ESTABLISHING A LEARNING PROGRESSION FOR THE SCIENCE AND ENGINEERING PRACTICE OF DEVELOPING AND USING MODELS FOR MIDDLE SCHOOL STEM STUDENTS

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2024

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GLOSSARY or NOMENCLATURE

BEAR – Berkely Evaluation and Assessment Research

CAT – Classroom Assessment Technique

DCI – Disciplinary Core Ideas

ESS – Earth and Space Science

ISHCMC-AA – International School Ho Chi Minh City – American Academy

LP – Learning Progression

LS – Life Science

MS – Middle School

NGSS – Next Generation Science Standards

PS – Physical Science

SEP – Science and Engineering Practices

SPA – Short Performance Assessment

STEM – Science Technology Engineering Math

ABSTRACT

The framework of the Next Generation Science Standards (NGSS) groups together middle school students as a single "grade band" for learner outcomes. At the International School of Ho Chi Minh City – American Academy (ISHCMC-AA) middle school STEM teachers have observed considerable differences academically between grade 6, 7, and 8 students. Therefore, establishing a learning progression (LP) for science and engineering practices (SEP) would be highly beneficial for the middle school STEM department. This action research used a mixed-methods approach to triangulate data of student performances and perceptions of strengths and weaknesses for the SEP of developing and using models of novel phenomena. Based on data collected from middle school STEM students (N=85) a LP that increases in science skills and cognitive abilities for learning outcomes by the ends of grades 6, 7, and 8 has been established and used as a department wide standard of student performance expectations.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

This action research (AR) project was aimed to establish a learning progression (LP) for the science and engineering practice (SEP) of developing and using models for the middle school STEM department at the International School of Ho Chi Minh City – American Academy (ISHCMC-AA). I chose this research topic as the framework of the Next Generation Science Standards (NGSS) groups together middle school learner outcomes as a single grade band for grades 6-8. However, I often considered how to better meet the needs of students at my school by establishing performance expectations for each individual grade level. To address this problem, I undertook this AR project to establish a LP of performance expectations of the SEP developing and using models. This LP would be beneficial to STEM teachers at ISHCMC-AA by providing direction and support in efforts to increase science literacy in middle school STEM students. Through this AR project, a LP that increases in science skills and cognitive abilities of performance expectations for the SEP of developing and using models has been established for grades 6, 7 and 8 STEM classes.

Focus Question

My focus question was, How does a leveled learning progression for the science and engineering practice of developing and using models increase science literacy skills through performance expectations in middle school STEM students?

My sub-questions include the following:

1. To what extent does providing a leveled learning progression for developing and using models impact student performances for grades 6, 7, and 8?
2. How do student perceptions of strengths and weaknesses differ for developing and using models for grades 6, 7, and 8?
3. How does a learning progression for developing and using models impact middle school STEM teachers at ISHCMC-AA?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Introduction and Background

The NGSS framework outlines a learning progression for students in grades K-12 which focuses on science literacy skills that increase in complexity from elementary to high school with grade bands: k-2, 3-5, 6-8, 9-12 (NGSS, 2013). Science literacy is broadly defined as equipping students with core ideas, practices, and crosscutting concepts necessary to become scientifically literate through developing critical thinking and problem-solving skills (NGSS, 2013). However, the decision of the National Research Council to utilize grade bands instead of creating specific standards that are grade-by-grade can create challenges through learning gaps for students, additional work for teachers, and difficulty creating textbooks that are grade specific. A LP for the SEP of developing and using models has been included within the NGSS framework, which builds on the experiences from the previous grade band and progresses in performance expectations (Figure 1) (NGSS, 2013). Within these grade bands there should be a "seamless articulation from elementary to middle to high school" where courses and assessments are carefully planned with little repetition of content in order to create a pathway to excellence in science literacy (Adams, 2014, p. 59). With the grade band expectations identified in the NGSS, teachers should also consider how to differentiate or scaffold assessments to support the ongoing development of individual student abilities and achieve equity in science education (Adams, 2014, p. 53).

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions. • Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences. • Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). • Develop a simple model based on evidence to represent a proposed object or tool.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Identify limitations of models. • Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Develop and/or use models to describe and/or predict phenomena. • Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Evaluate limitations of a model for a proposed object or tool. • Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms. • Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. • Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Figure 1. Screenshot of Appendix F of the NGSS with progression of grade bands for SEP developing and using models (NGSS, 2013).

When assessing students, teachers should not assume a *one size fits all* method of evaluation (Blaz, 2008). Dr. Carol Ann Tomlinson describes differentiation as "tailoring instruction to meet individual student needs" (Reading Rockets, n.d.). Teachers must be responsive to learners and differentiate instruction to "create different levels of expectations for task completion" (Tobin, 2008, p. 159). Tasks should be designed to match student readiness and growth that is ongoing and built into the curriculum. Assessments may be modified to include different grade-level performances identified in the NGSS and accurately gauge the growth of learners. Thus, creating a progression of performance expectations within the SEPs is a crucial

approach in differentiation at individual grade levels, and a leveled learning progression for developing and using models would benefit middle school STEM students.

Findings that Provide Direction

Learning progressions for science and engineering practices should be accessible and meaningful for learners and build skills essential for developing science literacy. Scientific modelling is defined as "including elements of the practice (constructing, using, evaluating, and revising scientific models) and the metaknowledge that guides and motivates the practice (e.g., understanding the nature and purpose of models)" (Schwartz et al., 2009, p. 632). A study in two Midwestern cities was conducted to develop a learning progression for 5th and 6th grade students engaged in scientific modelling (Schwartz et al., 2009). Illustrations were collected that showed both groups of students engaged in creating and revising increasingly accurate models throughout the progression that included explanations and predictions of phenomena. Follow-up interviews were conducted with students to explain their model (Schwartz et al., 2009). From this study, a learning progression that includes four learning levels of performance expectations was established for understanding models as generative tools for predicting and explaining.

Data collected from these 5th and 6th grade indicated increasing abilities to explain phenomena by using higher order thinking skills through developing models (Schwartz et al., 2009). Having students perform illustrations to model phenomena generates data that can be collected and analyzed to create an evidence-based learning progression. Important elements to consider in this progression include making connections between components to describe and explain the model, and to evaluate limitations of the model. Student feedback or follow-up

interviews can generate data to analyze student perceptions of strengths and weaknesses of their models.

Theoretical Articles that Provide a Framework

The transition through middle school and into adolescence is a period of developmental change. A study addressed this gap in development by examining normative patterns of mean-level change in 665 youth from 3rd, 6th, and 9th grades to determine positive and negative affects through adolescent development (Griffith et al., 2021). Negative and positive trait affects were sampled through a questionnaire to measure youth emotions on a 5-point Likert scale to sample emotional states over "the past few weeks" (Griffith et al., 2021). Positive emotional states comprised of 12 items such as "cheerful", "delighted", and "calm", while negative emotional states included "frightened", "ashamed" and "upset" (Griffith et al., 2021). Data was analyzed with multi-level growth curve models and revealed declines in positive affect and non-linear patterns of alternating increases and decreases in negative affect (Griffith et al., 2021). Results from this study reveal the importance of understanding the process of risk and resilience as students transition from middle childhood through adolescent years (Griffith et al., 2021).

Teachers can generate student feedback through 5-point Likert scales to help support challenges faced during periods of developmental change. A survey like this can be used to better understand student challenges and create a classroom environment that can adapt to the "neurological, physiological, cognitive, and social changes that occur during adolescence" (Coe-Odess et al., 2019, p. 595). For the purpose of developing a learning progression for SEPs, survey questions could generate data to better understand student strengths and weaknesses in the skills necessary to develop and use models. Along with this student survey, teachers should

differentiate assessment to meet each student at their individual needs or grade level expectation, while being mindful that students may face risk and resilience while performing the expectations in a middle school science class.

Articles that Provide Helpful Methodologies

The development and evaluation of a learning progression for argumentation in science is essential to the core practices of the NGSS. Osbourne et al. (2016) conducted a hypothesized three-tiered learning progression for scientific argumentation. This study was conducted over a four-year period that collected data from approximately 2000 students with the goal of answering two research questions: (1) How do middle school students demonstrate competence with increasingly complete argumentation in the context of the structure of matter? and (2) To what extent is student competence with increasingly complete argumentation generalizable? (Osbourne et al., 2016). Assessments were rigorously developed based on the Berkely Evaluation and Assessment Research (BEAR) system and includes three differentiated levels of intrinsic cognitive load, each increasing level requiring more connections made between claims and evidence (Osbourne et al., 2016). To determine the validity of each assessment, think aloud interviews with 8th grade students were conducted to identify item flaws and detailed scoring guides were established from items based on the pilot tests (Osbourne et al., 2016).

Assessments were then administered to 8th grade students and scored based on the moderated item rubrics, which were analyzed through Rasch analysis to determine findings form the schools (Osbourne et al., 2016). Results provided empirical evidence for a learning progression of students' ability to construct argumentation in science. In the lowest level of the learning progression, students are able to describe a claim and identify warrants and evidence. In

the second level of the progression, students are able to coordinate at least two elements of an argument, such as identify the elements of an argument and explain the relationship between them. In the third level, students are able to describe comparisons and critique arguments which requires the coordination of multiple cognitive elements (Osbourne et al., 2016).

Short performance assessments can be used to generate data and determine the level of science literacy in middle school STEM students. In order to practice higher order thinking skills in science, students should be provided opportunity to measure their achievements through carefully constructed learning tools. It is stated "to build coherent and evidence-based learning progressions, it is necessary to ensure the quality of assessments" (Osbourne et al., 2016, p. 831).

The BEAR assessment system is a tool used to validate learning progressions through assessments. This integrated approach is used to develop meaningful interpretations of student work relative to the cognitive and developmental goals of a curriculum (Draney, 2009). The BEAR system encompasses four building blocks to construct quality assessments to establish learning progressions:

- Construct Maps
- Items Design
- Outcome Space
- Measurement Model (Draney, 2009)

The first building block of the BEAR assessment system is the construct map, used to represent a theory of leaning from a developmental perspective how student progress from less expert to more expert. The second building block is the items design used to elicit specific kinds of evidence about student knowledge found in the construct map. The third building block is the outcome space, which describes the qualitatively different levels of responses as evidence on the construct map for each short performance assessment. The final building block of the BEAR

assessment system is the measurement model which describes the reasoning for student understandings and performance expectations (Draney, 2009).

CHAPTER THREE

METHODOLOGY

The purpose of this AR project was to establish a learning progression for the SEP of developing and using models for the middle school STEM department at the International School of Ho Chi Minh City – American Academy. The main question for this project is "How does a leveled learning progression for the science and engineering practice of developing and using models increase science literacy skills through performance expectations in middle school STEM students?" Supporting questions include "To what extent does providing a leveled learning progression for developing and using models impact student performances for grades 6, 7, and 8?", "How do student perceptions of strengths and weaknesses differ for developing and using models for grades 6, 7, and 8?" and "How does a learning progression for developing and using models impact middle school STEM teachers at ISHCMC-AA?". This project had approved protocol status by the IRB under protocol number 2023-1074-EXEMPT (Appendix A).

Demographics

The International School of Ho Chi Minh City – American Academy is located in Ho Chi Minh City, Vietnam. The school is fully accredited through the Council of International Schools and is Vietnam's leading American international secondary school. The middle school has a student body of 85 students (N=85) and focuses on development of foundational skills, effective attitudes for learning, and independence and positive relationships (AAVN, 2023). Students are from predominantly affluent socioeconomic background and have learned English as a second language. The teaching environment is supportive as the middle school STEM department has

two professional science teachers, two teaching assistants, one lab tech, two language specialists, and a behavior specialist.

Treatment

I implemented this AR in three treatments: within the first, second, and third quarters (Q1, Q2 and Q3) of the 2023-2024 academic school year. I collected data for all three rounds of treatment for STEM 6, 7 and 8 classes using four data collection methods:

1. A formative classroom assessment technique (CAT) of misconception probe.
2. A short performance assessment of the SEP developing and using models for a novel phenomenon.
3. A student survey with Likert scale.
4. Small group student interviews.

The focus treatment consists of students completing a short performance assessment on developing and using models aligned with an NGSS standard. For Q1, Q2 and Q3 I proceeded with my usual classroom instruction and the addition of the four data collection techniques.

Table 1. Treatment schedule for grade level with corresponding NGSS standard.

Date	Grade	NGSS Standard
Quarter 1 October	6	MS-ESS1-1 Earth-Sun-Moon System – Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons
	7	MS-PS1-1 Atomic Composition Model – Develop models to describe the atomic composition of simple molecules and extended structures.
	8	MS-ESS1-2 Gravity and Motions in Space – Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system
Quarter 2 December	6	MS-LS1-7 Food and Chemical Reactions – Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.
	7	MS-LS2-3 Matter Cycling and Energy Flow in Ecosystems – Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
	8	MS-ESS2-1 Cycling of the Earth's Materials – Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process (tectonic plates).
Quarter 3 March	6	MS-ESS2-4 Cycling of Water Through Earth's System – Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
	7	MS-PS4-2 Wave Reflection, Absorption, and Transmission – Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
	8	MS-ESS2-1 Cycling of the Earth's Materials – Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process (rock type and faults).

Treatments were completed during one 80-minute STEM class in which students completed a formative CAT of misconception probe, short performance assessment for developing and using a model, and a Likert survey of student perceptions of strengths and weaknesses, and a small group interview with students after completion of the assessment. Students were encouraged to use their science notebooks while completing assessments, as I have an open-notebook policy in all middle school classes to emphasize comprehension over

memorization. All phenomena used in the short performance assessments were novel and students did not have examples from which to copy or recall in their notebooks.

The formative misconception probe ensured students understood the disciplinary core idea of the model to be developed. For example, the STEM 6 class completed a misconception probe of a total solar eclipse (Appendix B) which uncovered student understandings and prepared the class to develop a model of a total lunar eclipse (Appendix K).

Students used the majority of class time to complete the short performance assessment of developing a model for the novel phenomenon. Background information about each phenomenon was given with instructions that provided direction of what to model. Students worked individually to complete their models and submitted when finished. Upon submission students answered a 5-point Likert survey questionnaire that reflected the rubric on the performance assessment.

Towards the end of class and after all assessments had been submitted, I conducted small group interviews with volunteer students to answer a few questions pertaining to their assessment (Appendix U). These conversations were casually held at a standing desk in the classroom and student responses were recorded on a word document.

Instrumentation

A construct map was established following the Berkely Evaluation and Assessment Research system for developing a learning progression. This construct map provided a theoretical proposal of how performance expectations should progress in skill level for each middle school grade (Table 2). To create this construct map of performance expectations I referenced Appendix F of the NGSS (Figure 1) (NGSS, 2013) and a single point rubric provided

for developing and using models from The Wonder of Science resources page (The Wonder of Science, n.d.).

Table 2. Construct map of performance expectations by grade level.

Level	Grade	Performance Expectations
1	6	◘ Develop a model to describe phenomena. ◘ Identify and label components of the model using a word bank. ◘ Describe connections between components of the model. ◘ Models developed include drawings and 3D constructed.
2	7	◘ Develop and/or use a model to predict and/or describe phenomena. ◘ Identify and label *correct* components of the model using a word bank. ◘ Describe connections between components of the model. ◘ Evaluate limitations of a model. ◘ Models developed include drawings, 3D constructed, and digitally produced.
3	8	◘ Develop and/or use a model to predict and/or describe phenomena. ◘ Identify and label components of the model. ◘ Describe connections between components of the model. ◘ Use connections to describe, explain and predict changes to the model. ◘ Develop a model to describe unobservable mechanisms, or causal accounts for the phenomenon. ◘ Connect the model to the phenomenon using the relevant crosscutting concept. ◘ Models developed include drawings, 3D constructed, digitally produced, and computer simulations.

The classroom asessment technique of misconception probe was a formative assessment to determine a baseline for student readiness prior to completing the performance assessment. The probes were created in the style of Page Keely's "Uncovering Student Ideas," (Uncovering Student Ideas, 2022) where students were presented a scenario of with novel phenomenon from which they choose a student response they agreed with most. This misconception probe ensured students understood the disciplinary core idea of the standard being assessed and were able to identify components of the model to be performed (Appendices B, C, D, E, F, G, H, I, J).

Short performance assessments (Appendices K, L, M, N, O, P, Q, R, S) were created for students to develop a model of a novel phenomenon. The core ideas of the assessment and phenomena used were primarily adapted from two resources: Inner Orbit (Inner Orbit, n.d.) and The Wonder of Science (The Wonder of Science, n.d.). These assessments have been constructed to reflect the Items Design building block of the BEAR system for validating a learning progression (Draney, 2009). To ensure quality and NGSS alignment I used the performance assessment screening tool provided by The Wonder of Science resources page (The Wonder of Science, n.d.). Data was collected on single-point, standards-met rubrics, which were used to validate student proficiency of science skills through performance expectations at each middle school grade level.

Data Collection and Analysis Strategies

I collected data from all middle school STEM students at ISHCMC-AA (*N*=85) using a mixed-methods approach. The sample size for STEM 6 includes 16 students in section 6.1 and 15 students in 6.2 (*N*=31), STEM 7 includes 16 students in section 7.1 and 14 students in 7.2 (*N*=30), and STEM 8 has one class of 23 students (*N*=24), however there were small fluctuations in class size for each treatment due to student absences or changes in student enrollment. This mixed-methods approach included triangulating data (Table 3) from short performance assessments, student survey with Likert scale (Appendix T), and small group interviews (Appendix U). I made arrangements to implement and collect data for all middle school STEM classes three times in the 2023-2024 academic school year. Data collected aligned with current units of study for all classes. Each treatment section included all four data collection methods.

Table 3. Data Triangulation Matrix.

Research Questions	Formative assessment	Short performance assessments	Student Survey with Likert scale	Small Group Interview
Main Question: *How does providing a leveled learning progression of science and engineering practices in differentiated assessments increase science literacy in middle school STEM students?*	X	X	X	X
Sub Question: *How do student perceptions of strengths and weaknesses differ for the science and engineering practice of developing and using models for grade 6, 7, and 8?*		X	X	X
Sub Question: *How does a learning progression for the science and engineering practice of developing and using models impact middle school STEM teachers at the International School of Ho Chi Minh City – American Academy?*		X	X	X

The formative results of the CAT were collected from students and immediately disseminated to the class by creating a bar graph of student responses drawn on the whiteboard (Figure 2). Each incorrect response was analyzed and explained why it was incorrect, and the correct response was described in detail to prepare students and set a baseline of understanding before moving on to the next step of treatment.

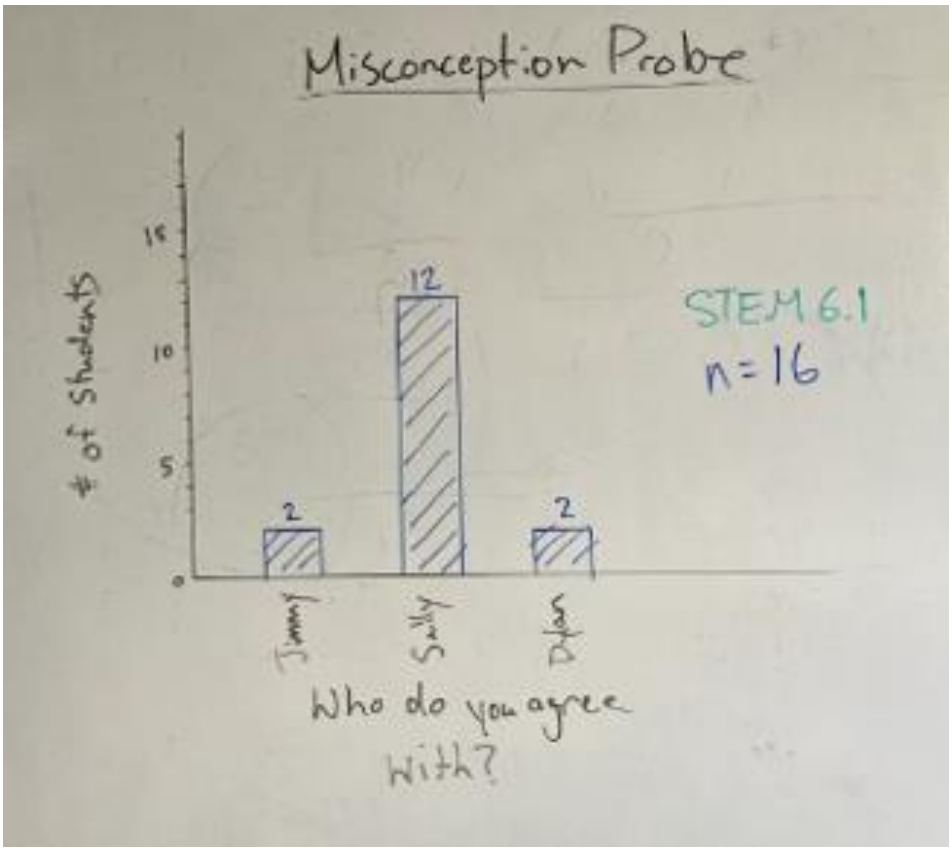


Figure 2. Example of how results from CAT were disseminated to class, (*n*=16).

The short performance assessments (Appendices K, L, M, N, O, P, Q, R, S) were used to collect quantitative data and provide evidence for a learning progression for the SEP of developing and using models. Data was collected on single-point, standards-met rubrics, which were used to validate student proficiency and performance expectations at each middle school grade level. Instructions and grading rubric for each treatment reflected one level of the learning progression from the concept map. For example, instructions and rubric provided on the short performance assessment in treatment two reflected the performance expectations in level two on the concept map.

Immediately following the short performance assessment, students completed a survey in the format of a 5-point Likert scale (Appendix T). This questionnaire and student survey

collected data to determine perceptions of strengths and weaknesses while developing and using models. Evidence from this Likert survey provided data for descriptive statistics and determined measurements of central tendencies for each grade level's range of student confidence.

Finally, qualitative data from small group student interviews was collected to support, explain, and provide reasoning for results of quantitative student performances. These interviews included volunteers to reflect on the particular phenomenon they modeled and share thoughts about strengths and weaknesses from the assessment (Appendix U). Responses were recorded on a word document and were used to validate a finalized learning progression for developing and using models for the middle school STEM department at ISHCMC-AA.

CHAPTER FOUR

DATA ANALYSIS

Results of Student Performances

The classroom assessment technique of misconception probe was a valuable measure to establish a baseline of student understanding by revealing prior knowledge, boosting engagement, and promoting discussion on the concepts to be modeled. The misconception probes were administered at the beginning of each treatment in quarters 1, 2, and 3 of the 2023-2024 school year. The results of each misconception probe were disseminated and described to the class prior to beginning the short performance assessment. These misconception probes revealed the majority of students understood the scientific concepts to be modeled in the treatment (Table 4). Data from each class was used to uncover student understandings of why responses were either correct or incorrect. For example, one STEM 6 student incorrectly responded to the misconception probe about the lunar cycle "[I agree with] Dylan, because there [is] no moon in the daytime" which was corrected through classroom discussion and explanation for the correct option of Sally. When asked if the misconception probe helped students prepare for the short performance assessment, and how it helped, one student responded "Yeah, I was able to understand some of the concepts better and point out incorrect problems in someone else's thinking." Another student responded "Yes, because it tells you what is wrong and what is right and more information to know for the assessment."

Table 4. CAT misconception probe student results by class per quarter.

Quarter	Class	Sample Size	Answered Incorrect	Answered Correct
1	STEM 6	31	26%	74%
	STEM 7	30	17%	83%
	STEM 8	23	17%	83%
2	STEM 6	31	19%	81%
	STEM 7	30	0%	100%
	STEM 8	23	22%	78%
3	STEM 6	30	0%	100%
	STEM 7	29	10%	90%
	STEM 8	23	35%	65%

Short performance assessments were scheduled for the ends of quarters 1, 2, and 3 and aligned with the current unit of study for each STEM class. If results of student performances showed a decrease in average scores over the course of the year, this would indicate the need for scaffolding of assessment and a learning progression to be established for the science and engineering practice of developing and using models.

Statistical analysis for STEM 6 indicated an increase in average student performance scores of 7% from Q1 to Q2, and a gain of averages of 0.3 which would be considered medium and normalized (Hake, 1998). The average student performance scores decreased 27% from Q2 to Q3 and had a -1.5 gain of averages. Graphical analysis through box and whisker plot shows variation between treatments and were used to visualize significance (Figure 3). The median of the STEM 6 Q3 result is well below the lower quartile of Q2 and below the quartile of Q1, which suggests that the groups are significantly different. An ANOVA test was performed and showed significant differences between SPA scores between quarters ($p<0.05$) and was further verified

through a T-test ($p<0.05$). Students were most engaged in the Q2 SPA on MS-LS1-7 Food and Chemical Reactions, which may explain the higher average in performance scores (Appendix N). When asked how they felt about the SPA for the standard, one student responded, “I liked drawing the picture of how Son get[s] his energy from eating the bhan mi [sandwich]”. Another student responded, “It was easy to show how the food gets rearranged in the human body to give the soccer player energy.” The low performance scores on the Q3 assessment appear to be indicative of the higher performance expectations outlined on the rubric, such as being able to connect the model to a phenomenon using the relevant crosscutting concept or using the model to describe unobservable mechanisms.

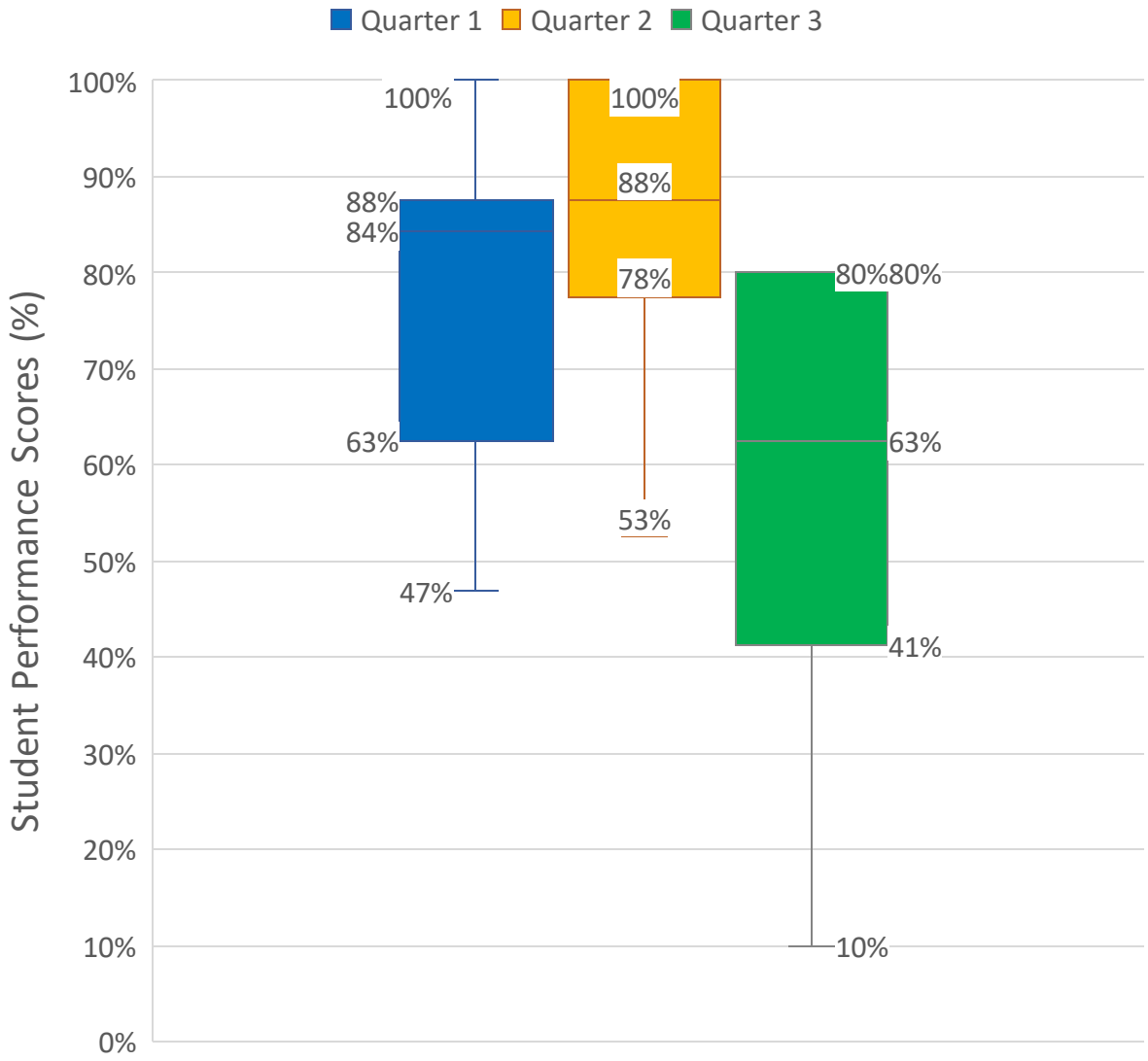


Figure 3. Box and whisker plot for STEM 6 short performance assessment scores by quarter. Q1: (*N*=31), Q2: (*N*=31), Q3 (*N*=30).

The results of the statistical analysis for STEM 7 showed a large decrease in average student performance scores of 17% from Q1 to Q2 and had a gain of averages of 0.0, or considered low (Hake, 1998). The average student performance scores decreased 3% from Q2 to Q3 and had a gain of 0.0, also considered low. Graphical analysis through box and whisker plot shows variation between treatments and were used to visualize significance (Figure 4). The

median decreased significantly from Q1 through Q3, and the medians for Q2 and Q3 are below the lower quartile of Q1 which indicates significant difference between student performance scores. An ANOVA test was performed and calculated with a p-value below 0.05 ($p<0.05$). A T-test to compare individual treatments indicated no significance between Q2 and Q3 performance scores with a p-value greater than 0.05, meaning the variance in scores is not significant. The drop on the Q3 short performance assessment on MS-PS4-2 could be due to students having just recently learned the concept of mechanical waves in the previous class. When asked if anything was unclear about the assessment one student responded, “We just learned this from Mr. Alan last class”. Another student stated they felt some weakness in modeling because, “I didn’t know what the components of a mechanical wave are.” Although this performance assessment was open notebook, it should be noted the STEM 7 teacher does not place as much emphasis on maintaining a well-organized notebook as the STEM 6 and 8 classes.

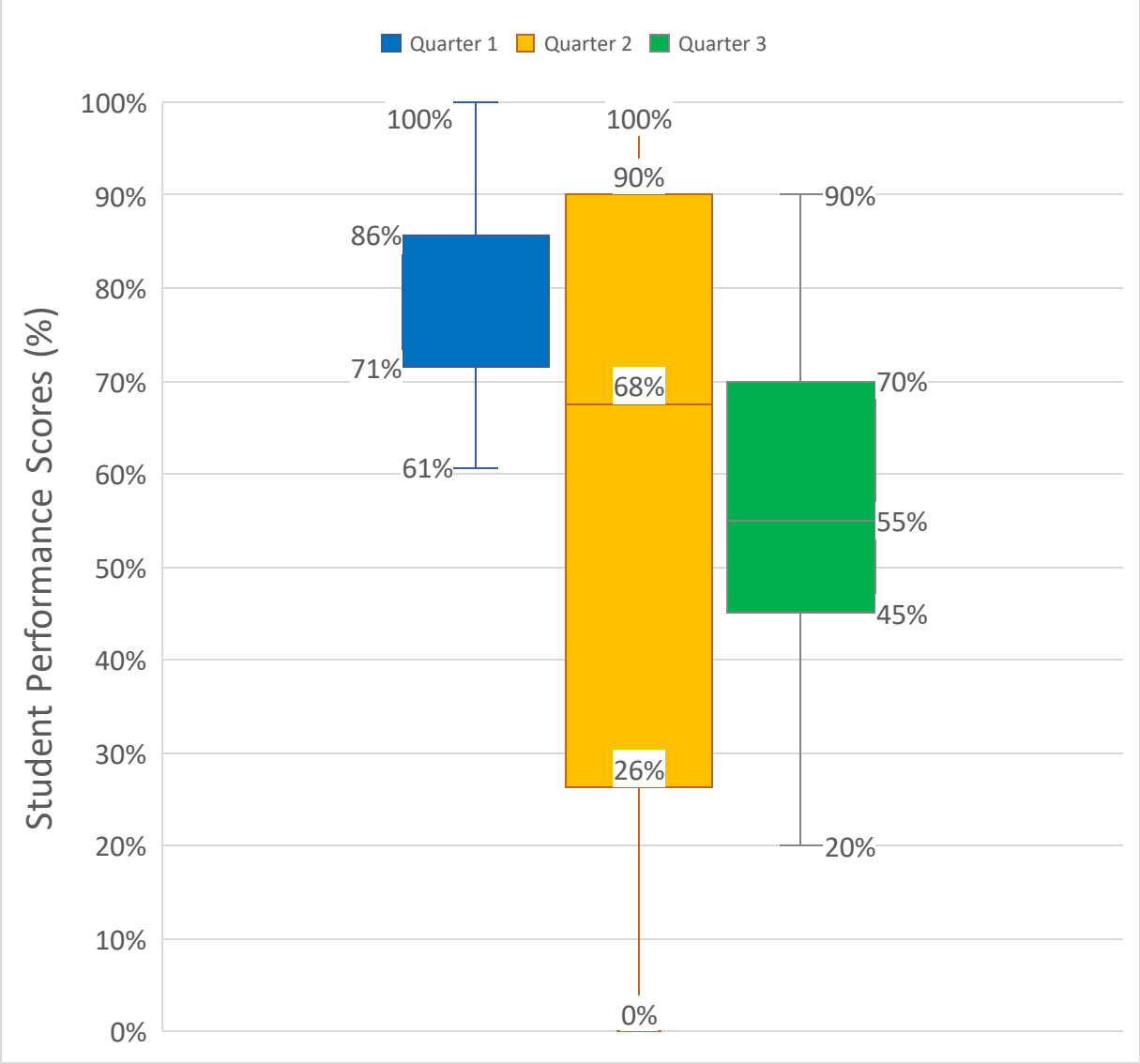


Figure 4. Box and whisker plot for STEM 7 short performance assessment scores by quarter. Q1: (*N*=30), Q2: (*N*=30), Q3 (*N*=29).

The results of statistical analysis from the STEM 8 class showed a large decrease in average student performance scores of 19% from Q1 to Q2 and had a gain of averages of 0.0, or considered low (Hake, 1998). The average student performance score increased 15% from Q2 to Q3 and had a gain of averages of 0.0, also considered low. Graphical analysis through box and whisker plot shows variation between treatments and were used to visualize significance (Figure

5). The median of the STEM 8 Q2 result is below the lower quartile of Q1, which suggests the groups are significantly different. An increase in median scores from Q2 to Q3 indicates less significance in student performance scores. An ANOVA test was performed and calculated a p-value below 0.05 and was further verified through a T-test. The T-test variance for Q1 and Q3 performance assessments calculated a p-value greater than 0.05 which indicates the performance scores are not significantly different from Q1 to Q3. When asked about the Q3 short performance assessment on the MS-ESS2-1 standard covering rock types and faults, one student stated, “This phenomenon is a bit more challenging than just modeling the rock cycle because we had to include what we learned about faults and tectonic plates in there, too.”

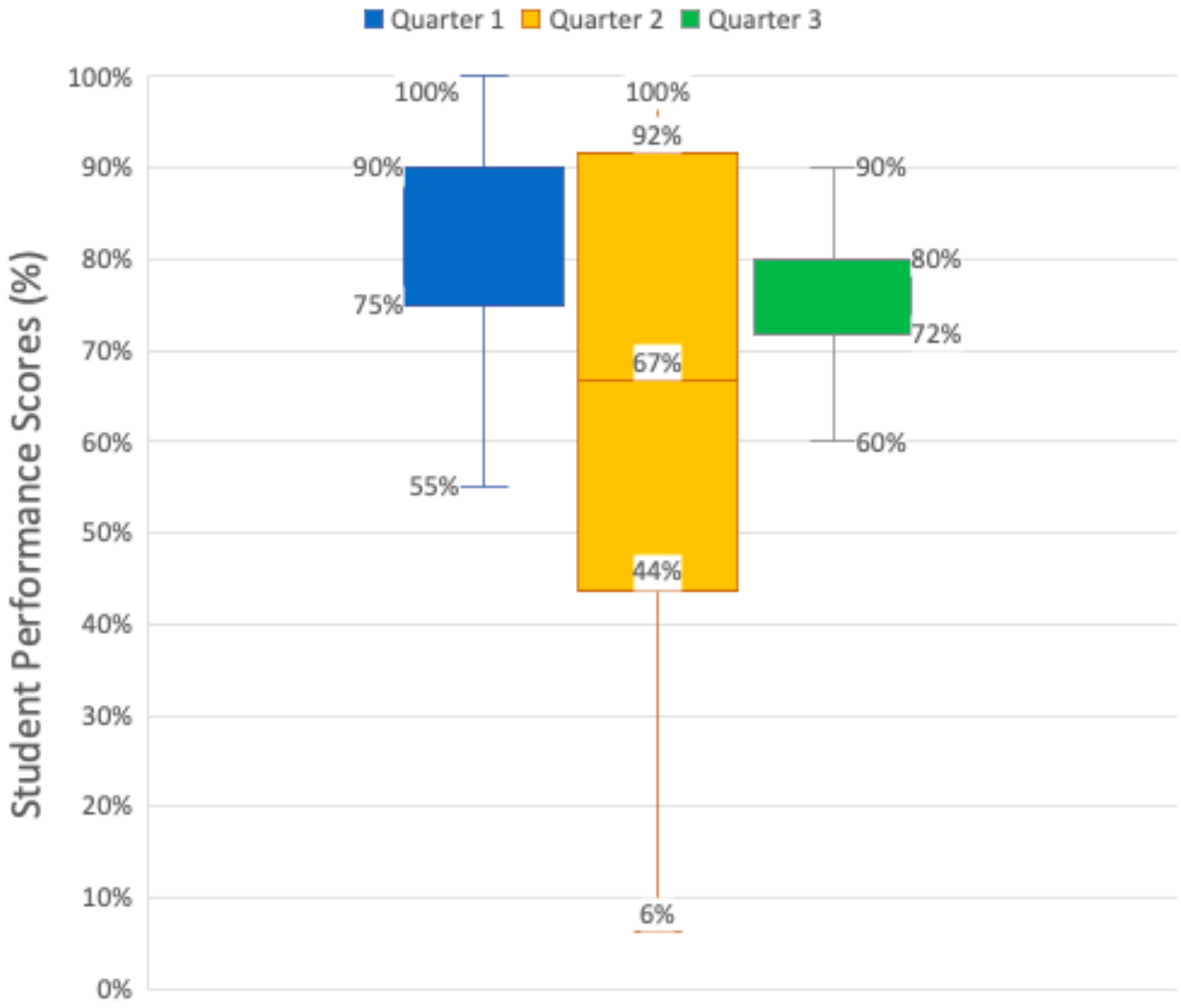


Figure 5. Box and whisker plot for STEM 8 short performance assessment scores by quarter. Q1: (*N*=23), Q2: (*N*=23), Q3 (*N*=20).

The statistical analysis from student results on SPAs for STEM 6, 7, and 8 indicate more significant variation in student scores in STEM 6, then STEM 7 and 8. Over the course of three treatments, the STEM 6 and STEM 7 classes had a similar decrease in average performance scores from Q1 to Q3 of 19% and 20% respectively, whereas STEM 8 had an average decrease of only 4%. STEM 6 and STEM 7 classes performed strongest when the expectations aligned with their grade level indicated on the concept map of learning progression and struggled

significantly more than STEM 8 when completing the Q3 assessment that aligned with STEM 8 performance expectations. This indicates scaffolding of assessments for the lower grade levels is necessary, and to establish a learning progression of performance expectations to better meet the needs of students at individual grade level.

Results of Student Perceptions of Strengths and Weakness

Students completed a survey in the form of 5-point Likert scale to indicate perceptions of strengths and weaknesses while performing the SEP of developing and using models. These Likert surveys were administered immediately following student submission of the short performance assessment. Data from each STEM class was collected and analyzed on a stacked bar graph. The graphs are organized by compiling questions 1-5 over the three treatments. Higher Likert survey scores represent strengths with the practice of developing and using models and indicate confidence in completing the performance task, while lower scores represent weaknesses and indicate lack of confidence in completing the performance task. Questions were the same for each treatment to display a comparative analysis over the three quarters. The questions include:

1. Identifying components of the model is easy
2. Labeling components of the model is easy
3. I can make connections between components in the model
4. I can use components to predict changes to the model
5. I can develop a model to explain a phenomenon

Visual analysis from the STEM 6 student surveys conducted show perceptions of strengths in identifying and labeling components of the model (Figure 6). The majority of students appear to have no opinion in making connections between components in the model,

predicting changes in the model, and developing a model to explain a phenomenon. There does not appear to be strong correlation between student perceptions and performance scores. For example, students scored strongest on the Q2 performance assessment yet there is no evidence from the Likert survey to indicate student perceptions of strengths. When asked how confident a student feels in their ability to develop and use models, one student responded they feel "somewhat confident, not much, like 1 to 5 I'd say 3."

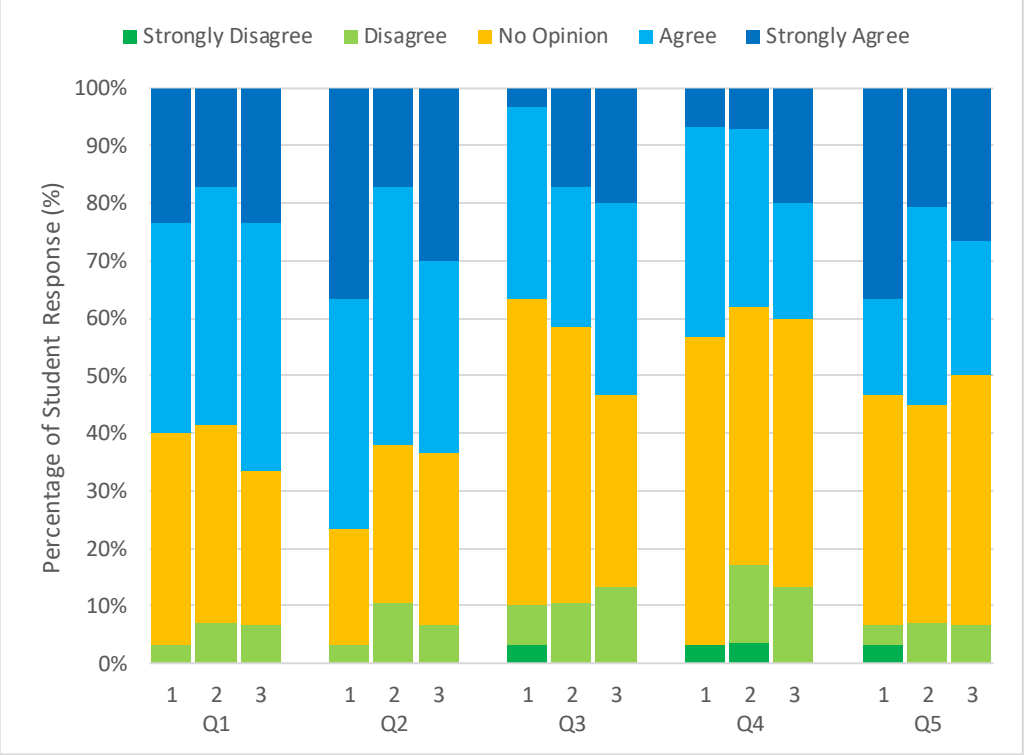


Figure 6. STEM 6 Likert data from 5-question student survey of strengths and weaknesses for each quarter, (*N*=92).

Visual analysis from the STEM 7 student surveys conducted show students felt strongest on the Q2 short performance assessment (Figure 7). There also appears to be a downward trend in feelings of weakness in using components of the model, to predict changes, and using a model to explain a phenomenon. There does not appear to be any significant differences in student

perceptions of strengths between performance assessments, however evidence from the performance scores suggests students had most difficulty completing the Q3 model which is not reflected in the Likert data. When asked how confident they feel in their ability to develop and use models in STEM class, one student responded "Yes, the more we do modelling activities the better I feel about connecting ideas and connecting to other concepts."

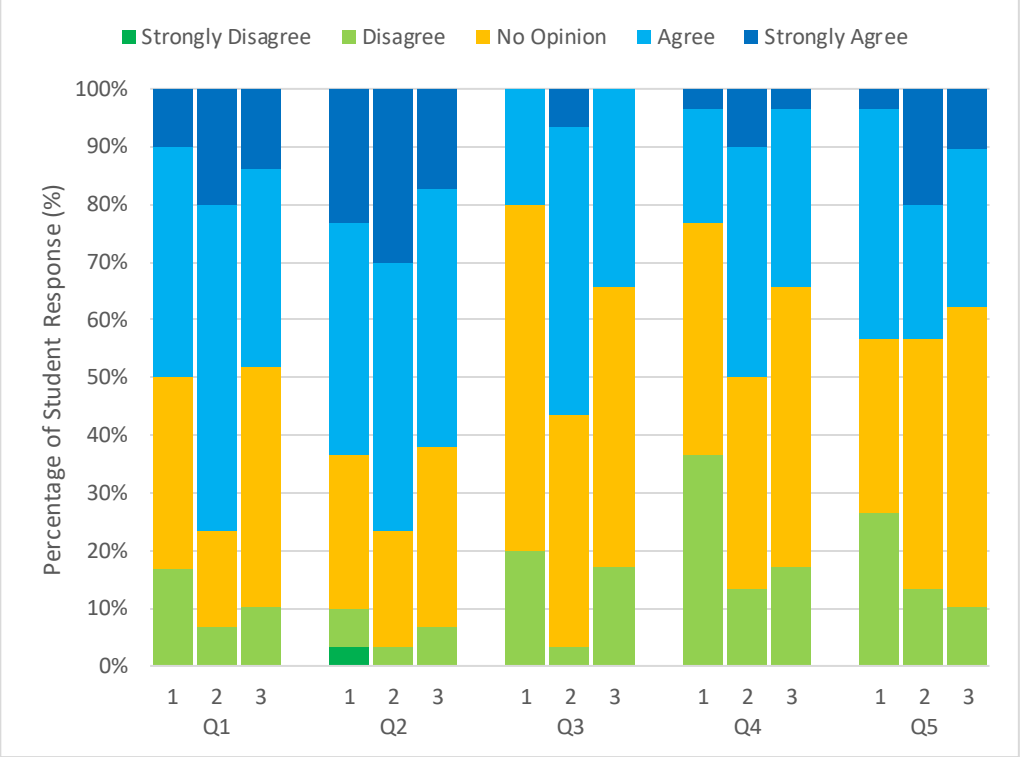


Figure 7. STEM 7 Likert data from 5-question student survey of strengths and weaknesses for each quarter (*N*=89).

Visual analysis from the STEM 8 student surveys conducted indicate the majority of students felt strongest on the Q1 short performance assessment (Figure 8). The most frequent response to all questions on the survey is "no opinion." Students appeared to feel weakest on the Q2 short performance assessment. There appears to be a downward trend in student responses that indicate feelings of strength over the three treatments, however evidence from the

performance assessments indicate an increase in student average of 15% from Q2 to Q3. Therefore, there does not appear to be any correlation between student perceptions of strengths and weaknesses and performance scores. When asked how confident a student feels in their ability to develop and use models after the Q3 assessment, one student responded, "I don't know if I've been right or wrong on these since we don't get them back and we don't get graded on it."

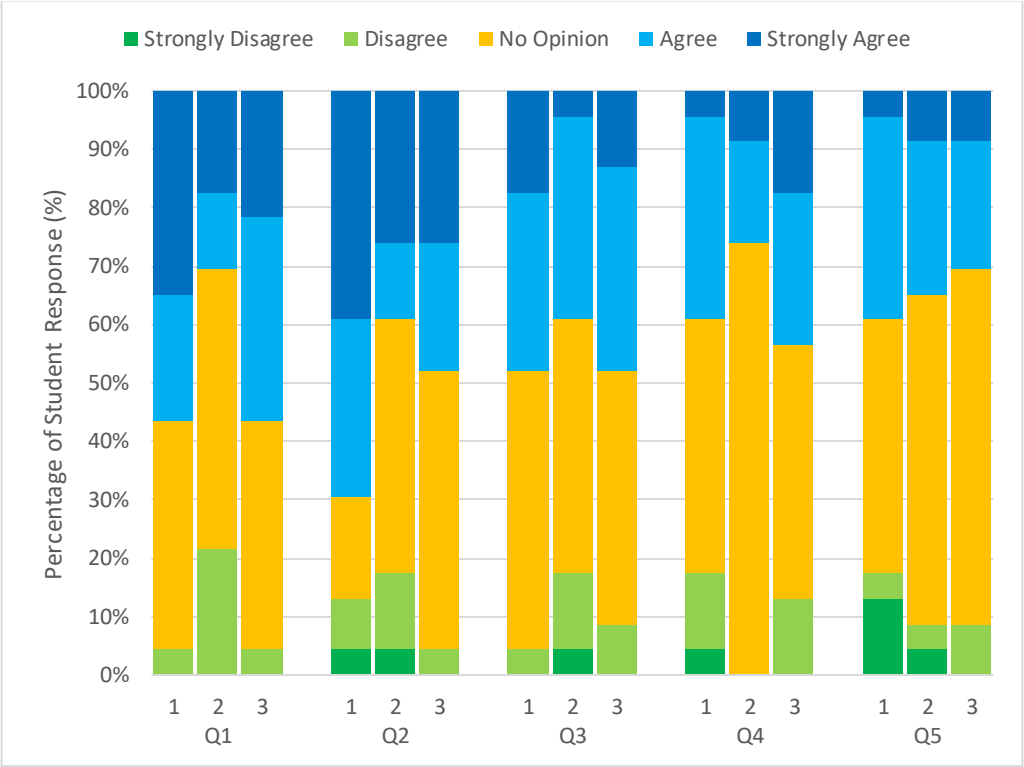


Figure 8. STEM 8 Likert data from 5-question student survey of strengths and weaknesses for each quarter, (*N*=66).

Visual analysis of all three STEM classes together do not indicate patterns or correlation between student perceptions of strength and weaknesses and performance scores. STEM 8 had the highest performance scores yet data from the Likert survey indicate large perceptions of no opinion or feelings of weakness. Likert data from the STEM 6 class indicates a high overall confidence level yet this was not reflected in performance scores, particularly in the Q3 short

performance assessment with greater performance expectations. STEM 7 had the lowest performance scores and moderate perceptions of strength and weaknesses and showed particular room for improvement on explaining their models.

CHAPTER FIVE

CLAIM, EVIDENCE, AND REASONING

Claims From the Study

The focus question for this AR project was to determine how a leveled learning progression of developing and using models impacted the science literacy skills of middle school STEM students. Within the focus question are three sub-questions: (a) how a learning progression for developing and using models impact student performances in grades 6, 7, and 8? (b) what do students feel are strengths and weaknesses for developing and using models? and (c) how does a learning progression for developing and using models impact MS STEM teachers at ISHCMC-AA?

A learning progression can positively impact MS STEM students' performance scores by aligning expectations to individual grade levels and cognitive abilities. From the box and whisker plots (Figures 3, 4, and 5), there is a clear distinction that STEM 8 met the highest level of performance expectations and had more competency in: making connections between components of the model, using components to make a change in the model, and using a model to explain a phenomenon. The average performance scores in STEM 8 were 81%, 65% and 77% in Q1, Q2, and Q3. STEM 7 performed lowest on the short performance assessments, with class averages of 75%, 57% and 55% in Q1, Q2, and Q3 respectively. One reason for this low student performance score outcome in STEM 7 could be due to the fact that another MS STEM teacher taught this class, whereas I taught both STEM 6 and STEM 8 and was able to build off prior knowledge from lessons for those classes. Another difficulty STEM 7 classes appeared to have

included using their model to explain a phenomenon. However, it should be noted that there are five (n=5) students in this class who are English language learners. STEM 6 appeared to do very well on the Q2 short performance assessment which had students develop a model of how a soccer player converts food to energy with a class average of 82%. There is a large student population of soccer players (n=12) in this class who appeared to take particular interest in this phenomenon and were very engaged in the activity. This showcases the importance of creating engaging assessments that spark student curiosity.

There does not appear to be any correlation of student perceptions of strengths and weaknesses and performance scores. STEM 8 students inversely had the highest performance scores yet the lowest perceptions of strengths when performing the short performance assessments. This could be due to a stage in adolescence when students feel cautious when facing risk and resilience that comes with performing in science class (Coe-Odess et al., 2019). Interestingly, the STEM 6 class had the highest perceptions of strengths when performing the assessments yet low performance score results. This could be due to students' willingness to take more risk at this stage in middle years development. STEM 7 had the highest trend of answering "no opinion" to the student survey, which seems to balance out the higher and lower grades.

This learning progression has impacted the MS STEM teachers at ISHCMC-AA by establishing a set of performance expectations for students to meet by the ends of grades 6, 7, and 8. The expectations in this progression have been discussed and agreed upon by both MS STEM teachers in the department and has received positive feedback from the high school science department, as well. This learning progression matches the construct map established following the BEAR system and reflects Appendix F of the NGSS framework (NGSS, 2013),

which represents a theory of learning from a developmental perspective how students will progress through grades 6, 7, and 8 (Draney, 2009). The following learning progression has been established:

Table 5. Established learning progression of performance expectations for grades 6, 7, and 8.

Grade	Performance Expectations
6	◘ Develop a model to describe phenomena. ◘ Identify and label components of the model using a word bank. ◘ Describe connections between components of the model. ◘ Models developed include drawings and 3D constructed.
7	◘ Develop and/or use a model to predict and/or describe phenomena. ◘ Identify and label *correct* components of the model using a word bank. ◘ Describe connections between components of the model. ◘ Evaluate limitations of a model. ◘ Models developed include drawings, 3D constructed, and digitally produced.
8	◘ Develop and/or use a model to predict and/or describe phenomena. ◘ Identify and label components of the model. ◘ Describe connections between components of the model. ◘ Use connections to describe, explain and predict changes to the model. ◘ Develop a model to describe unobservable mechanisms, or causal accounts for the phenomenon. ◘ Connect the model to the phenomenon using the relevant crosscutting concept. ◘ Models developed include drawings, 3D constructed, digitally produced, and computer simulations.

Value of the Study and Consideration for Future Research

This study has yielded valuable results that indicate a learning progression can positively impact MS STEM students' performance scores and abilities to predict phenomena in grades 6, 7, and 8. This learning progression includes clear performance expectations for the MS STEM department to follow at ISHCMC-AA and provide direction and support to increase science literacy in students as outlined by the NGSS. Elements of the science and engineering practice will guide and motivate students to build skills essential in modelling, including identifying and labeling components, making connections between components, predicting changes in a model,

and using a model to explain a phenomenon (Schwartz et al., 2009, p. 263). By identifying skills by grade level rather than grade band of the NGSS, teachers will be able to better differentiate or scaffold assessment to support the ongoing development of student abilities and create "a pathway to excellence in science literacy" (Adams, 2014, p. 59).

Future research could continue with establishing the remaining SEPs: asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating and communicating information. This study could have long term benefits to the MS STEM department at ISHCMC-AA, by outlining clear expectations for all assessments used at each grade level. Similar initiatives to establish learning progressions could be taken for the high school science courses and provide evidence for school-wide cohesion of vertical alignment in performance expectations.

Impact of Action Research on the Author

This action research project supported my professional development in better understanding how to meet the needs of MS students. Students embark on a number of developmental changes in the transition through middle school, which can have both positive and negative affects through adolescence (Griffith et al., 2021). It is important for teachers to be aware of these changes and create a classroom environment that can adapt to the diverse needs to students (Coe-Odess et al., 2019). An observation I have made while coaching middle school sports is the significant difference between a grade 6 and 8 students in their physiological, cognitive, and social abilities. Differentiated assessments should be created to spark interest and

curiosity of students, and a clear outline of performance expectations should be established in understanding student needs.

Creating and implementing rigorous assessments is a great teaching strategy to evaluate student performances. Misconception probes can be utilized to generate immediate feedback to both the teacher and students by uncovering student understanding and promoting class discussion through explanation of the science concept being studied. I will continue to create short performance assessments that provide students the opportunity to measure their abilities through carefully constructed learning activities that align with an NGSS standard. As the needs of each grade level will change from year to year and cohort to cohort, I can continue to use these short performance assessments as evidence-based learning to establish a progression of learner outcomes (Osbourne et al., 2016).

Generating student feedback through the 5-point Likert scale is a powerful and efficient way of allowing students to have a voice in their own learning. Even though it did not provide empirical evidence in establishing a learning progression in comparison to performance scores for grades 6, 7, and 8, I will continue to include student surveys following each unit to better understand student emotions on cognitive abilities. Rather than “Strongly Agree” to “Strongly Disagree”, I will adapt the method to sample emotional states such as “Cheerful” to “Upset” (Griffith et al., 2021).

Overall, the methods of implementing this AR project have most certainly allowed me to develop as a professional science educator, and I have enjoyed the challenges in understanding how to better meet the needs of students in the middle school years.

REFERENCES CITED

Adams, C. M. (2014). *Using the Next Generation Science Standards with gifted and advanced learners: A service publication of the national association for gifted children.* Prufrock Press Inc.

Coe-Odess, S., Narr, R., & Allen, J. (2019). Emergent emotions in adolescence. In V LoBue, K., Perez-Edgar, K. Buss (Eds.) *Handbook of emotional development*. Springer, 595-625.

Draney, K. (2009). Designing learning progressions with the BEAR assessment system. https://www.education.msu.edu/projects/leaps/proceedings/Draney.pdf

Griffith, J, M., Clark, H, M., Haraden, D, A., Young, J, F., & Hankin, B, L. (2021). Affective development from middle childhood to late adolescence: Trajectories of mean-level change in negative and positive affect. *Journal of Youth and Adolescence*, 50, 1550-1563.

Inner Orbit. (2017-2024). *Inner orbit assessments*. https://www.innerorbit.com/schools/teachers/assessments/

International School of Ho Chi Minh City – American Academy. (2023, September 12). https://www.aavn.edu.vn/

Keeley, P. (2022). *Formative assessment books by Page Keeley*. Uncovering Student Ideas. https://www.uncoveringstudentideas.org/books

National Science Teachers Association. (2013). Science and engineering practices in the Next Generation Science Standards progression matrix. https://static.nsta.org/ngss/resources/matrixfork12progressionofscienceandengineeringpracticesinngss.8.14.14.pdf.

NGSS Lead States. (2013a). *Next Generation Science Standards: For states, by states. How to read the Next Generation Science Standards*. National Academy Press.

NGSS Lead States. (2013b). *Next Generation Science Standards: For states, by states. APPENDIX E – Science and Engineering Practices in the NGSS*. National Academy Press. https://www.nextgenscience.org/resources/ngss-appendices

NGSS Lead States. (2013c). *Next Generation Science Standards: For states, by states. APPENDIX F – Science and Engineering Practices in the NGSS*. National Academy Press. https://www.nextgenscience.org/resources/ngss-appendices

Osbourne, J., Henderson, J., MacPherson, A., Szu, E., Wild, A., Yao, S. (2016). The development and validation of a learning progression for argumentation in science. *Journal of Research in Science Teaching, 53*(6), 821-846.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654. https://doi.org/10.1002/tea.20311

The Wonder of Science. (n.d.). Performance assessment screening tool. https://thewonderofscience.com/graphics

Tobin, R. (2008). Corundrums in differentiated literacy classroom. *Reading Improvement, 45*(4), 159-169.

APPENDICES

APPENDIX A

IRB PROTOCOL REPORT – STATUS APPROVED

Print Protocol Reports

Printed By: Wright, Joel

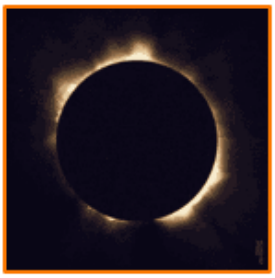
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Protocol #	Reference #	Version #	Principal Investigator	Author	Protocol Type	Protocol Status	Title	Submission Date	Approval Date	Renewal Date	Expiration Date	Parent Protocol #
2023-1074-EXEMPT	1074	1	Wright, Joel	Wright, Joel	Original	Approved	Validating a learning progression for the science and engineering practice of developing and using models for middle school STEM students at the International School of Ho Chi Minh City - American Academy.	12/3/2023	12/12/2023	12/12/2028	12/12/2028	
2023-1074-EXEMPT	1074	2	Wright, Joel	Wright, Joel	Amendment	Approved	Validating a learning progression for the science and engineering practice of developing and using models for middle school STEM students at the International School of Ho Chi Minh City - American Academy.	12/13/2023	12/14/2023	12/12/2028	12/12/2028	2023-1074-EXEMPT

APPENDIX B

STEM 6 CAT MISCOCEPTION PROBE TREATMENT 1 – PROMPT AND STUDENT RESPONSE

Your STEM class observed a total solar eclipse, where the moon casts a shadow on Earth. When Mr. Wright asked about which lunar phase the Moon is in, your classmates made these answers:



Jimmy: "The moon is a full moon, because the whole moon is blocking out the Sun."

Sally: "The moon is in the new moon phase, we just can't see it because the light reflecting off the moon is not visible to us from Earth".

Dylan: "There is no moon visible from Earth because it is daytime, and we can only see the moon at night".

Which student do you agree with and why? Explain your thinking.

MS-ESS1-1: Misconception Probe P___

Jimmy: "The moon is a full moon, because the whole moon is blocking out the Sun."

Sally: "The moon is in the new moon phase, we just can't see it because the light reflecting off the moon is not visible to us from Earth".

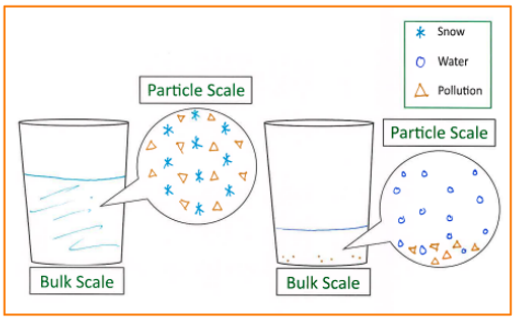
Dylan: "There is no moon visible from Earth because it is daytime, and we can only see the moon at night".

Which student do you agree with and why? Explain your reasoning.
I agree with Sally because Dylan said we can't see the moon in the day time but we can see the moon at the morning, that is lunar eclipse. Jimmy said the whole moon is blocking out the sun but full moon is not blocking out the sun, that is new moon.

APPENDIX C

STEM 7 CAT MISCONCEPTION PROBE TREATMENT 1 – PROMPT AND STUDENT RESPONSE

Your STEM class went on a field trip to Hanoi where it was snowing. You collected snow in a glass right next to a busy road and brought it inside to melt. The snow looked clean at first, but after it melted the water in the cup looked dirty. Mr. Wright drew the following model on the board and asked students to explain.



Peter: "The bulk scale model of snow doesn't show the pollution, so I don't think the particle scale model is correct."

Mary: "The particle scale models are correct, but there shouldn't be any difference between the snow and water because it's basically the same thing."

Will: "Pollution from cars on the road went into the snow.. we just can't see it in the bulk scale model. But, we can clearly see it in the pollution in the particle scale models for both snow and water."

Which student do you agree with and why? Explain your thinking.

No name

MS-PS1-1: Misconception Probe P___

Your STEM class went on a field trip to Hanoi where it was snowing. You collected snow in a glass right next to a busy road and brought it inside to melt. The snow looked clean at first, but after it melted the water in the cup looked dirty. Mr. Wright drew the following model on the board and asked students to explain.

Peter: "The bulk scale model of snow doesn't show the pollution, so I don't think the particle scale model is correct."

Mary: "The particle scale models are correct, but there shouldn't be any difference between the snow and water because it's basically the same thing."

Will: "Pollution from cars on the road went into the snow.. we just can't see it in the bulk scale model. But, we can clearly see it in the pollution in the particle scale models for both snow and water."

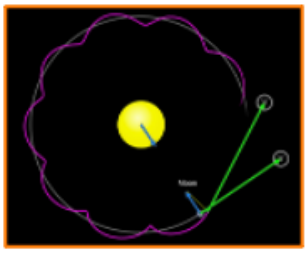
Which student do you agree with and why? Explain your thinking.

Will because they collect snow from beside a ~~ba~~ busy road so the pollution go into the snow but you cannot see it in the bulk scale but in the partical scale from melted ice and ice we can see the pollution, water, and snow

APPENDIX D

STEM 8 CAT MISCOCEPTION PROBE TREATMENT 1 – PROMPT AND STUDENT RESPONSE

After learning about the role of gravity in space, your STEM classmate asked what would happen to the moon is Earth suddenly disappeared. Your classmates made these answers:



Emilia: "The moon would move away from the solar system and out into space".

Roxanne: "The moon would continue along the same orbital path that Earth is on now".

Jorja: "The moon would rush inwards towards the Sun, because the Sun has the biggest mass and strongest gravitational force in our solar system".

Which student do you agree with and why? Explain your thinking.

MS-ESS1-2: **Misconception Probe** P___

After learning about the role of gravity in space, your STEM classmate asked what would happen to the moon is Earth suddenly disappeared. Your classmates made these answers:

Emilia: "The moon would move away from the solar system and out into space".

Roxanne: "The moon would continue along the same orbital path that Earth is on now".

Jorja: "The moon would rush inwards towards the Sun, because the Sun has the biggest mass and strongest gravitational force in our solar system".

Which student do you agree with and why? Explain your thinking.
I agree with Jorja because the sun does have the biggest mass and strongest gravitational force so it would pull the moon

APPENDIX E

STEM 6 CAT MISCOCEPTION PROBE TREATMENT 2 – PROMPT AND STUDENT RESPONSE

Three students in your STEM class were debating how their body turns lunch into nutrients and energy they need for the afternoon's phys-ed class.



Nathan: "As soon as we begin to chew food in our mouths, chemical digestion takes place changing molecules of food into energy we can use."

Jessica: "When we chew our food it's mechanical digestion, then after we swallow the food our stomachs have a digestive enzyme called pepsin than breaks the food down chemically into energy."

Evan: "Mechanical digestion occurs in the mouth and stomach where the food is broken down into smaller bits. Some chemical digestion also happens in our stomachs where the food is broken down into molecules with digestive enzymes, but most chemical digestion and absorption of nutrients takes place in the small intestine. From here, food molecules are transported around your body to give you the energy you need."

Which student do you agree with and why? Explain your thinking.

MS-LS1-7: Misconception Probe P 3

Nathan: As soon as we begin to chew food in our mouths, chemical digestion takes place changing molecules of food into energy we can use.

Jessica: When we chew our food it's mechanical digestion, then after we swallow the food our stomachs have a digestive enzyme called pepsin than breaks the food down chemically into energy.

Evan: "Mechanical digestion occurs in the mouth and stomach where the food is broken up into smaller bits. Some chemical digestion also happens in our stomachs where the food is broken down into molecules with digestive enzymes, but most chemical digestion and absorption of nutrients takes place in the small intestine. From here, food molecules are transported around your body to give you the energy you need."

Which student do you agree with and why? Explain your thinking.

I can't agree more with Evan! Using my notebook, mechanical digestion is where food is chewed & mixed, chemical digestion is where food is chemically turning into energy. Evan is the most reasonable.

APPENDIX F

STEM 7 CAT MISCOCEPTION PROBE TREATMENT 2 – PROMPT AND STUDENT RESPONSE

Three students in your STEM class were discussing how energy and matter flows through an ecosystem. This is what they said:



Khoa: Only energy flows through an ecosystem. Most of the energy comes from the Sun and makes the producers grow which feeds all the other organisms.

Sharon: Only matter flows through an ecosystem. Matter starts with producers, then the consumers eat the producers, and the producers eventually decompose.

Peggy: Both energy and matter flow through an ecosystem. Energy from the Sun is converted to matter and creates essential elements. These elements start with producers, then go to consumers, and eventually may be recycled by decomposers, and the matter cycles through the ecosystem again.

Which student do you agree with and why? Explain your thinking.

MS-LS2-3: Misconception Probe P 4

Three students in you STEM class were discussing how energy and matter flows through an ecosystem. This is what they said:

Khoa: Only energy flows through an ecosystem. Most of the energy comes from the Sun and makes the producers grow which feeds all the other organisms.

Sharon: Only matter flows through an ecosystem. Matter starts with producers, then the consumers eat the producers, and the producers eventually decompose.

Peggy: Both energy and matter flow through an ecosystem. Energy from the Sun is converted to matter and creates essential elements. These elements start with producers, then go to consumers, and eventually may be recycled by decomposers, and the matter cycles through the ecosystem again.

Which student do you agree with and why? Explain your thinking.

Peggy, because ~~energy~~ both energy and matter ~~flow~~ do flow through the ecosystem. Start with the sun g transfe energy to the producer and the producer convert it into matte

APPENDIX G

STEM 8 CAT MISCOCEPTION PROBE TREATMENT 2 – PROMPT AND STUDENT RESPONSE

Half Dome is made up of an igneous rock called granite, which formed underground when magma cooled. Over millions of years this dome was forced to the surface, driven by energy from Earth's interior in a process called uplift. The flat face was exposed to weathering processes due by energy from the sun, and eroded the vertical wall giving the half-dome shape. Based on this information, which of these students' statements best describes how Half Dome formed.



Mia: "Transform plate boundaries would have slid past each other causing a fault in Earth's crust and Half Dome to appear."

Tina: "Divergent plate boundaries would have pulled Earth's crust apart allowing space for Half Dome to appear."

Joel: "Magma cooled in Earth's crust and was forced upwards due to energy from convection currents in the mantle. Two convergent plates would have come together and pushed Half Dome to the surface like squeezing a pimple."

Caelan: "The only reason Half Dome appeared is because all of the Earth's crust has eroded away from it."

MS-ESS2-1: Misconception Probe P___

Mia: "Transform plate boundaries would have slid past each other causing a fault in Earth's crust and Half Dome to appear."

Tina: "Divergent plate boundaries would have pulled Earth's crust apart allowing space for Half Dome to appear."

Joel: "Magma cooled in Earth's crust and was forced upwards due to energy from convection currents in the mantle. Two convergent plates would have come together and pushed Half Dome through an eroding surface similar to squeezing a pimple."

Caelan: "The only reason Half Dome appeared is because all of the Earth's crust has eroded away from it."

Which student do you agree with and why? Explain your thinking.

I think Joel is the most correct because the Half Dome is made up of an igneous rock which is formed from cooled magma & it also says that the magma was forced upwards in the description of the Half Dome which is similar to what Joel said.

APPENDIX H

STEM 6 CAT MISCOCEPTION PROBE TREATMENT 3 – PROMPT AND STUDENT RESPONSE



Three STEM students were looking up at a rain cloud. Each had a different idea about how rain falls from the clouds. This is what they said:

Nai: I think clouds form when it gets cold, and the rain falls when the clouds melt.

Nguyen: I think clouds form when the Moon causes Water to evaporate and collect in the sky, then rain falls when the cloud gets too cold and from forces from the wind.

Joe: I think clouds form when energy from the Sun causes water on Earth to evaporate into the sky. Water molecules collect and condense as clouds. Once the water molecules are too heavy, they fall out of the sky back to Earth due to the force of gravity.

MS-ESS2-4: Misconception Probe P___

Nai: "I think clouds form when it gets cold, and the rain falls when the clouds melt."

Nguyen: "I think clouds form when the Moon causes water to evaporate and collect in the sky, then rain falls when the cloud gets too cold and from forces from the wind."

Joe: "I think clouds form when energy from the Sun causes water on Earth to evaporate into the sky. Water molecules collect and condense as clouds. Once the water molecules are too heavy, they fall out of the sky back to Earth due to the force of gravity.

Which student do you agree with and why? Explain your thinking.

I agree with Joe because it IS how the cycle works! Ü Water evaporates from the sun's heat and condenses into clouds.

APPENDIX I

STEM 7 CAT MISCOCEPTION PROBE TREATMENT 3 – PROMPT AND STUDENT RESPONSE

Three STEM students were having a discussion about the cause and effect of why a lady's hair moved when loud noise was played. Here's what the classmates said:



VK: The sound waves are moving through the air and that causes the air to move.

Tien: The air particles in front of the speaker are travelling through the air causing her hair to move.

Pep: The sound source near the speaker causes the air particles to vibrate, which causes the particles beside it to vibrate, and the next ones to vibrate too, all the way to her hair making it stand up.

MS-PS4-2: Misconception Probe P___

Three STEM students were having a discussion about the cause and effect of why a lady's hair moved when loud noise was played. Here's what the classmates said:

VK: The sound waves are moving through the air and that causes the air to move.

Tien: The air particles in front of the speaker are travelling through the air causing her hair to move.

Pep: The sound source near the speaker causes the air particles to vibrate, which causes the particles beside it to vibrate, and the next ones to vibrate too, all the way to her hair making it stand up.

Which student do you agree with and why? Explain your thinking.

I agree with Pep because the sound source causes the air particles to vibrate, one particle vibrate so ~~it~~ ~~with~~ will collide in to each other particles and all the way ~~to~~ till to her hair making it stand up.

APPENDIX J

STEM 8 CAT MISCOCEPTION PROBE TREATMENT 3 – PROMPT AND STUDENT RESPONSE

Four STEM students were having a disagreement about changes in different types of rocks.



Ivory: "A sedimentary rock can turn into either a metamorphic rock or an igneous rock, depending on what forces work to change it."

Jason: "An igneous rock will always be an igneous rock because it's made of lava and magma."

Peter: "Once a rock has moved to Earth's surface, it can only be sedimentary."

Stella: "A sedimentary rock can only turn into a metamorphic rock before it can change into a different type of rock."

MS-ESS2-1: Misconception Probe P___

Ivory: "A sedimentary rock can turn into either a metamorphic rock or an igneous rock, depending on what forces work to change it."

Jason: "An igneous rock will always be an igneous rock because it's made of lava and magma."

Peter: "Once a rock has moved to Earth's surface, it can only be sedimentary."

Stella: "A sedimentary rock can only turn into a metamorphic rock before it can change into a different type of rock."

Which student do you agree with and why? Explain your thinking.

Ivory because sedimentary rock can turn into different type of rock depending on what force, it can turn to metamorphic rock by heat and pressure and igneous rock by melting and volcanic activity.

APPENDIX K

STEM 6 MS-ESS1-1 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 1

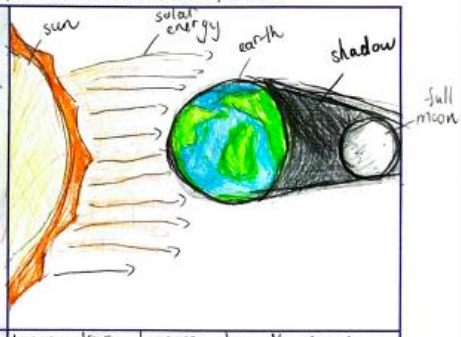
29

MS-ESS1-1: Total Lunar Eclipse Name: P 1

Background: The total lunar eclipse shown to the right was recorded at the Griffith Observatory in Los Angeles on January 31, 2018. A total lunar eclipse occurs when the Earth passes between the Sun and the Moon. Nearly four hours of video footage is compressed into this short video. A more detailed view can be seen on YouTube.



According to Robert Roy Britt of Space.com, "A lunar eclipse can occur only at full moon." Use the space below to explain this phenomenon. Your model should include the following: Sun, Moon, Earth, solar energy, and include colour. Your explanation should make connections between components and evaluate limitations of your model.

Model Develop a model of the Earth-sun-moon system.	
Explanation Use your model to describe this phenomenon.	Lunar eclipse happens when the moon passes through the Earth's shadow, the Earth blocks sunlight from reflecting off the surface of the moon. It only happens on a full moon, but not every full moon because the Earth on a t/t,

MS-ESS1-1: Earth-Sun-Moon System Name: P:___

Develop and use a model of the earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	✓ Sun ✓ Earth ✓ Moon ✓ Solar Energy ✓ Colour 5	Nice model!
	Explanation	
No limitations	✓ Components of phenomenon are identified ◦ Sun ◦ Earth ◦ Moon ◦ Solar Energy 2 ✓ Connections between components are used to explain and describe ✗ Limitations of model are evaluated	

7/8

APPENDIX L

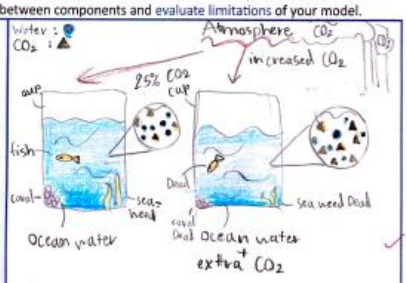
STEM 7 MS-PS1-1 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 1

MS-PS1-1: Acid in our Oceans? Name: P___ 23

Ocean acidification is the increase in acidity of the Earth's oceans. It is caused by an increase of carbon dioxide (CO_2) that humans put into the atmosphere. About 25% of the CO_2 in the air goes into the oceans. When CO_2 in the atmosphere increases, CO_2 in the ocean increases too. When CO_2 enters the ocean it can dissolve the structure of coral reefs and shelled organisms.



Use the space below to explain this phenomenon. Your model should be of particle scale and include the following: carbon dioxide (CO_2), ocean water, coral reef and shelled organisms, and include colour. Your explanation should make connections between components and evaluate limitations of your model.

Model Develop a model of the ocean acidification. Include particle scale CO_2 and ocean water.	
Explanation Use your model to describe this phenomenon.	Ocean water was once healthy with fishs & corals with only taking 25% CO_2 of the atmosphere. But as humans pollute the atmosphere with more CO_2, so does the ocean. We can also see in the models how little O_2 is in the ocean until now as fishs and corals start to die due to the poisonous amount of CO_2 in the water. Great!

MS-PS1-1: Atomic Composition Model Name: P:___

Develop and use a model to describe the atomic composition of simple molecules and extended structures. (Scale, Proportion, and Quantity)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	☑ Carbon dioxide (CO_2) ☑ Ocean water ☑ Coral reefs and shelled organisms ☑ Particle scale	4
	Explanation	
No Lim	☑ Components of phenomenon are identified ▫ Carbon dioxide (CO_2) ▫ Ocean water ▫ Coral reefs and shelled organisms ▫ Particle scale ☑ Connections between components are used to explain and describe ▫ Limitations of model are evaluated	2

6/7

APPENDIX M

STEM 8 MS-ESS1-2 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 1

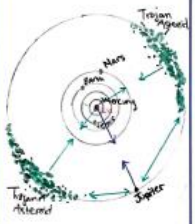
MS-ESS1-2: **Trojan Asteroids** Name: P___

18

Background: Trojan asteroids orbit the Sun in the same orbital path as Jupiter. These are clusters of asteroids in what are known as Lagrange points, 60° ahead of and 60° behind the massive planet. Lagrange points are gravitationally stable positions near large bodies in orbit, where if an object is put there, it will stay there in the same orbital path.



Use the space below to explain this phenomenon. Develop a before and after model to show what would happen to the Trojan asteroids if Jupiter suddenly disappeared. Your model should include the following: Sun, Jupiter, Trojan asteroids, gravity, and orbital path. Draw blue arrows to show the direction and force responsible for keeping Jupiter in orbit. Draw green arrows to show the direction and forces responsible for keeping the asteroids in orbit. Your explanation should make connections between components and evaluate limitations of your model.

Model Develop a model of the Jupiter-Sun-Trojan Asteroids system.	Before	After
		Great model 
Explanation Use your model to describe this phenomenon.	In the first model, the green arrows show the gravity force of the Sun and Jupiter pulling the Trojan Asteroids, keeping them in orbit. However if Jupiter disappeared, the gravity force of the Sun would pull the asteroids towards it (the sun), as shown in the 2nd model with green arrows. Nice explanation!	

Limitations:
- NOT to scale
- Still drawing, not a simulation ✓

MS-ESS1-2: **Gravity and Motion in Space**

Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. (Systems and System Models)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
Model		
	✓ Sun ✓ Jupiter ✓ Trojan asteroids (leading and trailing) ✓ Gravity (Jupiter's orbit) ✓ Gravity (Trojan asteroids' orbit) ✓ Orbital path ✓ Trojan asteroids if Jupiter disappears	7
Explanation		
	✓ Components of phenomenon are identified ▫ Sun ▫ Jupiter ▫ Trojan asteroids ▫ Gravity ▫ If Jupiter disappeared ✓ Connections between components are used to explain and describe ✓ Limitations of model are evaluated	3

10/10

APPENDIX N

STEM 6 MS-LS1-7 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 2

MS-LS1-7: **Football Energy** Name: P__ 23

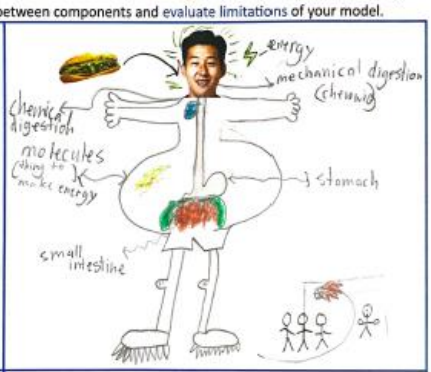
Background: South Korean footballer, Son Heung-min, visited Ho Chi Minh City to play a game against the Vietnamese national team. Before his match, Son had a pre-game meal of banh mi. Develop a model to show how this food was digested, and new molecules used to support Son to have the energy he needed to play the game.



Use the correct words (six) for the digestive system for the components in your model. Draw arrows to show motion or movement of food to energy. Explain your model by making connections between components and evaluate limitations of your model.

Model
Develop a model of the digestive system.

Word bank:
-Energy
-Neuron
-Mechanical digestion
-Chemical digestion
-Molecules
-Tidal volume
-Stomach
-Small intestine



Explanation
Use your model to describe this phenomenon.

went son ate banh mi then he is chewing then it come to the stomach came to small intestine, they it will became energy

MS-LS1-7: **Food and Chemical Reactions** Name: P__

Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	☐ Six terms for digestive system are selected from word bank and included as components on model (x6) ✓ All components are labelled on model ✓ Arrows represent motion or movement of food to energy	
	Explanation	
-No connections btwn components described -No Lim	✓ Components of the digestive system are identified ☐ Connections between components are used to explain and describe ☐ Limitations of model are evaluated	

8

1

9/11

APPENDIX O

STEM 7 MS-LS2-3 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 2

MS-LS2-3: **Yellowstone Park** P 4

Background: A tourist captured this photograph of a lone wolf and herd of bison in the Lamar Valley of Yellowstone Park. The wolf photographed in this ecosystem has been named "Dot" by local onlookers.



Develop a model to show how energy flows into and out of the ecosystem. Use this model to explain how the material in the bison dung could cycle to dot.

Model
Develop a model of the ecosystem.

Word bank:
- Electron
- Producer
- Consumer
- Decomposer
- Synthetic material
- Non-living matter
- Energy
- Phase change

Key: → Energy ---> matter



Explanation
Use your model to describe this phenomenon.

- So the fungi convert the energy to the soil, which went to the grass. From the grass, it went to the bison and so the wolf.
- The matter from the already broken down molecule transfer to the grass, to the bison, and so the wolf. eventually
- EVERYTHING WENT TO THE DECOMPOSER.

- Limitations are:
- Couldn't see them changing
- Ain't 3D model!

MS-LS2-3: Matter Cycling and Energy Flow in Ecosystems

Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	✓ Five terms for ecosystems are selected from word bank and included as components on model (x5) ✓ All components are labelled on model ✓ Arrows represent cycling of matter and flow of energy	
	Explanation	
	✓ Components of the ecosystem are identified ✓ Connections between components are used to explain and describe ✓ Limitations of model are evaluated	

10/10 Nice Work!

APPENDIX P

STEM 8 MS-ESS2-1 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 2

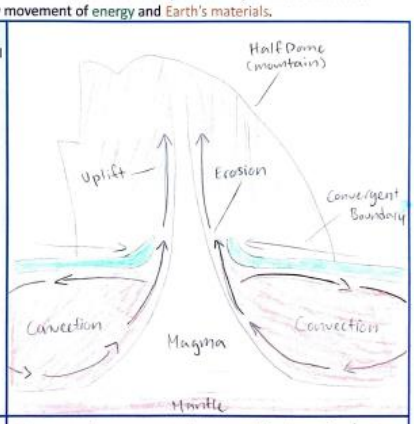
MS-ESS2-1: The Uplift of Half Dome P___ 1

Background: World-famous rock-climbing wall, Half Dome, is an igneous granite rock which formed underground when magma cooled and was brought through an eroding surface in a process called uplift. Uplift occurs when magma is forced upward due to tectonic plate movements. The flat rock-climbing face was created overtime due to erosion.

Develop a model that demonstrates a different series of processes that could occur to the materials beneath Earth's crust to form Half Dome. Use seven correct words from the word bank for components of your model. Include arrows to show movement of energy and Earth's materials.

Model
Develop a model of how Half Dome could have formed.

Word bank:
- Uplift
- Convection
- Mantle
- Convergent boundary
- Divergent boundary
- Transform boundary
- Erosion
- Lava
- Magma
- Volcano
- Ridge
- Mountain



Explanation
Use your model to describe this phenomenon.

The cooled magma in the mantle is pushed up in a process called uplift by convections and because it lies on a convergent boundary. It breaks through the crust and overtime forms a mountain due to erosion. My model is not 100% accurate as this process takes years to form but my model is just one drawing of every thing that happens.

Nice Work!

MS-ESS2-1: Cycling of Earth's Materials
Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. (Stability and Change)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
Model		
	✓ Seven terms for the formation of half dome are selected from word bank and included as components on model (x7) ✓ All components are labelled on model ✓ Arrows represent cycling of matter and flow of energy	
Explanation		
	✓ Components of the Half Dome are identified ✓ Connections between components are used to explain and describe ✓ Limitations of model are evaluated	Great Work!

12/12

APPENDIX Q

STEM 6 MS-ESS2-4 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 3

MS-ESS2-4: Car Surfing in a Mudslide P___

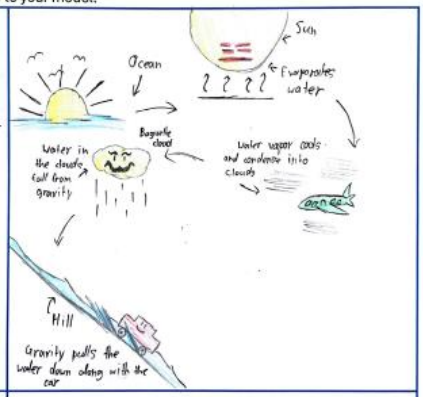
Background: Torrential rainfall triggered a mudslide that sent one car surfing down the road. Mudslides are most likely to happen in areas that get a lot of rain and are located on or at the bottom of steep hillsides.



18

Develop a model do describe this phenomenon of how water can start in the ocean and end up flowing down a hill. Identify how energy and matter and the force of gravity apply to your model.

Model
Develop a model to describe the processes of this phenomenon.



Explanation
Use your model to describe the energy and matter of this phenomenon.

First, the heat and energy from the sun evaporates water from the ocean. Then, water vapors cool down and condense into clouds. After that, water falls from the clouds because of gravity. Finally, gravity pulls the water along with the car down the hill.

MS-ESS2-4: Cycling of Water through Earth's Systems

Develop a model to describe the cycling of water through Earth's systems driven by energy by the sun and the force of gravity. (Energy and Matter)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	F Model developed describes the phenomenon 5 Correct terms are identified and labeled as components on the model (5) F Model describes energy and matter of cycling of water through earth's systems	
	Explanation	
	F Connections are described between components of the model □ Connections are used to predict changes in the model □ Limitations of model are evaluated	

8/10

APPENDIX R

STEM 7 MS-PS4-2 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 3

MS-PS4-2: Blast Wave P__ 9

Background: The image beside shows a field of trees as a wave from a nuclear blast passes through them. This is an example of a matter, or mechanical wave being transmitted through the air and shocking the trees.



Develop a model to do describe this phenomenon how the trees located far away from the site of the explosion can behave this way. Identify how the structure and function of the matter/mechanical wave impacts the trees.

Model Develop a model to describe this phenomenon. Identify the structure and function of.	
Explanation Use your model to describe the structure and function of mechnical waves in this phenomenon.	The model show a nuclear bost that transmitted a wave that go through the trees. matter In a wave zoomed up: - Particles vibrate & transmitted through the air. Limit.

- Can't move like a simulator.

MS-PS4-2: Wave Reflection, Absorption, and Transmission

Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. (Structure and Function)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	✓ Model developed describes the phenomenon ☐ S Correct terms are identified and labeled as components on the model (5) ✓ Model describes structure and function of mechanical waves	
	Explanation	
No connections used to predict changes	✓ Connections are described between components of the model ☐ Connections are used to predict changes in the model ✓ Limitations of model are evaluated	

9/10

APPENDIX S

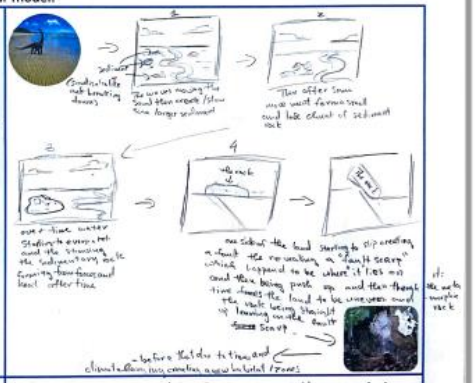
STEM 8 MS-ESS2-1 PERFORMANCE ASSESSMENT STUDENT EXEMPLAR – TREATMENT 3

MS-ESS2-1: A Metamorphic Beach? P___

Background: This vertical cliff found in Wisconsin, USA, displays ripples from an ancient beach. Millions of years ago, flowing water moved sand sediments to form ripples, and over time the sand was transformed into solid sedimentary rock. Today, this vertical ancient beach is exposed as a new type of rock, metamorphic rock.



Develop a model do describe this phenomenon of how an ancient beach can become a vertical metamorphic rock. Identify processes in the stability and change of your model.

Model Develop a model to describe the processes of this phenomenon.	
Explanation Use your model to describe the stability and change of this phenomenon.	Sediment forming over/on unconsolidated sand and sediment rock it starting to be there with a change in rock then over time, heating from sedimentary rock to metamorphic rock and either being it happened to lay on a fault and being push up after being pushup and laying on the fault scarp.

MS-ESS2-1: Cycling of Earth's Materials

Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. (Stability and Change)

Concerns Areas for improvement	Criteria Standards for this performance	Advanced Evidence of exceeding standard
	Model	
	✓ Model developed describes the phenomenon ☐ Correct terms are identified and labeled as components on the model (5) ✓ Model developed shows stability and change (time) to describe the cycling of Earth's materials	
	Explanation	
No Lim	✓ Connections are described between components of the model ✓ Connections are used to predict changes in the model ☐ Limitations of model are evaluated	

9/10

APPENDIX T

STUDENT LIKERT SURVEY

Student Evaluation of Short Performance Assessment for Developing and Using Models

The purpose of this questionnaire is to help your teachers better understand student strengths and weaknesses. Five statements about your assessment are listed below. Please circle the number, using the code, that describes how much you agree with each statement. Please respond to each statement as honestly as you can and by circling only one number for each statement.

1	2	3	4	5
Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree

1.	Identifying components of the model is easy	1	2	3	4	5
2.	Labeling components of the model is easy	1	2	3	4	5
3.	I can make connections between components in the model	1	2	3	4	5
4.	I can use the components to predict changes to the model	1	2	3	4	5
5.	I can develop a model to explain a phenomenon	1	2	3	4	5

APPENDIX U

SMALL GROUP STUDENT INTERVIEW QUESTIONS

Small group interviews

Questions:

1. What do you think about the SPA for developing and using models of _____?

2. Was anything unclear about the assessment?

3. What do you think your strengths were on the assessment?

4. What were some weaknesses?

5. Did the misconception probe help prepare you for the SPA? How did the probe help?

6. How confident do you feel in your ability to develop and use models in STEM class?

7. Do you feel more confident in modeling since the beginning of the year?

8. Do you ever apply modeling to a phenomenon you experience in regular life?