two complementary nitrogen bases (4)

AQ4

4. How many different types of nucleotides are used to make DNA molecules?

- One type (1)
- Two types (2)
- **Four types (3)**
- Twenty types (4)

AQ5

5. How many nucleotides are needed to code for one amino acid?

- One (1)
- **Three (2)**
- Four (3)
- Twenty (4)

AQ6

6. Which of the following statements is true?

- DNA is made up of proteins (1)
- Proteins are made up of DNA (2)

- DNA is made up of amino acids (3)
- **Proteins are made up of amino acids (4)**

Page Break

AQ7

7. Gene mutations can be caused by many things. These mutations are biologically important because they

- Occur at regular rate and therefore can be controlled (1)
- Can be passed to the offspring if they occur in any cell of the body (2)
- Are always harmful and therefore help to eliminate weak traits (3)
- **Can result in a new variety of gene combinations in the species (4)**

AQ8

8. Which of the following could be affected by the information in the DNA molecules of an organism?

- **Both an organism's physical characteristics and the function of the organism's cells (1)**
- An organism's physical characteristics but not the function of the organism's cells (2)
- The function of the organism's cells but not the organism's physical characteristics (3)
- Neither an organism's physical characteristics nor the function of the organism's cells (4)

AQ9

9. Some events that take place during the synthesis of a specific protein are listed below.

A. Messenger RNA attaches to a ribosome
B. DNA serves as a template for RNA production
C. Transfer RNA bonds to a specific codon
D. Amino acids are bonded together
E. RNA moves from the nucleus to the cytoplasm

What is the correct order of these events?

- **BEACD (1)**
- DAECB (2)
- BCEDA (3)
- CBAED (4)

Page Break

AQ10

First Letter	Second Letter: U	Second Letter: C	Second Letter: A	Second Letter: G	Third Letter
U	**UUU** Phenylalanine **UUC** Phenylalanine **UUA** Leucine **UUG** Leucine	**UCU** Serine **UCC** Serine **UCA** Serine **UCG** Serine	**UAU** Tyrosine **UAC** Tyrosine **UAA** STOP **UAG** STOP	**UGU** Cysteine **UGC** Cysteine **UGA** STOP **UGG** Tryptophan	**U** **C** **A** **G**
C	**CUU** Leucine **CUC** Leucine **CUA** Leucine **CUG** Leucine	**CCU** Proline **CCC** Proline **CCA** Proline **CCG** Proline	**CAU** Histidine **CAC** Histidine **CAA** Glutamine **CAG** Glutamine	**CGU** Arginine **CGC** Arginine **CGA** Arginine **CGG** Arginine	**U** **C** **A** **G**
A	**AUU** Isoleucine **AUC** Isoleucine **AUA** Isoleucine **AUG** Methionine	**ACU** Threonine **ACC** Threonine **ACA** Threonine **ACG** Threonine	**AAU** Asparagine **AAC** Asparagine **AAA** Lysine **AAG** Lysine	**AGU** Serine **AGC** Serine **AGA** Arginine **AGG** Arginine	**U** **C** **A** **G**
G	**GUU** Valine **GUC** Valine **GUA** Valine **GUG** Valine	**GCU** Alanine **GCC** Alanine **GCA** Alanine **GCG** Alanine	**GAU** Aspartic acid **GAC** Aspartic acid **GAA** Glutamic acid **GAG** Glutamic acid	**GGU** Glycine **GGC** Glycine **GGA** Glycine **GGG** Glycine	**U** **C** **A** **G**

10. What amino acids do the following codons code for?

- CUA: (1) ___**Leucine**_____
- AGG: (2) ___**Arginine**_____
- UAC: (3) ___**Tyrosine**_____

Page Break

AQ11

First Letter	Second Letter: U	Second Letter: C	Second Letter: A	Second Letter: G	Third Letter
U	**UUU** Phenylalanine **UUC** Phenylalanine **UUA** Leucine **UUG** Leucine	**UCU** Serine **UCC** Serine **UCA** Serine **UCG** Serine	**UAU** Tyrosine **UAC** Tyrosine **UAA** STOP **UAG** STOP	**UGU** Cysteine **UGC** Cysteine **UGA** STOP **UGG** Tryptophan	**U** **C** **A** **G**
C	**CUU** Leucine **CUC** Leucine **CUA** Leucine **CUG** Leucine	**CCU** Proline **CCC** Proline **CCA** Proline **CCG** Proline	**CAU** Histidine **CAC** Histidine **CAA** Glutamine **CAG** Glutamine	**CGU** Arginine **CGC** Arginine **CGA** Arginine **CGG** Arginine	**U** **C** **A** **G**
A	**AUU** Isoleucine **AUC** Isoleucine **AUA** Isoleucine **AUG** Methionine	**ACU** Threonine **ACC** Threonine **ACA** Threonine **ACG** Threonine	**AAU** Asparagine **AAC** Asparagine **AAA** Lysine **AAG** Lysine	**AGU** Serine **AGC** Serine **AGA** Arginine **AGG** Arginine	**U** **C** **A** **G**
G	**GUU** Valine **GUC** Valine **GUA** Valine **GUG** Valine	**GCU** Alanine **GCC** Alanine **GCA** Alanine **GCG** Alanine	**GAU** Aspartic acid **GAC** Aspartic acid **GAA** Glutamic acid **GAG** Glutamic acid	**GGU** Glycine **GGC** Glycine **GGA** Glycine **GGG** Glycine	**U** **C** **A** **G**

11. Imagine you want to create a protein that has the following amino acid sequence: Arginine, Lysine, Valine. Write an mRNA sequence that would code for this protein:

- Codon 1 (1) __**CGU, CGC, CGA, CGG, AGA, or AGG**_____
- Codon 2 (2) __**AAA or AAG**_____
- Codon 3 (3) __**GUU, GUC, GUA, or GUG**_____

Page Break

AQ12

12. What do DNA and proteins have to do with each other?

- DNA is a type of protein (1)
- Proteins are a type of DNA (2)
- **DNA provides information for making proteins (3)**
- DNA and proteins have nothing to do with each other (4)

AQ13

13. During the process of transcription, which of the following is produced?

- Sugar (1)
- ATP (2)
- **mRNA (3)**
- DNA (4)

AQ14

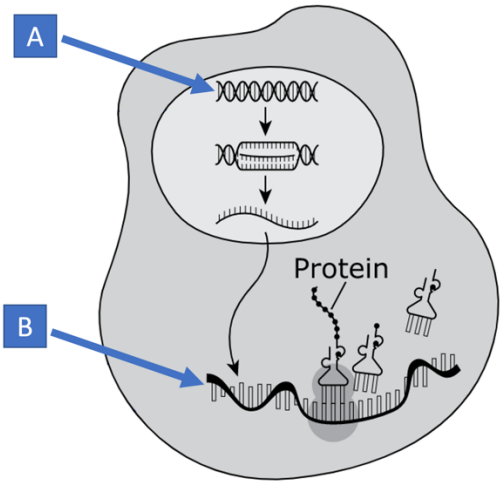
14. How are proteins made in an organism?

- Smaller subunits are randomly linked together to form proteins (1)
- **A code indicates which smaller subunits get linked together to form proteins (2)**
- A code indicates which larger molecules get broken apart to form proteins (3)
- Organisms eat proteins, but they do not make proteins (4)

Page Break

AQ15

15. The enzyme lactase is needed for a person to be able to digest sugar in dairy products, such as cow's milk. The model shows how the enzyme lactase is produced by a cell.



Drag and drop the two correct labels from the word bank into the corresponding boxes for molecules **A** and **B** (as indicated in the diagram) that are involved in the formation of lactase. (Each label may be used once or not at all)

Molecule A	Molecule B
_____ ATP (1)	_____ ATP (1)
_____ DNA (2)	_____ DNA (2)
_____ Glucose (3)	_____ Glucose (3)
_____ RNA (4)	**_____ RNA (4)**

Page Break

AQ16

16. The actual site of protein synthesis is the

- Nucleus (1)
- Mitochondrion (2)
- Chloroplast (3)
- **Ribosome (4)**

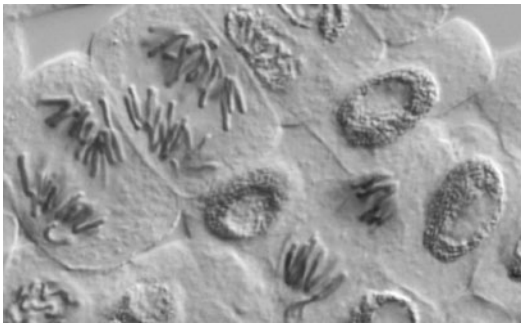
AQ17

17. A certain DNA sequence is ATC CGG AGT GTA. What is its mRNA sequence?

- TAG GCC TCA CAT (1)
- AUC CGG AGU GTA (2)
- **UAG GCC UCA CAU (3)**
- ATC CGG AGT GTA (4)

AQ18

18. A student used a microscope to examine some cells. He observed strands located in the nuclei of these cells.



These strands are responsible for coding different proteins and are known as:

- **Chromosomes (1)**
- Mitochondria (2)
- Ribosomes (3)
- Chloroplasts (4)

Page Break

AQ19

19. What is the role of tRNA during translation?

- Bond to open the DNA strand to carry the code for protein synthesis out of the nucleus (1)
- Carry ribosomes to the site of protein synthesis (2)
- Break apart mRNA and send it back to the nucleus so that it can be reused (3)
- **Carry amino acids to the mRNA for correct placement into the protein chain (4)**

AQ20

20. Traits are passed from parents to offspring. These traits are determined by

- Chromosomes, located on genes, found in the nucleus (1)
- **Genes, located on chromosomes, found in the nucleus (2)**
- Chromosomes, located on genes, found in the ribosomes (3)
- Genes, located on chromosomes, found in the ribosomes (4)

AQ21

21. One similarity between DNA and messenger RNA molecules is that they both contain

- The same sugar (1)
- **Genetic codes based on sequences of bases (2)**
- A nitrogenous base known as uracil (3)
- Double-stranded polymers (4)

AQ22

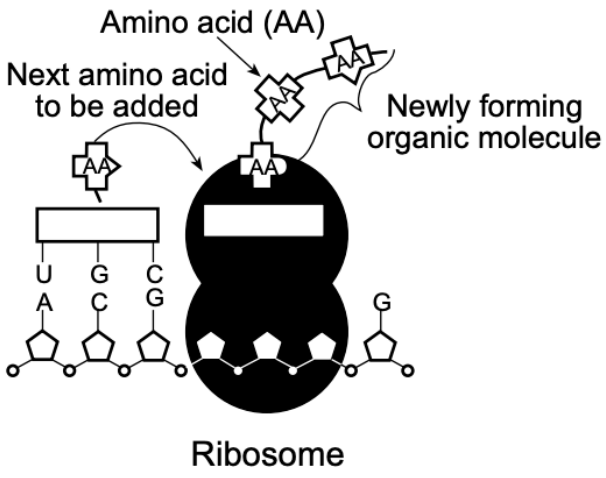
22. The process of translation occurs in which part of a cell?

- Nucleus (1)
- Cell membrane (2)
- **Ribosome (3)**
- Mitochondria (4)

Page Break

AQ23

23. The diagram below represents a process taking place in a cell.

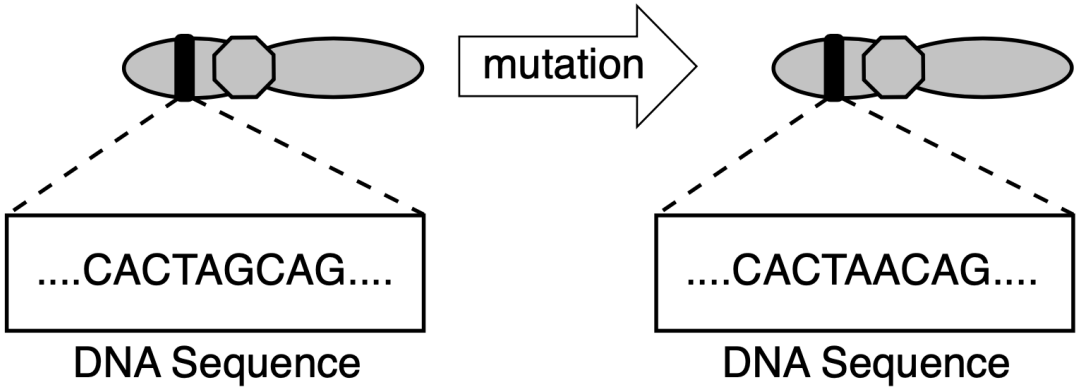


The type of organic molecule that is being synthesized is

- DNA (1)
- Starch (2)
- **Protein (3)**
- Fat (4)

AQ24

24. The diagram below represents one of a number of different types of mutations that can occur in DNA.



This mutation can best be described as the

- Pairing of an adenine (A) base with thymine (T) (1)
- The insertion of an adenine (A) base into both strands of the DNA molecule (2)
- **The substitution of an adenine (A) base for guanine (G) (3)**
- Deletion of an adenine (A) base from the DNA molecule (4)

Page Break

AQ25

25. Which of the following is TRUE about genes?

- Genes are traits (1)
- Genes are proteins (2)
- **Genes are sequences of nucleotides (3)**
- Genes are sequences of amino acids (4)

AQ26

26. What is the flow of information for the synthesis of proteins according to the central dogma?

- DNA to mRNA to protein (1)
- **DNA to mRNA to tRNA to protein (2)**
- DNA to protein to mRNA (3)
- DNA to tRNA to protein (4)

AQ27

27. What process transfers heritable material to the next generation?

- **Replication (1)**
- Splicing (2)
- Transcription (3)
- Translation (4)

AQ28

28. Mitochondria provide ribosome with

- **ATP for protein synthesis (1)**
- Amino acids for protein synthesis (2)
- Oxygen for respiration (3)
- Carbon dioxide for the production of RNA (4)

AQ29

29. What does the information in DNA molecules provide instructions for?

- **Assembling amino acids into protein molecules (1)**
- Assembling protein molecules into amino acids (2)
- Rearranging genes into protein molecules (3)
- Rearranging genes into traits (4)

End of Block: NIH_Assessment_Questions

Appendix C. Student Survey

Survey Items and Additional Survey Tables

Table 5. Survey Questions and Composite Variable Groupings

Composite	Survey Question	Response Scale
	Matrix Question 1: How confident are you that you can do the following things:	
Sci_Confidence	Figure out the reasons why things happen in nature.	1 = Not at all confident, 2 = A little confident,
	Look at the data that I collect and see how it fits together.	3 = Somewhat confident, 4 = Confident,
	Connect the things that I am learning about in science with what I already know.	5 = Very confident
	Figure out what causes changes in a cell.	
	Explain my reasoning using relevant information.	
	Test out different ideas and work to improve them.	
	Matrix Question 2: How much do you agree or disagree with the following statements?	
Sci_Attitude	I find science enjoyable	1 = Strongly Disagree, 2 = Disagree,
	Science is just NOT interesting to me	3 = Neither agree nor disagree, 4 = Somewhat agree,
	I like doing work in my science class	5 = Strongly agree
	I like learning new things in science.	
	I am curious about science.	
	Matrix Question 3: How much do you agree or disagree with the following statements?	
Sci_Identity	You can always change how much science ability you have.	1 = Strongly Disagree, 2 = Disagree,
	I consider myself a science person.	3 = Neither agree nor disagree, 4 = Somewhat agree,
Sci_Mindset	I am sure of myself when I do science.	5 = Strongly agree
	You can learn new things in science, but you can't really change your basic science	
	I can see myself being involved in a science-related career.	

A correlation matrix of all the survey items as well as composite variables showed that only the statements in matrix question 1 (Sci_Attitude items) showed a noticeably high positive correlation to each other.

Despite lack of strong correlation for a majority of the survey items, the same single level regression analysis that was run on student post assessment scores was also run on all of the survey items as well as the composite variables. The Sci_Attitude composite variable had close to significant results with a p value of .05 as seen in Table 6.

Table 6. T-test of Coefficients for Science Matrix Questions

T test of coefficients for Science Confidence				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.369	0.189	7.241	0.000*
Tx Group	0.052	0.070	0.746	0.469
Pre-Survey Score	0.596	0.058	10.234	0.000*
Multiple R-squared: 0.337, Adjusted R-squared: 0.333				
F-statistic: 69.47 on 2 and 13 DF, p-value: 1.147e-07				
T-test of coefficients for Science Attitudes				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	0.916	0.171	5.370	0.000*
Tx Group	0.147	0.068	2.156	0.050
Pre-Survey Score	0.696	0.044	15.670	0.000*
Multiple R-squared: 0.440, Adjusted R-squared: 0.437				
F-statistic: 137.2 on 2 and 13 DF, p-value: 1.821e-09				
T-test of coefficients for Science Identity				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	0.960	0.197	4.882	0.000*
Tx Group	0.143	0.095	1.493	0.159
Pre-Survey Score	0.679	0.053	12.906	0.000*
Multiple R-squared: 0.485, Adjusted R-squared: 0.483				
F-statistic: 83.39 on 2 and 13 DF, p-value: 3.84-e08				
T-test of coefficients for Science Mindset				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.788	0.229	7.809	0.000*
Tx Group	0.016	0.082	0.196	0.848
Pre-Survey Score	0.502	0.063	8.013	0.000*
Multiple R-squared: .0270, Adjusted R-squared: 0.266				
F-statistic: 32.45 on 2 and 13 DF, p-value: 8.827e-06				

Table 7. Pre and Post Student Survey Outcomes by Item – Matrix Question 1

Matrix Question 1	Time	Group	n	mean	sd	shift
Figure out the reasons why things happen in nature (SQ1_1)	Pre	Cx	108	3.04	0.90	0.11
	Post	Cx	108	3.15	0.87	
	Pre	Tx	258	3.25	0.93	0.03
	Post	Tx	258	3.29	0.91	
Look at the data that I collect and see how it fits together (SQ1_2)	Pre	Cx	108	3.09	0.92	0.19
	Post	Cx	108	3.28	0.88	
	Pre	Tx	258	3.42	0.86	0.09
	Post	Tx	258	3.51	0.88	
Connect the things that I am learning about in science with what I already know (SQ1_3)	Pre	Cx	108	3.30	0.98	0.03
	Post	Cx	108	3.32	0.85	
	Pre	Tx	258	3.57	0.92	-0.04
	Post	Tx	258	3.53	0.92	
Figure out what causes changes in a cell (SQ1_4)	Pre	Cx	108	2.85	0.97	0.28
	Post	Cx	108	3.13	0.82	
	Pre	Tx	258	2.98	1.05	0.31
	Post	Tx	258	3.29	0.94	
Explain my reasoning using relevant information (SQ1_5)	Pre	Cx	108	3.18	1.02	-0.05
	Post	Cx	108	3.13	0.91	
	Pre	Tx	258	3.26	0.95	0.11
	Post	Tx	257	3.37	0.90	
Test out different ideas and work to improve them (SQ1_6)	Pre	Cx	108	3.38	1.02	0.05
	Post	Cx	108	3.43	0.90	
	Pre	Tx	258	3.66	0.99	-0.11
	Post	Tx	258	3.55	0.90	

Table 8. Pre and Post Student Survey Outcomes by Item – Matrix Question 2

Matrix Question 2	Time	Group	n	mean	sd	shift
I find science enjoyable (SQ2_1)	Pre	Cx	108	3.81	0.88	-0.35
	Post	Cx	108	3.45	0.98	
	Pre	Tx	258	3.92	0.94	-0.10
	Post	Tx	258	3.81	1.02	
Science is just NOT interesting to me (SQ2_2.R)	Pre	Cx	108	3.38	0.96	-0.25
	Post	Cx	108	3.13	1.01	
	Pre	Tx	258	3.75	1.06	-0.16
	Post	Tx	258	3.59	1.07	
I like doing work in my science class (SQ2_3)	Pre	Cx	108	3.33	0.96	0.04
	Post	Cx	108	3.37	0.90	
	Pre	Tx	258	3.63	0.97	-0.06
	Post	Tx	258	3.57	1.00	
I like learning new things in science (SQ2_4)	Pre	Cx	108	4.04	0.91	-0.19
	Post	Cx	108	3.84	0.82	
	Pre	Tx	258	4.14	0.85	-0.12
	Post	Tx	258	4.02	0.91	
I am curious about science (SQ2_5)	Pre	Cx	108	3.93	0.98	-0.13
	Post	Cx	108	3.80	0.85	
	Pre	Tx	258	4.05	0.92	-0.19
	Post	Tx	258	3.86	0.98	

Table 9. Pre and Post Student Survey Outcomes by Item – Matrix Question 3

Matrix Question 3	Time	Group	n	mean	sd	shift
You can always change how much science ability you have (SQ3_1)	Pre	Cx	108	4.07	0.88	-0.06
	Post	Cx	108	4.01	0.87	
	Pre	Tx	258	3.99	0.91	-0.01
	Post	Tx	258	3.98	0.99	
I consider myself a science person (SQ3_2)	Pre	Cx	108	2.75	1.01	0.04
	Post	Cx	108	2.79	1.01	
	Pre	Tx	258	2.98	1.04	0.12
	Post	Tx	257	3.10	1.01	
I am sure of myself when I do science (SQ3_3)	Pre	Cx	108	3.07	0.88	0.09
	Post	Cx	108	3.17	0.90	
	Pre	Tx	258	3.26	0.90	0.09
	Post	Tx	258	3.35	0.88	
You can learn new things in science, but you can't really change your basic science ability (SQ3_4.R)	Pre	Cx	108	3.01	1.06	0.11
	Post	Cx	108	3.12	1.08	
	Pre	Tx	258	3.05	1.04	0.11
	Post	Tx	258	3.16	1.07	
I can see myself being involved in a science-related career (SQ3_5)	Pre	Cx	108	2.95	1.19	-0.06
	Post	Cx	108	2.89	1.07	
	Pre	Tx	258	3.17	1.28	0.07
	Post	Tx	258	3.24	1.22	

Table 10. Student Survey Outcomes by Composite Variable – Pre and Post

Composite Variables	Time	Group	n	mean	sd	shift
Sci_Confidence	Pre	Cx	108	3.14	0.68	0.10
	Post	Cx	108	3.24	0.69	
	Pre	Tx	258	3.36	0.73	0.06
	Post	Tx	258	3.42	0.76	
Sci_Attitude	Pre	Cx	108	3.64	0.71	-0.19
	Post	Cx	108	3.45	0.71	
	Pre	Tx	258	3.86	0.73	-0.11
	Post	Tx	258	3.75	0.80	
Sci_Identity	Pre	Cx	108	2.93	0.87	0.02
	Post	Cx	108	2.95	0.83	
	Pre	Tx	258	3.14	0.90	0.10
	Post	Tx	258	3.23	0.89	
Sci_Mindset	Pre	Cx	108	3.54	0.82	0.02
	Post	Cx	108	3.56	0.76	
	Pre	Tx	258	3.52	0.78	0.05
	Post	Tx	258	3.57	0.76	

Table 11. Student Survey Outcomes – Nano Specific Survey Items

Matrix Question 5	Time	Group	n	mean	Sd
I enjoyed using Nano VR (SQ5_1)	Post	Tx	271	4.22	0.95
Nano VR was easy to use (SQ5_2)	Post	Tx	271	3.77	0.98
It was hard to complete the activities in VR because of the technology (SQ5_3.R)	Post	Tx	271	3.10	1.02
It was easy to figure out how to use the VR controls (SQ5_4)	Post	Tx	271	4.05	0.95
It was difficult to use the VR headset (SQ5_5.R)	Post	Tx	271	3.56	1.06
It was easy to understand the directions for activities in VR (SQ5_6)	Post	Tx	271	3.69	0.96
It was easy to move around in VR (SQ5_7)	Post	Tx	271	3.88	0.99
I struggled to complete the activities because of the VR technology (SQ5_8.R)	Post	Tx	271	3.34	1.05
It was easy to go between the VR and non-VR activities (SQ5_9)	Post	Tx	270	3.71	0.95
Matrix Question 6	**Time**	**Group**	**n**	**mean**	**Sd**
Understanding how proteins are made (SQ6_1)	Post	Tx	271	3.70	0.93
Understanding what amino acids are (SQ6_2)	Post	Tx	271	3.57	0.93
Understanding how DNA determines the structure of a protein (SQ6_3)	Post	Tx	271	3.71	0.91
Understanding the difference between mRNA, RNA, and tRNA (SQ6_4)	Post	Tx	271	3.73	0.95
Understanding the different functions proteins carry out in the body (SQ6_5)	Post	Tx	271	3.81	0.97

Matrix Question 7	Time	Group	n	mean	Sd
Choosing the correct protein (SQ7_1)	Post	Tx	271	3.77	0.85
Synthesizing a protein (SQ7_2)	Post	Tx	270	3.73	0.83
Delivering a protein (SQ7_3)	Post	Tx	271	4.03	0.82
Using the codon chart (SQ7_4)	Post	Tx	271	3.81	0.92
Designing a DNA sequence (SQ7_5)	19	271.00	271	3.84	0.96

Table 12. T-test of Coefficients for Individual Questions

T-test of coefficients for SQ 1_1: Figure out the reasons why things happen in nature.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.833	0.132	13.919	0.000*
Tx Group	0.046	0.070	0.650	0.527
Pre-Survey Score	0.433	0.044	9.800	0.000*
Multiple R-squared: 0.1993 , Adjusted R-squared: 0.1949				
F-statistic: 58.23 on 2 and 13 DF, p-value: 3.25e-07				
T-test of coefficients for SQ 1_2: Look at the data that I collect and see how it fits together.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	2.025	0.203	9.958	0.000*
Tx Group	0.100	0.099	1.017	0.328
Pre-Survey Score	0.405	0.059	6.820	0.000*
Multiple R-squared: 0.1751 , Adjusted R-squared: 0.1706				
F-statistic: 24.22 on 2 and 13 DF, p-value: 4.127e-05				
T-test of coefficients for SQ 1_3: Connect the things that I am learning about in science with what I already know.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.983	0.207	9.557	0.000*
Tx Group	0.094	0.075	1.252	0.233
Pre-Survey Score	0.407	0.055	7.346	0.000*
Multiple R-squared: 0.189 , Adjusted R-squared: 0.1845				
F-statistic: 28.78 on 2 and 13 DF, p-value: 1.679e-05				
T-test of coefficients for SQ 1_4: Figure out what causes changes in a cell.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	2.221	0.138	16.119	0.000*
Tx Group	0.123	0.078	1.576	0.139
Pre-Survey Score	0.319	0.040	7.958	0.000*
Multiple R-squared: 0.1359 , Adjusted R-squared: 0.1312				
F-statistic: 38.04 on 2 and 13 DF, p-value: 3.693e-06				

T-test of coefficients for SQ 1_5: Explain my reasoning using relevant information.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.832	0.165	11.128	0.000*
Tx Group	0.201	0.078	2.599	0.022*
Pre-Survey Score	0.409	0.057	7.137	0.000*
Multiple R-squared: 0.2062 , Adjusted R-squared: 0.2018				
F-statistic: 169.4 on 2 and 13 DF, p-value: 4.891e-10				
T-test of coefficients for SQ 1_6: Test out different ideas and work to improve them.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	2.330	0.138	16.873	0.000*
Tx Group	0.033	0.120	0.271	0.790
Pre-Survey Score	0.324	0.042	7.724	0.000*
Multiple R-squared: 0.134 , Adjusted R-squared: 0.1292				
F-statistic: 31.05 on 2 and 13 DF, p-value: 1.12e-05				
T-test of coefficients for SQ 2_1: I find science enjoyable.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.066	0.222	4.807	0.000*
Tx Group	0.289	0.073	3.952	0.002*
Pre-Survey Score	0.627	0.052	12.016	0.000*
Multiple R-squared: 0.3494 , Adjusted R-squared: 0.3458				
F-statistic: 72.99 on 2 and 13 DF, p-value: 8.55e-08				
T-test of coefficients for SQ 2_2: Science is just NOT interesting to me. [REVERSED]				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.578	0.247	6.389	0.000*
Tx Group	0.294	0.119	2.476	0.028*
Pre-Survey Score	0.459	0.067	6.850	0.000*
Multiple R-squared: 0.2344 , Adjusted R-squared: 0.2302				
F-statistic: 25.23 on 2 and 13 DF, p-value: 3.346e-05				
T-test of coefficients for SQ 2_3: I like doing work in my science class.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.800	0.219	8.214	0.000*
Tx Group	0.063	0.084	0.742	0.471*
Pre-Survey Score	0.471	0.049	9.581	0.000*
Multiple R-squared: 0.229 , Adjusted R-squared: 0.2247				
F-statistic: 62.44 on 2 and 13 DF, p-value: 2.158e-07				

T-test of coefficients for SQ 2_4: I like learning new things in science.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.913	0.199	9.628	0.000*
Tx Group	0.126	0.103	1.225	0.242
Pre-Survey Score	0.478	0.050	9.606	0.000*
Multiple R-squared: 0.225 , Adjusted R-squared: 0.2207				
F-statistic: 71.53 on 2 and 13 DF, p-value: 9.645e-08				

T-test of coefficients for SQ 2_5: I am curious about science.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.643	0.242	6.781	0.000*
Tx Group	-0.002	0.091	-0.022	0.983
Pre-Survey Score	0.548	0.057	9.669	0.000*
Multiple R-squared: 0.2999 , Adjusted R-squared: 0.296				
F-statistic: 48.42 on 2 and 13 DF, p-value: 9.458e-07				

T-test of coefficients for SQ 3_1: You can always change how much science ability you have.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.983	0.270	7.348	0.000*
Tx Group	0.016	0.093	0.172	0.866
Pre-Survey Score	0.497	0.064	7.713	0.000*
Multiple R-squared: 0.2195 , Adjusted R-squared: 0.2152				
F-statistic: 29.97 on 2 and 13 DF, p-value: 1.353e-05				

T-test of coefficients for SQ 3_2: I consider myself a science person.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.098	0.182	6.034	0.000*
Tx Group	0.173	0.082	2.101	0.056†
Pre-Survey Score	0.614	0.059	10.449	0.000*
Multiple R-squared: 0.4072 , Adjusted R-squared: 0.4039				
F-statistic: 54.96 on 2 and 13 DF, p-value: 4.552e-07				

T-test of coefficients for SQ 3_3: I am sure of myself when I do science.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.833	0.188	9.736	0.000*
Tx Group	0.102	0.111	0.918	0.375
Pre-Survey Score	0.434	0.043	10.172	0.000*
Multiple R-squared: 0.199 , Adjusted R-squared: 0.1946				
F-statistic: 51.74 on 2 and 13 DF, p-value: 6.459e-07				

T-test of coefficients for SQ 3_4: You can learn new things in science, but you can't really change your basic science ability. [REVERSED]				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.940	0.275	7.062	0.000*
Tx Group	0.020	0.112	0.180	0.860
Pre-Survey Score	0.392	0.080	4.881	0.000*
Multiple R-squared: 0.1478 , Adjusted R-squared: 0.1431				
F-statistic: 12.24 on 2 and 13 DF, p-value: 0.001026				

T-test of coefficients for SQ 3_5: I can see myself being involved in a science-related career.				
	Estimate	Standard Error	t-value	p-value
(Intercept) Cx Group	1.077	0.203	5.296	0.000*
Tx Group	0.222	0.132	1.683	0.116
Pre-Survey Score	0.614	0.050	12.344	0.000*
Multiple R-squared: 0.4369 , Adjusted R-squared: 0.4338				
F-statistic: 76.34 on 2 and 13 DF, p-value: 6.535e-08				

***indicates statistical significance at the .05 alpha level.**

† indicates near statistical significance (< .10)