

# **Student Outcomes from the Airborne Astronomy Ambassador Teacher Program:**

Results from Student Assessment in a  
Randomized Controlled Trial during the 2017-  
2018 School Year

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## Executive Summary

Since 2011, the SETI Institute has managed the NASA Airborne Astronomy Ambassadors (AAA) program to provide teachers with professional development experiences regarding airborne infrared astronomy and the practices of scientific research. This includes providing access to NASA content experts and the opportunity to visit and fly on the Stratospheric Observation for Infrared Astronomy (SOFIA). Starting in 2017, the SETI Institute implemented a 10-day curriculum module – hereafter, the NASA AAA curriculum module – for participating teachers to incorporate into their formal classroom curricula. The curriculum module was carefully aligned with national Next Generation Science Standards (NGSS). To assess the impact of this new NASA AAA curriculum module on student learning, the SETI Institute hired WestEd to perform a randomized control trial (RCT) to test student learning related to the electromagnetic spectrum and multi-wavelength astronomy. WestEd developed and administered a student assessment to test the content knowledge of students whose teachers were involved in the AAA program and those who had been selected but wait-listed until the next year to serve as a delayed-treatment comparison group.

The results of this assessment indicate students who experienced the NASA AAA curriculum module performed better on the student assessment than those who did not. Results were based on a total of 2343 students, including 1473 treatment students and 870 control. Hierarchical linear modeling (defined in Appendix A) shows that students exposed to the curriculum did between 1.12 and 1.54 points (out of 23; 5-7%) better on the post-assessment than students not exposed. These results were both statistically significant and substantively meaningful, i.e., meeting the p-value and effect-size thresholds (see page 10, OR see Appendix A) recommended by the Department of Education’s What Works Clearinghouse (WWC 2017). Analyses were performed to look at the effect of the curriculum module when controlling for class characteristics, student characteristics, and the interaction between the curriculum module and student characteristics. The results of each analysis indicated similar results: students who were exposed to the NASA AAA curriculum module performed better than those who were not exposed. This finding was consistent for students of both genders and for

students from under-represented minority groups as well as those not from underrepresented minority groups. No significant interaction was found between the effects of the NASA AAA curriculum module and either gender or ethnicity.

Students were also surveyed on their attitudes towards STEM education and STEM careers. Results indicate students exposed to the NASA AAA curriculum module felt they gained more from their course and showed a larger change in attitudes from the beginning to the end of their course than did students not exposed. This change was largest for questions related to content knowledge – such as knowing about the electromagnetic spectrum, infrared radiation, and infrared astronomy – and to questions related to the collaborative nature of science. Student survey results indicate a lesser impact on student interest in science or science-related careers.

The results of this assessment confirm that the NASA AAA curriculum module had a positive and substantively important impact on student learning outcomes related to the electromagnetic spectrum and infrared astronomy. Study limitations include potential over-alignment between the curriculum and assessment and having only moderate instrument reliability (see Appendix A for definition). Also, only limited information was available regarding how the NASA AAA curriculum module was actually implemented and regarding the “business as usual” instruction that the comparison students received

## Overview and Background

The NASA Airborne Astronomy Ambassadors (AAA) program is a professional development program developed and managed by the SETI Institute. In the current paradigm, the AAA program is aimed at high school science teachers – providing content knowledge regarding the electromagnetic spectrum and infrared astronomy. Started in 2011, the program provides science teachers with hands-on professional development experiences, including a trip to NASA’s Armstrong Flight Research Center and the opportunity to fly on NASA’s premier infrared astronomy observatory, the Stratospheric Observation for Infrared Astronomy (SOFIA), a specialized Boeing 747SP carrying an infrared telescope. Participating teachers called Airborne Astronomy Ambassadors (AAAs) spend a week at the Armstrong Flight Research Center, meet with key scientists, engineers, and technicians, tour instrument and hangar facilities, and spend one to two nights flying aboard SOFIA. Prior to the week at Armstrong, teachers are provided with six months of training. In addition to providing participants with SOFIA flight experiences, AAA professional development includes an online, college-level introductory astronomy course, and webinars providing infrared-specific astronomy tied to SOFIA. The program also gives participants a 1-day in-person training regarding the contents of the SETI Institute-developed NASA AAA curriculum module and pedagogies for teaching it.

Starting in 2017-2018, the AAA program has also included a 10-day curriculum module (the NASA AAA curriculum module) regarding infrared astronomy and the electromagnetic spectrum for Ambassadors to deliver to their students as part of their formal course curricula. This new curriculum module is part of an effort by the SETI Institute to restructure the AAA program to provide more direct impact on student learning in the classroom. The 10-day NASA AAA curriculum module aims to support teaching students about the electromagnetic spectrum and multi-wavelength astronomy . The SETI Institute AAA staff carefully designed the curriculum module to align with national Next Generation Science Standards (NGSS) and the corresponding California Science Framework. The curriculum module makes use of real-world examples of research conducted using SOFIA, teacher experience aboard the aircraft, and by using hands-on activities and investigations tied to the electromagnetic spectrum. The ultimate goal of the

NASA AAA curriculum module is to give students a more in-depth and retainable understanding of the electromagnetic spectrum than is attained in a traditional science course. A secondary aim of the program is to increase students' interest in science education and career paths. The AAA teacher professional development obtained during the intensive SOFIA flight week aimed to provide real-world examples and personal experiences to support teaching of the NASA AAA curriculum module, which incorporated opportunities to include personal AAA stories and learnings. To enhance student connection to real-world research and highlight AAA experience, the curriculum module included three specific instances for teachers to insert details personally observed during their flight week.

The SETI Institute contracted WestEd to serve as external evaluators to the AAA program. WestEd has served as the external evaluator for 6 of the 7 years since the Ambassador program first launched. To most rigorously assess the impact of the NASA AAA curriculum module on student learning outcomes, WestEd worked with the SETI Institute to conduct a randomized control trial (RCT) study on the assessment. To evaluate the impact of the NASA AAA curriculum module on students' content knowledge related to infrared astronomy and the electromagnetic spectrum, WestEd in conjunction with the SETI Institute developed a student content-assessment that WestEd had teachers administer to their students during the 2017-2018 academic year. The assessment was administered both to students of teachers who participated in the program as well as to students of teachers in a comparison group who were wait-listed to participate in the program in 2018-2019. The SETI Institute partnered with eight school districts in California, from which teachers applied to the program. The SETI Institute selected 40 applicants total to participate in the program. The SETI Institute had capacity to fly 24 Ambassadors in the 2017-2018 school year, meaning 16 of the selected teachers would have to wait until the next school year to receive training and fly onboard SOFIA. WestEd was provided with a list of the 40 selected applicants and from this list randomly assigned 24 to serve as the treatment group while the other 16 were designated as a delayed-treatment comparison group. Of these teachers, one each from the treatment and comparison group (including the sole participant from one of the eight districts) left the study before any training

or data collection was performed. Both these teachers cited personal issues as their rationale for discontinuing their participation in the program. Thus, the final RCT study samples were students of 23 teachers in the treatment group and 15 teachers in the control group.

The 23 teachers selected as the treatment group comprised Cycle 5 of the Airborne Astronomy Ambassadors program and were given professional development experiences during the spring and summer of 2017 as well as the opportunity to visit the Armstrong Flight Research Center and fly on SOFIA. The remaining 15 teachers did not receive any training or exposure to NASA or SETI Institute content experts until spring 2018. Teachers in the treatment group were given the NASA AAA 10-day curriculum module to teach to their students during the 2017-2018 academic year, while teachers in the comparison group were instructed to use their standard curricula.

To assess the impact of the NASA AAA curriculum module on student learning, WestEd developed and administered a twenty-three item multiple choice content-assessment to students in the treatment and comparison groups during the 2017-2018 academic year. WestEd developed the student assessment in conjunction with the SETI Institute. WestEd worked with teachers in both the treatment and comparison groups to have teachers administer the assessment in class. The assessment was administered online using the SurveyMonkey online-survey platform. Teachers in both groups were given the assessment on September 5<sup>th</sup> 2017 and were asked to administer it before teaching any content related to the electromagnetic spectrum. In both groups, teachers were also asked to administer a post-assessment at some point during the final three weeks of their course. Because teachers were not all teaching courses of the same length (i.e. some taught semester long courses while others taught yearlong courses), asking teachers to administer the pre- and post-assessments in timeframes relative to the start and end of their course was the most practical way to establish equivalent testing procedures across treatment and comparison groups. Teachers were given a three-week timeframe to administer the post-assessment to ensure teachers had adequate opportunity to conduct their normal final exams and projects.

Student pre- and post-assessment data were collected and analyzed by WestEd researchers to investigate the impact of the NASA AAA curriculum module on student performance. This report contains information and findings from the student assessment.

## Student Assessment Data Analysis Procedure

Students assessment results were analyzed using hierarchical linear modeling (defined in Appendix A) to look at student post-assessment scores, taking into account students' pre-assessment scores and students' teacher as a random effect.

Impact analysis was conducted with all students with valid pre- and post-assessment data (n = 2324). For each analysis, four models were explored: a Condition Model, a Class Covariate Model, a Student-Class Covariate Model, and an Interaction Model. The Condition Model included students' pre-score, condition status, and teacher as a random effect. The Class Covariate Model included the Condition Model variables and class characteristics such as subject and AP status. The Student-Class Model took those variables into account along with student gender, ethnicity, and grade. The Interaction Model included all variables in the Student-Class Model, as well as the interaction between condition and demographic variables (i.e. gender and ethnicity). In all models, students' pre-assessment scores were included as a level-1 covariate. A complete description of each model is provided in Appendix C.

### **Student Assessment Internal Reliability**

Cronbach's alpha was used to assess the internal reliability of the student-assessment (see Appendix A). Cronbach's alpha was run on both the pre- and the post-assessment. For both the pre- and post-assessment, all 23 assessment items and 2343 respondents were included in the Cronbach alpha analysis. The Cronbach alpha value for the pre-assessment was .51 and the value for the post-assessment was .60. The What Works Clearinghouse (WWC) defines the minimum standard for internal reliability to be a Cronbach's alpha of 0.50 or higher (WWC, 2018). This indicates the student assessment had acceptable levels of internal reliability.

### **Baseline Equivalence**

Overall teacher attrition from assignment to post-assessment data collection was 5% (2 of 40), with a 4% (1 of 25) attrition for the treatment group and a 6% attrition rate for the comparison group (1 of 16). Two treatment teachers did not have their students do the attitudinal survey,

leading to an overall attrition rate of 10%, with a treatment attrition rate of 12% and a comparison attrition rate of 6%. The teacher attrition rate for both the assessment and attitudinal survey is considered *low attrition* according to WWC standards (WWC, 2018).

The overall attrition rate for students from pre- to post-assessment was 22%, with a differential rate of 3% between treatment and control. This is considered *low attrition* according to WWC standards (WWC, 2018). This is associated with a low expected bias and indicates baseline equivalence between treatment and control. Nonetheless, the between-groups difference on the pre-assessment was examined and a between-groups effect size of -0.9 was observed. This is a small difference and indicates group equivalence on the pre-assessment.

Attitudinal survey responses showed an overall attrition rate of 26%, with a differential rate of 2% between treatment and control. As with the assessment data, this is considered a *low attrition* according to WWC standards (WWC, 2018).

### **Effect Size and P-Values**

Two important statistics reported in this paper are p-values and effect size.

**P-values** give information about the precision of the statistical analyses. Lower p-values are representative of higher precision, and would indicate a higher likelihood that the differences are statistically significant from zero, if there was truly no difference. The standard convention in educational research, adopted by the WWC, is to consider p-values smaller than 0.05 to be statistically significant from zero (WWC, 2018).

**Effect sizes** (reported as Cohen's *d*; defined in Appendix A) represent the magnitude of the statistical effects. Effect sizes represent the changes from pre-to post-test, in units of standard deviations. Effect sizes below 0.25 are considered small, but could still be educationally meaningful. Those above 0.25 are considered substantive for education according to the WWC (WWC, 2018).

## Overview of Student Assessment Findings

Student assessment results were analyzed using hierarchical linear modeling (see Appendix A) to look at student post-assessment scores, taking into account students' pre-assessment scores and students' teacher as a random effect. Impact analysis was conducted with all students with valid pre- and post-assessment data (n = 2343). Further analysis was also conducted to look at outcome data only for students enrolled in astronomy, earth-space science, or physics, three courses identified by the SETI Institute as most-relevant for the NASA AAA curriculum module. For each analysis, four models were explored: a Condition Model, a Class Covariate Model, a Student-Class Covariate model, and an Interaction Model. In all models, students' pre-assessment score was included as a level-1 covariate. These models are explained in full in Appendix D.

**Findings across models indicate a consistent, significant, and substantively important positive effect of the NASA AAA curriculum module on student assessment performance** across impact analysis models. Table 1 shows the condition coefficients and associated effect sizes for the NASA AAA curriculum module. Table 1 does not include the results for the interaction models as the main effects of interaction models are not readily interpretable. A full report of each of the eight analytic models with complete information on coefficient, standard error, p-value, and effect size information is provided in Appendix D.

**Table 1. Coefficients, p-values, and effect sizes for condition variable across analysis models.**

	Coefficient	p-value	Effect Size
Condition Model	1.12	0.01*	0.35
Class-Covariate Model	1.44	0.00*	0.44
Student-Class-Covariate Model	1.47	0.00*	0.45
Condition Model (for select subjects)	1.22	0.01*	0.37
Class-Covariate Model (for select subjects)	1.49	0.01*	0.45
Student-Class-Covariate Model (for select subjects)	1.54	0.01*	0.46

The above table illustrates that for each analysis that was run, students who were exposed to the NASA AAA curriculum module performed better on the student-assessment than those who were not exposed. In each analysis, it was found that students who were taught the NASA AAA curriculum module performed better than those who were not. This difference ranged from a 1.12 points to 1.54 points difference across the models. This is to say, students exposed to the curriculum module did 1.12 to 1.54 points better on the post-assessment than did comparison students, when controlling for pre-assessment score and other variables. All models had associated p-values under the 0.05 alpha threshold.

According to What Works Clearinghouse (WWC) procedural guidelines, “an effect size of 0.25 standard deviations or larger is considered to be substantively important” (WWC, 2018). In addition, the WWC considers p-values less than .05 to be considered statistically significant. With these guidelines in mind, it can be concluded that **the NASA AAA curriculum module provided a statistically significant and substantively important positive effect on student learning outcomes** across all analytic models. This represents a robust and reliable impact of the curriculum module on the student assessment.

**Figure 1. Average Post-assessment Content Knowledge Performance for Treatment and Control**

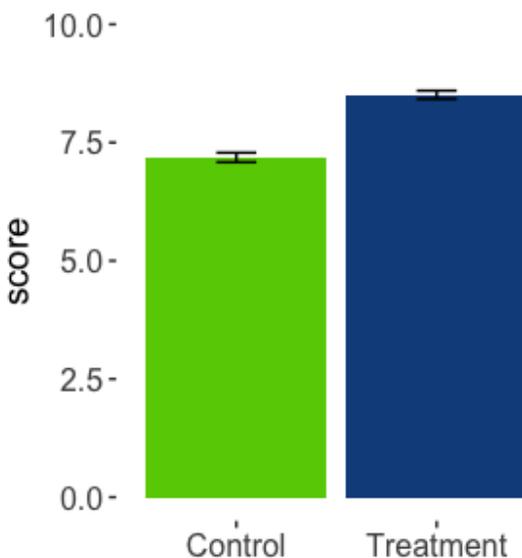


Figure 1 shows average post-assessment student content knowledge performance for treatment and control groups. This figure illustrates that treatment students scored higher than did control students. This trend persisted when controlling for both course and student demographics, as well as when limiting the analysis to only students enrolled in astronomy, physics, or earth-space science courses.

### Trends Across Models

A comparison of impact models revealed some consistent trends in student performance. Across all models, students in AP courses did better on the post-assessment. Astronomy students did better than biology or earth science students, but not chemistry students; the results in relation to physics were mixed. Students of underrepresented minority (URM) groups scored lower on the post-assessment than did non-URM students. Gender and grade showed no significant differences. Likewise, there was no significant interaction between the condition variable and either gender or ethnicity.

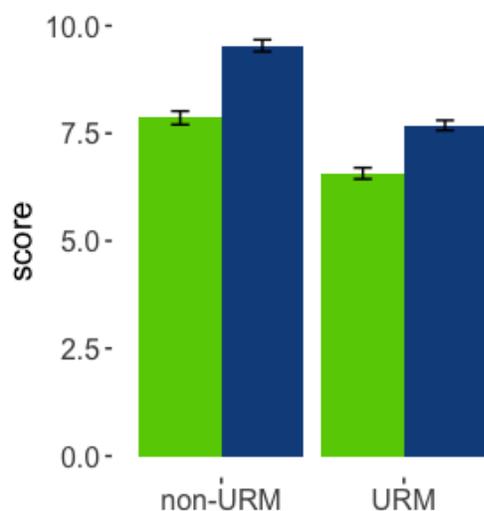
**AP Courses:** AP course status was a variable included in the Class covariate, Student-Class Covariate, and Interaction models. Across all models, AP status had a significant impact on assessment performance. Students in AP courses on average did 2.45 and 3.04 points better on the post-assessment than did students in non-AP courses, when controlling for other variables.

**Astronomy Courses:** Across all analytic models, students in astronomy courses did better than students in other courses. Astronomy students did significantly better than biology and earth-space science students in each of the models. Astronomy students did better than physics students, though this difference was not statistically significant in the full data set (there was a significant difference when comparing only astronomy, earth space science, and physics). Interestingly, astronomy students did *not* do significantly better on the assessment than did chemistry students; though astronomy students did slightly better than did chemistry students this difference was not statistically significant when controlling for other factors. It is important to bear in mind that only the control group had chemistry students; there were no chemistry

students in the treatment group. Thus, there is evidence that chemistry students perform similarly to astronomy students on the assessment, but evidence does not address whether chemistry students would benefit from the curriculum as much as astronomy students. In addition, the results of course comparisons in this report should not be over interpreted due to the small number of classes involved in the study for a given course topic.

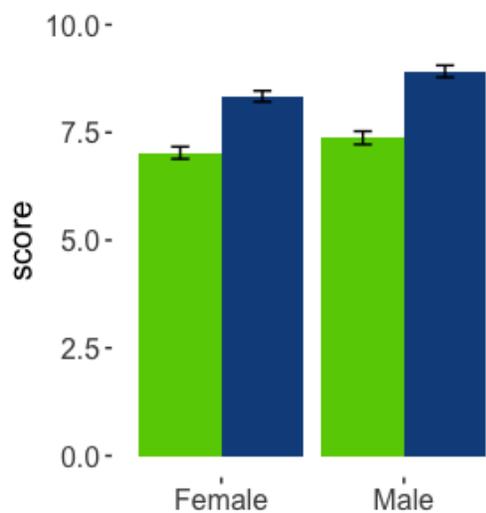
**URM Students:** Students from underrepresented minority groups showed significantly lower post-assessment scores compared to students not in these groups. Students whose background was Black/African American, Hispanic/Latino, or Native American/American Indian were considered URM students, as defined by the National Action Council for Minorities in Engineering (NACME, 2013). The impact of the curriculum module was similar for both groups. Figure 2 shows the average assessment scores for URM and non-URM students in treatment and control.

**Figure 2. Average Post-assessment Content Knowledge Scores for non-URM and URM students in Treatment and Control**



**Gender:** There was no significant gender difference. Both male and female students did approximately the same on the post-assessment, when controlling for other factors. The impact of the curriculum module was similar for both groups. Figure 3 shows the average post-assessment scores for female and male students in treatment and control.

**Figure 3. Average Content Knowledge**  
Post-assessment scores for Female and Male students in Treatment and Control.



**Grade:** There was no significant difference across grade levels. Students performed roughly the same on the post-assessment regardless of their grade level, controlling for other factors.

**Interaction Effects:** There was no significant interaction between the condition variable and either gender or ethnicity. The NASA AAA curriculum module provided similar impact on students of both genders and across ethnicities.

### Attitudinal Survey Findings

To assess the impact of the NASA AAA curriculum module on students' attitudes towards science, students responded to 11 questions about how they believe their course has impacted them and to 7 retrospective pre-post questions which asked about their views related to science at the beginning and end of their course. All questions were on a five-point scale:

“strongly disagree”; “disagree”; “neutral”; “agree”; “strongly agree.” This scale was converted to a numeric scale with “strongly disagree” = 1 and “strongly agree” = 5. Student responses on each item were analyzed individually for each of the 11 belief questions and for each of the 7 post items for the retrospective pre-post item pairs.

Table 2 shows average retrospective pre- and post-scores for treatment and control students. Treatment students showed higher post-ratings than did control students for all but two of the questions. Treatment and control students gave equal ratings on both the pre- and post-questions regarding interest in formally studying science after high school. Treatment students gave a slightly lower rating on the pre- and post-questions regarding interest in becoming a scientist. For all other questions, treatment students showed a higher rating than did control.

**Table 2. Average Pre and Post Ratings on Retrospective Pre-Post Items by Condition Status**

	Control (N = 841)		Treatment (N = 1397)	
	Pre	Post	Pre	Post
I am interested in formally studying more science after high school (e.g. in college)	M = 2.87 (SD = 1.18)	M = 2.94 (SD = 1.18)	M = 2.87 (SD = 1.12)	M = 2.94 (SD = 1.16)
I am interested in informally learning more about science on my own after high school (e.g. media, science center)	M = 2.88 (SD = 1.14)	M = 2.93 (SD = 1.17)	M = 2.91 (SD = 1.04)	M = 2.98 (SD = 1.15)
I would be comfortable with a job/career that requires using science	M = 2.96 (SD = 1.13)	M = 3.01 (SD = 1.15)	M = 3.00 (SD = 1.08)	M = 3.06 (SD = 1.14)
I am interested in becoming a scientist	M = 2.54 (SD = 1.11)	M = 2.66 (SD = 1.12)	M = 2.49 (SD = 1.06)	M = 2.62 (SD = 1.12)
I think there are multiple ways I can become involved in science	M = 3.18 (SD = 1.08)	M = 3.24 (SD = 1.11)	M = 3.22 (SD = 1.04)	M = 3.35 (SD = 1.09)
Scientific research requires a team of people with different types of skills	M = 3.49 (SD = 1.10)	M = 3.56 (SD = 1.13)	M = 3.68 (SD = 1.03)	M = 3.79 (SD = 1.08)
Scientists DO NOT mostly work on their own**	M = 3.44 (SD = 1.16)	M = 3.44 (SD = 1.09)	M = 3.49 (SD = 1.02)	M = 3.58 (SD = 1.10)

\*\*Item was reworded for reporting and scaling was reversed for analysis; original wording for this item was “Scientists work mostly on their own”

Figure 4 shows the change from pre to post-ratings for each of the seven retrospective pre-post attitudinal questions. Figure 4 shows that treatment students had pre-post gains that were greater than those of the control, for all questions except formal study, which showed an equivalent change for treatment and control. This change is especially pronounced with regards to questions about students' belief that there are multiple ways to become involved in science, that science requires different skill sets, and that scientists work with others.

**Figure 4. Retrospective Pre-Post STEM Engagement Changes for Treatment and Control Students**

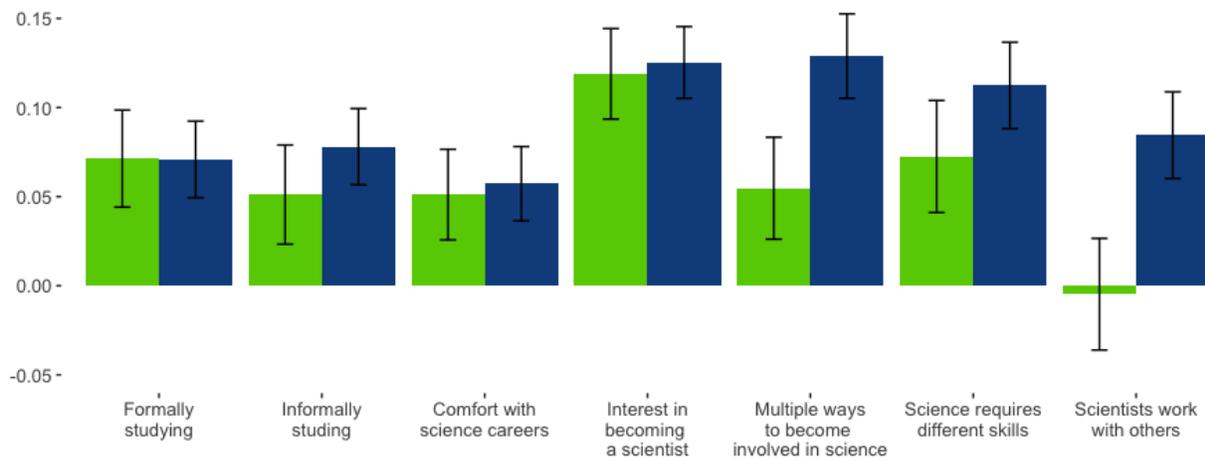


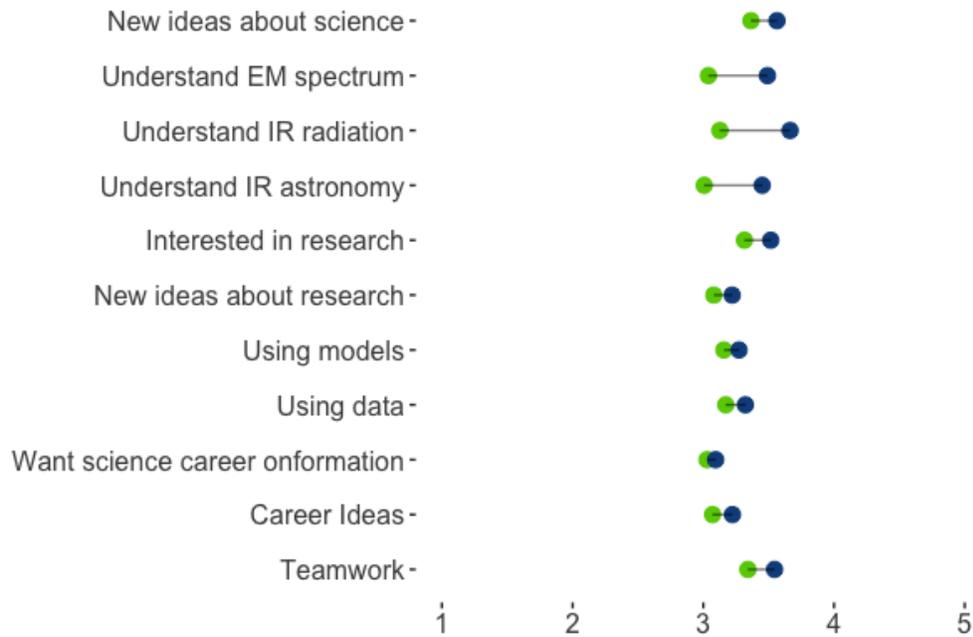
Table 3 shows average ratings for the 11 questions students were asked about how much they learned from their course. Students in the treatment group provided higher ratings than did control students for all 11 questions.

**Table 3. Average Ratings on Attitudinal Questions by Condition Status**

	<b>Control (N = 845)</b>	<b>Treatment (N = 1398)</b>
I got some new ideas about what science is	M = 3.36 (SD = 1.05)	M = 3.56 (SD = 0.97)
I better understand the electromagnetic spectrum	M = 3.04 (SD = 1.04)	M = 3.49 (SD = 0.99)
I better understand infrared radiation/light	M = 3.13 (SD = 1.02)	M = 3.66 (SD = 0.95)
I better understand infrared astronomy	M = 3.01 (SD = 1.04)	M = 3.45 (SD = 0.97)
I got some new ideas about what happens in scientific research projects	M = 3.31 (SD = 1.03)	M = 3.52 (SD = 0.98)
I am more interested in learning about scientific research	M = 3.08 (SD = 1.12)	M = 3.22 (SD = 1.09)
I am better at using models to explain science concepts	M = 3.16 (SD = 1.04)	M = 3.27 (SD = 1.01)
I am better at using data to answer questions	M = 3.17 (SD = 1.04)	M = 3.32 (SD = 0.96)
I want to know more about what science-related careers there are	M = 3.03 (SD = 1.11)	M = 3.09 (SD = 1.12)
I got new ideas about what science-related careers there are	M = 3.07 (SD = 1.02)	M = 3.22 (SD = 1.01)
I learned the importance of teamwork in science	M = 3.34 (SD = 1.09)	M = 3.55 (SD = 1.06)

Figure 5, like Table 3, shows students' average ratings for how much they learned from their course. This figure shows that treatment students provided higher ratings for all 11 items. The results show that the largest differences between these two groups were in relation to understanding the EM spectrum, understanding IR radiation, and understanding IR astronomy. All items showed a similar pattern of treatment students providing higher ratings than control.

**Figure 5. Average student ratings for Treatment and Control**



### Trends Across Survey Findings

Student responses across survey items reveal trends in the impact of the NASA AAA curriculum module on student interests and attitudes. Students exposed to the curriculum module in general expressed a more collaborative and interdependent view of scientific research. These students also expressed that they gained more knowledge about science content and the scientific process. A smaller difference was observed in relation to questions about interest in science.

**Collaboration in science:** Students in the treatment group consistently provided higher ratings on questions related to teamwork and collaboration in science. Treatment students expressed that they learned more about the importance of teamwork in science compared to comparison groups and had higher levels of agreement that science requires teams of people with different skills and that scientists do not work alone. This indicates that students who are exposed to the NASA AAA curriculum module develop a greater appreciation for the collaborative and interdependent nature of contemporary scientific enterprise.

**Content and Science Process Knowledge:** Students exposed to the NASA AAA curriculum module felt they gained more from their course about content knowledge related to the electromagnetic spectrum, infrared radiation, and infrared astronomy. Similarly, these students felt they gained more ideas about what science is and what happens in scientific research projects. This indicates that students exposed to the NASA AAA curriculum module felt they learned more content knowledge than those who were not exposed.

**Interest in Science:** Student interest in learning more about science or pursuing a scientific career was slightly higher for treatment students than comparison. Retrospective pre-post changes in learning more science informally and interest or comfort in scientific careers was greater for treatment than comparison students, though this difference was less than for other items. Similarly, treatment students gave slightly higher ratings than control of how much their course increased their interest in learning about scientific research or what science related careers there are. However, these differences were less than those regarding content knowledge.

Together, these findings indicate that the NASA AAA curriculum module has an impact on students' understanding of scientific content and scientific processes, as well as provides students with a more collaborative view of scientific research but had a lesser impact on students' interest in science.

## Study Limitations

When interpreting the results of this report, it is important to keep in mind several key limitations of the study.

**(Over)Alignment:** One important limitation to this report is that the information it is based on comes from an assessment that was designed for the NASA AAA curriculum module. The WWC states that the outcome must not be overaligned with the intervention in order for a research study to meet their standards (WWC, 2018). Results were based on a researcher-developed test, developed around the NASA AAA curriculum module.

**Psychometrics:** Though the internal reliability for both the pre- and post-assessments was considered acceptable according to WWC standards, the internal reliability is lower than that of many existing standardized testing instruments. Future research should explore the effects of the curriculum module with more validated measures.

**Mechanisms of Change:** This study was not designed to study implementation. The study reported on in this report was designed to serve as a study of promise on student outcomes. The study did not address how the curriculum module was implemented or how it compares to instruction provided to students not receiving the curriculum module. Further research is needed to investigate what causal mechanisms are driving differences in student performance.

**Generalizability:** This study was conducted with students drawn exclusively from California public schools. As such, the generalizability of these findings may be limited. For instance, the weighted average percentage of URM students across districts involved in this study was 59%, compared to the statewide average of 60% across California. This indicates that this study can be generalized to other students in California in terms of ethnicity. However, the results cannot be generalized to other states with other ethnic distributions. In addition, the study also may not be generalizable to other districts within the state of California in terms of other

characteristics, such as urban/rural or socioeconomic status. Future studies should look at the effects of the curriculum module with more heterogeneous samples of students.

## Conclusions

The results of this report indicate that students who were taught the NASA AAA curriculum module learned more about the electromagnetic spectrum and infrared astronomy than did students who were not exposed. Students exposed to the NASA AAA curriculum module did better on the student-assessment developed by WestEd researchers than those not exposed. This finding was consistent when controlling for both class characteristics and student demographics. The finding was similar for both male and female students and for students from underrepresented minority groups and those not from underrepresented minority groups. The effects of the curriculum module did not appear to have any notable interaction with either gender or ethnicity.

Attitudinal survey items showed a consistent trend of treatment students providing more favorable ratings than did comparison students. This difference was most notable with regards to questions related to the collaborative nature of science and to content knowledge and scientific process knowledge. Treatment students gave higher levels of agreement that science requires teams of people with different skills and that scientists do not work alone. Treatment students also gave higher ratings of how much they learned about the electromagnetic spectrum, infrared radiation, and infrared astronomy. Other items showed a similar trend of more favorable ratings from treatment students, though to a lesser degree.

The results of this report should be interpreted in light of the limitations outlined in the preceding section. First, this report is based on an assessment that was designed around the NASA AAA curriculum module and thus may be over-aligned with it. Testing with standardized testing instruments may yield a more subtle impact of the curriculum module than that observed in this report. This report also does not include information on how the curriculum

module was implemented in classrooms, or what instruction was given to students not exposed to the NASA AAA curriculum module. This study was also based on students in only seven districts in the state of California and may not be generalizable to students in other states or from districts with different characteristics.

Within the limitations of this study, the results do clearly indicate a consistent positive impact of the curriculum module, at substantively important sizes, on student performance. Taking into account this is an early state research study aimed at understanding the NASA AAA curriculum module, the results of this study demonstrate the promise of improving student learning outcomes. Together, these results indicate that the NASA AAA curriculum module had a substantively important positive effect on student learning outcomes and attitudes.

## Appendix A: Terminology Glossary

**Coefficient:** The average difference in outcome (e.g. post-test) scores between two groups, controlling for all other variables in the analysis.

**Cohen's  $d$ :** A measure of effect size, defined as the between-group difference in means divided by the pooled standard deviation, where **pooled standard deviation** is the weighted average of standard deviation for two or more groups.

**Cronbach's alpha:** A measure of internal reliability, ranging from 0.0 to 1.0. Higher values indicate higher internal reliability. The WWC defines 0.50 as the minimum threshold for acceptable levels of internal reliability using Cronbach's alpha.

**Effect sizes:** Magnitude of the statistical effects. Effect sizes represent the changes from pre- to post-test, in units of standard deviations. Effect size is often reported using Cohen's  $d$ . Effect sizes below 0.25 are considered small but could still be educationally meaningful. Those above 0.25 are considered substantive for education according to the WWC (WWC, 2018).

**Hedges  $g$ :** A measure of effect size used to measure the difference between two means. Hedge's  $g$  is similar to Cohen's  $d$ , but corrects for small sample sizes. Hedge's  $g$  is recommended measure of effect size for regression models according to WWC standards (WWC, 2018).

**Hierarchical Linear Modeling:** A regression-based (i.e. predictive) analytic technique that takes the hierarchical structure of the data into account, where groups of units (e.g. students) are clustered together in an organized fashion (e.g. within teachers). Hierarchical linear modeling accounts for variance amongst scores that is due to clustering (e.g. the effects of teachers), when looking at the effects of other variables.

**Internal Reliability:** A measure of the correlation between different items on the same test. A higher correlation between items on a test indicates higher internal reliability. It is often measured using Cronbach's alpha.

**P-values:** Give information about the precision of the statistical analyses. Lower p-values are representative of higher precision and would indicate a higher likelihood that the differences are statistically significant from zero, if there was truly no difference. The standard convention in educational research, adopted by the WWC, is to consider p-values smaller than 0.05 to be statistically significant from zero (WWC, 2018).

**Standard deviation:** A measure of the amount of variability in a data set. It is defined as the square root of the sum of scores subtracted from the mean, divided by the number of observations. The larger the standard deviation, the more spread out scores are within a data set.

**Standard Error:** The standard deviation for a given sample, divided by the number of observations in the sample.

## Appendix B: Testing Development and Administration

### Testing Development

The assessment was developed by WestEd researchers and reviewed by the SETI Institute. WestEd researchers developed the assessment by reviewing the NASA AAA curriculum module developed by the SETI Institute AAA staff. Two researchers from WestEd contributed to the creation of this assessment – Dr. Daniel Brenner and Matt David Silberglitt, M.A. Dr. Brenner has a Ph.D. in chemistry and manages the technology aspects of the SimScientist projects, developing and testing simulation-based assessments and instruction for middle school science. Matt Silberglitt has taught high school astronomy as well as worked on research and development for science assessments for small-scale projects and state-level accountability assessments. WestEd researchers developed the assessment to address the NGSS dimensions covered by the curriculum module, as determined by the SETI Institute. WestEd created a 23-item assessment which consisted of 21 multiple-choice questions with four answer choices, and two questions where students were asked to choose three correct statements out of a total of five. The SETI Institute reviewed the assessment to ensure all questions were scientifically accurate and contained viable distractor response options.

The assessment covered seven of the eight Science and Engineering Practices (SEPs), three of the seven Crosscutting Concepts (CCCs), and four separate Disciplinary Core Ideas (DCIs) from the Next Generation Science Standards. The list below shows the SEPs, CCCs, and DCIs covered by the assessment. Table B-1 shows the relevant NGSS dimensions for each question on the pre-assessment. The post-assessment contained the same questions as the pre-assessment, but with a new ordering of items and response options.

### SEPs covered in the student-assessment

2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

### CCCs covered in the student-assessment

1. **Patterns.** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. **Cause and effect: Mechanism and explanation.** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
4. **Systems and system models.** Defining the system under study — specifying its boundaries and making explicit a model of that system — provides tools for understanding and testing ideas that are applicable throughout science and engineering.

### DCIs covered in the student-assessment

1. PS4.A: Wave Properties  
Sound can make matter vibrate, and vibrating matter can make sound. (1-PS4-1)
2. PS4.B: Electromagnetic Radiation  
Objects can be seen if light is available to illuminate them or if they give off their own light. (1-PS4-2)  
Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them,

where the light cannot reach. Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.) (1-PS4-3)

3. PS4.C: Information Technologies and Instrumentation

People also use a variety of devices to communicate (send and receive information) over long distances.

4. ESS1.A: The Universe and its Stars

Patterns of the motion of the sun, moon, and stars in the sky can be observed, described, and predicted. (1-ESS1-1)

**Table B-1. Relevant NGSS SEPs, CCCs, and DCIs for each item on the student pre-assessment**

Q#	SEP	CCC	DCI	Q#	SEP	CCC	DCI
Q1	2		PS4.B	Q13	8		PS4.C
Q2	2		PS4.B	Q14	6		ESS1.A
Q3	7		PS4.B	Q15	2		PS4.B
Q4	3		PS4.B	Q16	2		PS4.B
Q5	6		PS4.B	Q17	2		PS4.B
Q6	2		PS4.B	Q18	7		ESS1.A
Q7	5	1	PS4.A	Q19	4		PS4.C
Q8	6		PS4.B	Q20	4	2	PS4.B
Q9	6		PS4.B	Q21	6	4	PS4.B
Q10		1	PS4.B	Q22	7	1	PS4.B
Q11		1	PS4.B	Q23	8		
Q12	8		PS4.C				

## Testing Procedure

The NASA AAA student assessment was administered online via the online survey tool, SurveyMonkey. Assessment data were collected in-class, where students were given the class period to complete the assessment. The assessment was administered by the teacher involved in the study, or in the case of one treatment teacher (who was on extended leave during the time of post-assessment), a substitute proctor. Participating teachers were sent a student roster to fill out for each class where they administered the assessment. Teachers assigned each student an ID number based on the roster and gave students a strip of paper with their ID number and a link to the assessment. Teachers provided WestEd with a list of the courses in which they were administering the assessment and the subject of each course. Students used the link they were provided to access the assessment and provided their teacher-provided ID so that WestEd could track responses between each student's pre- and post-assessment.

Teachers were provided with the link to the pre-assessment on September 5<sup>th</sup>, 2017 to administer to their students and were asked to administer it before they started covering content related to the electromagnetic spectrum. Twenty one (21) of the 23 treatment teachers and 14 of the 15 control teachers administered the pre-assessment between September 5<sup>th</sup> and October 25<sup>th</sup>. The remaining three teachers administered the pre-assessment in January, during the Spring semester. The average date of pre-assessment administration was 12 days after September 5<sup>th</sup> for the comparison group and 17 days after September 5<sup>th</sup> for the treatment group.

Teachers were asked to administer the post-assessment during the last three weeks of their course, to make the administration process as comparable as possible between treatment and control. Teachers were asked to select a date within the last three weeks of their course on which to administer the post-assessment. WestEd sent teachers the link to the post-assessment one to five days before the day on which they planned to administer the post-assessment. Thirteen (13) of the 23 treatment teachers and 6 of the 15 control teachers administered the post-assessment between November 1<sup>st</sup> and December 22<sup>nd</sup> of 2017. The remaining 10

treatment and 9 control teachers administered the post-assessment between May 8<sup>th</sup> and June 5<sup>th</sup> of 2018.

The average time between pre-assessment and post-assessment administration was 160 days for treatment students and 170 days for comparison students. Hierarchical linear modeling was used to analyze whether there was a significant difference between treatment and comparison with regards to when the assessments were administered. A hierarchical linear model with status as a fixed effect and teacher as a random effect showed there was no significant difference with regards to pre-assessment administration date, post- assessment administration date, or the time from pre- to post-assessment between treatment and control. In addition, entering time from pre- to post-assessment as a fixed effect covariate indicated time did not have an impact on post-assessment performance, nor did its inclusion in the model notably alter the impact of any other variables, including the condition variable. Based on this, it can be concluded there is no significant difference in the administration timing between treatment and control students.

## Data Reduction

### Respondent Validation

A total of 3269 responses were recorded on the pre-assessment. Of these, 3009 responses were considered valid. A total of 260 responses were removed during the cleaning process, including:

- 98 incomplete records (i.e. did not get at least half way through assessment)
- 89 students who intended to take post but retook pre
- 19 without valid IDs
- 54 were duplicate IDs

Of the 3009 valid responses to the pre-assessment, 1148 were from control students and 1861 were from treatment students.

A total of 2665 responses were recorded on the post-assessment. In addition, 88 responses of students who retook the pre-assessment instead of taking the post-assessment were added to the post-assessment data. Of these, 2580 were considered valid. A total of 173 were removed during the cleaning process, including:

- 117 incomplete records (i.e. did not get at least half way through assessment)
- 13 without valid IDs
- 43 were duplicate IDs

Of the 2580 valid responses on the post-assessment, 950 were from control students and 1630 were from treatment students.

A total of 2343 respondents completed both the pre- and post-assessments. Of these 870 were control students and 1473 were treatment students. This yields an overall retention rate of 77.8% (2343/3009), with a retention rate of 75.8% for control (870/1148) and 79.2% for treatment (1473/1861).

A total of 2238 respondents completed all survey items in the post-assessment. Of these, 841 were control students and 1397 were treatment students. This yields an overall retention rate of 74.4%, with a retention rate of 33.3% for control and 74.6% for treatment.

With an overall attrition rate of 22% and a differential attrition rate of 3%, the attrition rate is considered *low attrition* according to the What Works Clearinghouse Procedures and Standards Handbook (WWC, 2018). This is considered to be associated with a low expected bias, indicating baseline equivalence between the treatment and control groups.

Though attrition was low and the integrity of the random assignment should not have been compromised, we examined the difference between groups on the pre-assessment, with status as a fixed effect and teacher as a random effect. The effect size difference between groups on their pre-score was .9. This is a small difference and within the range of statistical correction.

### **Score Calculation**

Student-assessment data were collected via the online survey platform, SurveyMonkey and exported as a .csv file to RStudio for data analysis. For each question in the assessment, responses were recoded as a “0” for incorrect responses and “1” for correct responses. For questions where students had to select three of five possible choices, only students who selected the three correct choices (and no more) were given a 1 for said question. Scores were calculated by summing the total number of correct answers. Frequency distributions were run on each question before and after recoding to ensure the number of correct responses after the recoding matched the number of respondents who selected the correct answer.

### **Ethnicity**

Students were asked at the end of the post-assessment what their race/ethnicity was. Students were given six ethnic groups to choose from including: African American or Black; American Indian or Alaska Native; Asian; Caucasian or White; Latino or Hispanic; Native Hawaiian or Other Pacific Islander. Students could also select “Other” or “Prefer not to answer”. Students were asked to mark all that applied.

For analytic purposes, ethnicity was dummy coded for underrepresented minority status. Students who selected African American or Black, American Indian or Alaska Native, or Latino

or Hispanic were coded as underrepresented minorities. Students who did not select any of these three categories were considered to not be underrepresented minorities.

### **Gender**

Students were asked at the end of the post-assessment to indicate their gender as female, male, or prefer not to answer. For analytic purposes, gender was dummy coded, with those indicating female receiving a “1” and those indicating male receiving a “0”. Students who selected prefer not to answer or who skipped the question were excluded from analysis.

### **Grade**

Students were asked at the end of the post-assessment to indicate their grade, with response options including 9<sup>th</sup>, 10<sup>th</sup>, 11<sup>th</sup>, 12<sup>th</sup>, and other. Grade was considered a categorical variable during analysis.

### Course Subject and AP Status

The subject of the course in which each student took the assessment was provided by students' teachers. Teachers provided WestEd with a list of which periods they administered the student assessment to and what the course title was for each. WestEd researchers compiled teacher responses into a .csv file and recoded each one into one of six subjects: astronomy, biology, chemistry, earth science, intro science, or physics. Table B-2 shows the original course titles for each course the assessment was administered in. Courses with AP in the title (AP Physics, AP Physics 1, AP Physics 2, AP Physics C: Mechanics- E &M) were coded as AP for analysis.

**Table B-2. Course subject as defined by analytic recoding, and original teacher description**

Subject	Teacher Description
Astronomy	Astronomy
	Astronomy Term 1
	Honors Astronomy
Biology	Biology
	Biology with Earth Science
	Lab Biology 1
Chemistry	Chemistry
	Honors Chemistry
Earth-Space Science	Academic Earth Science
	Earth Science
	Living Earth
Intro Science	Int. Science
Physics	AP Physics
	AP Physics 1
	AP Physics 2
	AP Physics C: Mechanics-E&M
	Conceptual Physics
	Physics
	Physics A

## Appendix C: Baseline Equivalence

### Subject

Table C-1 shows the number and proportion of students in each subject, by condition group.

Table X shows there is not an equal distribution of students across subjects in the two conditions. For example, only 4% of control students are biology, compared to 26% of treatment students. Conversely, 9% of control students are chemistry compared to none of the treatment students. However, subject was taken into account in impact analysis modeling to control for this difference.

**Table C-1. Number and proportion of students in each subject by condition group**

	Control		Treatment	
Astronomy	131	15%	172	12%
Biology	32	4%	384	26%
Chemistry	80	9%	0	0%
Earth Science	338	39%	404	27%
Intro Science	0	0%	24	2%
Physics	289	33%	489	33%

Table C-2 shows the number and proportion of students that took the assessment in an AP course, by condition group. Table C-2 shows there is a similar distribution of AP students across conditions. Nonetheless, AP status was taken into account in impact analysis modeling to control for its effects.

**Table C-2. Number and proportion of students in AP courses by condition group**

	Control		Treatment	
AP	39	4%	39	3%
Non-AP	831	96%	1434	97%

Table C-3 shows the number and proportion of students of each gender, by condition. This table shows there is a similar distribution of gender across the two conditions. Nonetheless, gender was taken into account in impact analysis modeling to control for its effects.

**Table C-3. Number and proportion of students of each gender by condition**

	Control		Treatment	
Female	377	47%	653	49%
Male	418	53%	669	51%

Table C-4 shows the number and proportion of students in each grade by condition. This table shows there was a somewhat higher proportion of 9<sup>th</sup> grade students in the treatment group than the control group, and that there were slightly fewer 10<sup>th</sup> and 11<sup>th</sup> grade students. Grade was taken into account in impact analysis modeling to control for this difference.

**Table C-4. Number and proportion of students in each grade by condition**

	Control		Treatment	
9th grade	147	18%	485	37%
10th grade	201	25%	213	16%
11th grade	315	40%	410	31%
12th grade	132	17%	214	16%

Table C-5 shows the number and proportion of students that are underrepresented minorities (URM), by condition. URM students are defined as those who identified as African American/Black, Native American/American Indian, or Hispanic/Latino, as per the NACME definition (NACME, 2013). This table shows there is an equivalent distribution of URM students across the two conditions. Nonetheless, URM status was taken into account in impact analysis modeling to control for its effects.

**Table C-5. Number and proportion of students of that are underrepresented minorities by condition**

	Control		Comparison	
Non-URM	395	50%	676	51%
URM	400	50%	646	49%

Table C-6 shows the percentage of students in each school district involved in the study that are from underrepresented minority groups. The information in this table is taken from the California Department of Education’s website Enrollment by Ethnicity tables for the 2017-2018 academic year. Table C-6 shows that the percentage of URM students ranged from 37.7% to 79.6%. The statewide average for under-represented minority percentage was 60.3%. The weighted average of districts in this study was 59.1%. This indicates that the districts in this sample are representative of the state of California in terms of student ethnicity.

**Table C-6. Proportion of students from underrepresented minority groups in each school district involved in the study**

<b>School District</b>	<b>Percent URM</b>
Anaheim Union High	70.4%
Antelope Valley Union High	79.6%
Campbell Union High	37.7%
East Side Union High	53.4%
Manteca Unified	62.7%
Santa Clara Unified	37.7%
Vista Unified	66.7%
William S. Hart Union High	42.5%
<b>Average of Districts in Study (weighted)</b>	<b>59.1%</b>
<b>Statewide (California)</b>	<b>60.3%</b>

It is worth noting that the California Department of Education website categorizes students’ ethnicity in terms of: African American, American Indian, Asian, Filipino, Hispanic, Pacific Islander, White, or Two or More Races. For the purposes of Table C-6, the percentage URM was calculated by summing the percentage of students that were African American, American Indian, or Hispanic. This means students who reported two-or-more races were not counted in the percentage of URM students displayed in Table C-6. This is in contrast of the approach used for identifying URM students in this study, where students were given a list of ethnicities from which they could select all that applied and researchers designated any students as URM who selected African American/Black, Native American/American Indian, or Hispanic/Latino,

regardless of what other options a student chose. According to the California Department of Education, the percentage of students who were two-or-more races was 3.5% statewide, which is equal to the weighted average of the percentage of students that were two-or-more races across the districts involved in this study. The percentage in each district involved in this study ranged from 1.6% to 4.9%, for a weighted average of 3.5%. This indicates that despite the difference in reporting methods, the districts in this study are representative of the state at large in terms of student demographics.

## Appendix D: Impact Analysis Models

Four models were used to explore student assessment data: a Condition Model, a Class Covariate Model, a Student-Class Covariate Model, and an Interaction Model.

**Condition Model:** The Condition Model (model 1) included fixed effects, including the condition variable and students' pre-test (i.e. post-assessment) score. The Condition Model took the following form:

$$\gamma_{ij} = \beta_{00} + \beta_{01}TX_j + \beta_{10}Pre_{ij} + \zeta_{0j} + \epsilon_{i0}$$

Where  $\gamma_{ij}$  is the post-test (i.e. post-assessment) score for the  $i$ -th student of the  $j$ -th teacher,  $TX_j$  is a dichotomous variable indicating assignment to treatment,  $Pre$  represents students' pre-test score, and  $\beta_{00}$  is the grand mean of student scores.  $\epsilon_{i0}$  is a random level-1 error term and  $\zeta_{0j}$  is the teacher random effect, the variance component of which captures the nesting of students within instructors. Importantly, the main effect of treatment assignment is captured by  $\beta_{01}$ .

**Class Covariate Model:** In addition to the condition and pre-terms in the Condition Model, the Class-Covariate Model (model 2) included class-level fixed effects of subject (Astronomy, Biology, Chemistry, Earth Science, Intro Science, or Physics), and AP status.

**Student-Class-Covariate Model:** This model included all variables in the Class Covariate Model, and added student-level fixed effects of students' gender (Female or Male), students' ethnicity (coded as URM or not) and grade (9<sup>th</sup> – 12<sup>th</sup> grade or Other). Due to administration issues, student level demographic data were not collected from two teachers whose students were excluded from this analysis.

**Interaction Model:** This model included all variables in the Student-Class Covariate Model, and added interaction effects between condition and gender, as well as between condition and

ethnicity. This model includes the same sample of students included in the Student-Class-Covariate Model.

We examined overall gains from pre-assessment to post-assessment scores for all students who completed the pre- and post-assessments. As displayed in Table D-1 below, there is a statistically significant difference, at the 0.05 significance level, in pre-assessment to post-assessment scores for both the control and treatment groups. Results in Table D-1 show that post-assessment scores decreased for the control group, while they increased for the treatment group after exposure to the NASA AAA curriculum module.

**Table D-1. Student Assessment Pre-test and Post-test Scores (Mean, Standard Deviations and Cohen’s D Effect Size of the Difference) for both condition groups**

CONDITION	N	PRE-TEST MEAN, SD	POST-TEST MEAN, SD	GAIN	95% CI FOR MEAN DIFF.	T-STATISTIC	P-VALUE	EFFECT SIZE
CONTROL	870	7.88 2.99	7.19 2.97	-0.69	-0.47- -0.92	-5.96	.00	-0.23
TREATMENT	1473	7.99 3.01	8.51 3.39	0.52	0.34- 0.70	5.68	.00	0.16

### Impact on Assessment

The output from the Condition and Class-Covariate Models are presented in Table D-2. The model attempts to address the question: After attempting to control for student pre-test (i.e. pre-assessment) scores (and other baseline variables), what is the impact of the NASA AAA curriculum module on students’ knowledge of infrared astronomy and the electromagnetic spectrum? In other words, we are interested in what a control student’s knowledge of the electromagnetic spectrum would be if his/her instructor, in an alternative universe, were assigned to teach the NASA AAA curriculum module. Because students cannot participate in both conditions simultaneously, our randomized trial is a proxy for this counterfactual scenario.

**Table D-2. Student Assessment Modeling Output with Class Characteristics**

	Condition Model			Class Covariate Model		
	Coef	SE	P	Coef	SE	p
Intercept	4.60	0.34	0.00*	5.50	0.48	.00*
PreTest	0.33	0.02	0.00*	0.31	0.02	.00*
Condition	1.12	0.38	0.01*	1.44	0.44	.00*
AP				2.85	0.52	.00*
Biology				-1.22	0.63	.06
Chemistry				-0.95	0.98	.34
Earth Science				-1.39	0.33	.00*
Intro Science				-2.89	1.35	.04*
Physics				-1.30	0.46	.01*
Condition Effect Size (hedges g)	0.35			.44		
Number of observations	2343			2343		

The main variable of interest in the models is the condition variable. For this variable, positive coefficients indicate higher post-test (i.e. post-assessment) scores for treatment students. The condition coefficient can be interpreted as the average difference in post-assessment achievement scores in the treatment relative to the control condition, given that the groups were equivalent prior to the intervention.

In both the Condition and Class-Covariate models, the estimate of the condition variable is positive – indicating greater post-test achievement in the treatment relative to the control group. **In both the Condition Model and Class-Covariate Model, there was a statistically significant positive effect of the condition variable.** In other words, in both models the effect of condition on student post-assessment scores is both statistically significant (p-value < .05) and has a substantively important effect size (> .25). The Department of Education’s What Works Clearinghouse considers effect sizes at or above 0.25 to be substantively important (WWC, 2018).

For example, in the Condition Model, the effect of condition is positive when controlling for pre-assessment score, with a 1.12 question improvement in post-assessment score; this

translates to a p value of  $< .05$  and an effect size of 0.35. In the Class-Covariate Model, the effect of condition is positive when controlling for pre-assessment and class characteristics, with a 1.44 question improvement translating to a p value of  $< .05$  and effect size of 0.44.

Table D-3 shows the number and proportion of students in each subject with complete demographics data, by condition group. Table D-3 shows there is not an equal distribution of subjects across subjects in the two conditions. For example, only 4% of control students are biology, compared to 27% of treatment students. Conversely, 10% of control students are chemistry but none of the treatment students are. However, subject was taken into account in impact analysis modeling to control for this difference.

**Table D-3. Number and proportion of students with complete demographics data in each subject by condition group**

	Control		Treatment	
Astronomy	119	15%	160	12%
Biology	31	4%	356	27%
Chemistry	76	10%	0	0%
Earth Science	319	40%	348	26%
Intro Science	0	0%	0	0%
Physics	251	32%	459	35%

Of the 2343 students who completed the post-assessment, 2117 completed the student survey section and provided demographic variables such as gender, ethnicity, and grade. There were 795 students in the control group and 1322 students in the comparison group who completed all demographics information.

We examined overall gains from pre-assessment to post-assessment for the subset of students who provided complete demographics information. As displayed in Table D-4 below, there is a statistically significant difference, at the 0.05 significance level, in pre-assessment to post-assessment scores for both the control and treatment groups. Results show that post-assessment scores decreased for the control group, while they increased for the treatment group after exposure to the NASA AAA curriculum module.

**Table D-4. Student Assessment Pre-test and Post-test Scores (Mean, Standard Deviations and Cohen’s D Effect Size of the Difference) for both condition groups**

CONDITION	N	PRE-TEST MEAN, SD	POST-TEST MEAN, SD	GAIN	95% CI FOR MEAN DIFF.	T-STATISTIC	P-VALUE	EFFECT SIZE
CONTROL	795	7.90 2.93	7.21 2.95	-0.68	-0.45- -0.92	-5.69	.00	-0.23
TREATMENT	1322	8.03 2.99	8.63 3.42	0.60	0.41- 080	6.22	.00	0.19

The output from the original Condition Model and the Student-Class-Covariate Model are presented in Table D-5. Both the Condition and the Student-Class-covariate models in Table D-5 were analyzed using only the data of students who provided complete demographics information. As such, the Condition Model from Table D-5 does not match the Condition Model from the preceding table.

As with the original Condition and Class-Covariate models, the models in Table D-5 attempt to address the question: After attempting to control for student pre-test scores (and other baseline variables), what is the impact of the NASA AAA curriculum module on students’ knowledge of infrared astronomy and the electromagnetic spectrum?

**Table D-5. Student Assessment Modeling Output with Student and Class Characteristics**

	Condition			Student-Class-Covariate			Student-Class-Interactions		
	Coef	SE	p	Coef	SE	p	Coef	SE	p
Intercept	4.53	0.34	0.00*	6.31	0.57	0.00*	6.26	0.58	0.00*
PreTest	0.34	0.02	0.00*	0.30	0.02	0.00*	0.30	0.02	0.00*
Condition	1.24	0.38	0.00*	1.47	0.42	0.00*	1.55	0.46	0.00*
AP				2.45	0.55	0.00*	2.44	0.55	0.00*
Biology				-1.39	0.67	0.05*	-1.39	0.67	0.05*
Chemistry				-0.47	0.96	0.63	-0.49	0.95	0.61
Earth Science				-1.49	0.41	0.00*	-1.49	.41	0.00*
Intro Science**	-	-	-						
Physics				-0.74	0.49	0.14	-0.73	0.49	0.14
Female				-0.21	0.12	0.09	-0.18	0.20	0.37
URM				-0.76	0.13	0.00*	-0.68	0.21	0.00*
10th Grade				-0.47	0.26	0.07	-0.47	0.26	0.07
11 <sup>th</sup> Grade				-0.56	0.32	0.08	-0.56	0.32	0.08
12 <sup>th</sup> Grade				-0.45	0.34	0.19	-0.45	0.34	0.20
Condition * Female							-0.04	0.26	0.87
Condition * URM							-0.13	0.27	0.62
Condition Effect Size (hedges g)	0.38			0.45			0.48		
Number of observations	2117			2117			2117		

\*indicates a statistically significant impact at the .05 alpha threshold

\*\* indicates no data in the model

In both models, the estimate of the condition variable is positive, with both a statistically significant effect (p-value < 0.05) and a substantively important effect size (> 0.25). **This indicates there was a statistically significant positive effect of the condition variable in both models.** In the Condition Model, the condition had a positive impact of a 1.24 question improvement in post-assessment scores, corresponding to a p value of < .05 and an effect size of 0.38. This is similar to the effect size we saw amongst the overall data set, of 0.35. In the Student-Class-Covariate Model, the effect of condition had a positive impact of a 1.47 question improvement in post-assessment scores, corresponding to a p value of < .05 and an effect size of 0.45, similar to the Class-Covariate Model effect size of 0.44. The Student-Class-Interaction

Model in Table D-5 also shows that there is no significant interaction between the treatment condition and student’s gender, nor between treatment condition and their ethnicity. This is to say that the NASA AAA curriculum module had a similar impact for both genders and across ethnic groups. The effect size for interaction models such as this are not typically interpreted.

**Astronomy/Physics/Earth Science Only**

Because the NASA AAA curriculum module was designed specifically for integration into courses centered on astronomy, physics, integrated science, or earth-space science, WestEd researchers conducted an impact analysis to look at the effects of the NASA AAA curriculum module on student learning outcomes for the subset of students who were enrolled in astronomy, physics, or earth science. As with the overall data set, three models were explored: a Condition model, a Class Covariate Model, and a Student-Class Covariate Model.

As with the overall data set, we examined overall gains from pre-assessment to post-assessment for students in astronomy, physics, or earth science, who completed the pre- and post-assessments. As displayed in Table D-6 below, there is a statistically significant difference, at the 0.05 significance level, in pre-assessment to post-assessment scores for both the control and treatment groups. Results show that post-assessment scores decreased for the control group, while they increased for the treatment group after exposure to the NASA AAA curriculum module.

**Table D-6. Student Assessment Pre-test and Post-test Scores (Mean, Standard Deviations and Cohen’s D Effect Size of the Difference) for students in select subjects by condition groups**

CONDITION	N	PRE-TEST MEAN, SD	POST-TEST MEAN, SD	GAIN	95% CI FOR MEAN DIFF.	T-STATISTIC	P-VALUE	EFFECT SIZE
CONTROL	758	7.95 3.04	7.23 3.03	-.73	-0.48 - -0.97	-5.71	0.00*	-0.24
TREATMENT	1065	8.11 3.09	8.66 3.51	.55	0.33- 0.77	4.93	0.00*	0.17

The output from the original Condition model and the Student-Class-Covariate Model are presented in Table D-7. Both the Condition and the Student-Class-Covariate models in Table D-7 were analyzed using only the data of students who were enrolled in astronomy, earth space science, or physics. As before, these models attempt to address the question: After attempting to control for student pre-test scores (and class variables), what is the impact of the NASA AAA curriculum module on students’ knowledge of infrared astronomy and the electromagnetic spectrum?

**Table D-7. Achievement modeling output for students in select subjects**

	Condition			Class-Covariate		
	Coef	SE	P	Coef	SE	p
Intercept	4.83	0.41	0.00*	5.70	0.53	0.00*
PreTest	0.31	0.02	0.00*	0.28	0.02	0.00*
Condition	1.22	0.46	0.01*	1.49	0.51	0.01*
AP				3.04	0.54	0.00*
Earth Science				-1.42	0.34	0.00*
Physics				-1.40	0.49	0.01*
Condition Effect Size (hedges g)	0.37			0.45		
Number of observations	1823			1823		

As before, the main variable of interest is the Condition variable, for which positive coefficients indicate higher post-test scores for treatment students. In both the Condition and Class-Covariate models, the estimate of the condition variable is positive – indicating greater post-test achievement in the treatment relative to the control group. **In both the Condition Model and the Class Covariate Model, there was a statistically significant positive effect of the condition variable.**

For both the Condition Model and the Class Covariate Model, the condition variable had a statistically significant positive effect and a substantively important effect size. The coefficients and effect sizes for the condition variable in both models were similar to those observed amongst the overall data. For example, the effect size was 0.37 for the subset Condition Model

(i.e. students enrolled in astronomy, physics, or earth science) and 0.35 for the overall Condition Model. Similarly, the effect size was 0.45 for the Class-Covariate Model in the subset and 0.44 in the overall Class-Covariate Model.

As with the overall data set, we examined overall gains from pre-assessment to post-assessment for the subset of students enrolled in astronomy, physics, or earth science, who provided complete demographic information. As displayed in Table D-8 below, there is a statistically significant difference, at the 0.05 significance level, in pre-assessment to post-assessment scores for both the control and treatment groups. Results show that post-assessment scores decreased for the control group, while they increased for the treatment group after exposure to the NASA AAA curriculum module. This trend mirrors that observed amongst the complete data set.

**Table D-8. Student Assessment Pre-test and Post-test Scores (Mean, Standard Deviations and Cohen’s D Effect Size of the Difference) for students in select subjects with demographics data in both condition groups**

CONDITION	N	PRE-TEST MEAN, SD	POST-TEST MEAN, SD	GAIN	95% CI FOR MEAN DIFF.	T-STATISTIC	P-VALUE	EFFECT SIZE
CONTROL	688	7.98 2.98	7.24 3.01	-0.74	-0.48- -1.00	-5.60	0.00*	-0.25
TREATMENT	967	8.12 3.07	8.76 3.54	0.64	0.41- 0.87	5.42	0.00*	0.19

For the subset of students enrolled in astronomy, physics, or earth science, the output from the original Condition Model and the Student-Class-Covariate Model in Table D-9 were analyzed using only the data of students who provided complete demographics information. As such, the Condition Model from Table D-9 does not match the Condition Model from the preceding table.

**Table D-9. Student Assessment Modeling Output with Student and Class Characteristics for Students In Select Classes**

	Condition			Student-Class-Covariate			Student-Class Interaction		
	Coef	SE	p	Coef	SE	p	Coef	SE	p
Intercept	4.75	0.42	0.00*	6.54	0.64	0.00*	6.50	0.65	0.00*
PreTest	0.31	0.03	0.00*	0.27	0.03	0.00*	0.27	0.03	0.00*
Condition	1.31	0.48	0.01*	1.54	0.50	0.01*	1.62	0.53	0.01*
AP				2.67	0.57	0.00*	2.65	0.57	0.00*
Earth Science				-1.60	0.44	0.00*	-1.60	0.44	0.00*
Physics				-0.79	0.53	0.15	-0.78	0.53	0.15
Female				-0.30	0.14	0.04*	-0.17	0.22	0.44
URM				-0.74	0.16	0.00*	-0.76	0.23	0.00*
10th Grade				-0.37	0.31	0.23	-0.37	0.31	0.23
11 <sup>th</sup> Grade				-0.57	0.37	0.12	-0.57	0.37	0.12
12 <sup>th</sup> Grade				-0.48	0.39	0.22	-0.47	0.39	0.23
Condition * Female							-0.22	0.29	0.44
Condition * URM							0.04	0.31	0.90
Condition Effect Size (hedges g)	0.39			0.46			0.49		
Number of observations	1655			1655			1655		

In both models, the estimate of the condition variable remained positive, with both a statistically significant effect size (p value < 0.05) and a substantively important effect size (> 0.25). **This indicates there was a statistically significant positive effect of the condition variable in both models.** The condition variable had a positive impact of a 1.31 question improvement on post-assessment scores in the Condition Model, and a positive impact of a 1.54 question improvement in the Student-Class-Covariate Model; these values correspond to effect sizes of 0.39 and 0.46 for the condition variable in the Condition and Student-Class-Covariate models respectively. These values are similar to those observed in the overall Condition and Student-Class-Covariate models from Table D-5. Like the model in Table D-5, this model shows there is no significant interaction between the curriculum module and either gender or ethnicity.

## Appendix E: About the Authors

This report was written by Joshua Valcarcel and Dr. Ted Britton, with substantial quantitative consulting from Dr. Bryan Matlen. The report is based on a student assessment developed by Dr. Daniel Brenner and Matt Silberglitt, M.A. Josh Valcarcel completed his Master's degree in program evaluation at Claremont Graduate University and has conducted numerous educational evaluations at WestEd, including serving as the Project Director for the past two-years for evaluation of the NASA AAA program. Ted Britton serves as Associate Director of the WestEd STEM program, and has lead several major research and evaluation projects. Bryan Matlen is a senior methodologist for several large-scale efficacy studies at WestEd and leads formative and summative evaluations of educational technology products. Bryan Matlen currently serves as the Principle Investigator (PI) of an IES funded project which investigates optimal ways of designing STEM visuals and co-PI on an NSF funded project which explores how analogical principles interact to support learning in mathematics classrooms. Matt Silberglitt has managed development of science assessments for WestEd in the states of Massachusetts and Nevada, and contributed to the development of science assessments in Kentucky, Kansas, Ohio, Louisiana, and West Virginia. Matt has also overseen development of science assessments at Minnesota Department of Education and developed assessments at Data Recognition Corporation. Matt Silberglitt has also taught high school astronomy and started astronomy clubs at two schools in Minnesota. Dr. Daniel Brenner received his Ph.D. in chemistry and manages the technology aspects of the SimScientists projects, developing and testing simulation-based assessments and instruction for middle school science.

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