Science Analysis Learning Pathway Exploration Study Report

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Respectfully Submitted by: Jeri Thompson, Ed.D.

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Background

In 2019, the Pennsylvania's State Board of Education and the Pennsylvania Department of Education started the process of updating the 2002 Academic Standards for Science and Technology and Academic Standards for Environment and Ecology (PA Bulletin, 2021). The State's proposed 2024 standards were informed by the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012) to include a multidimensional approach for science instruction and learning that includes the practices, crosscutting concepts, and disciplinary core ideas (p. 14). Once the science standards are revised, the Pennsylvania science assessment will also require revisions.

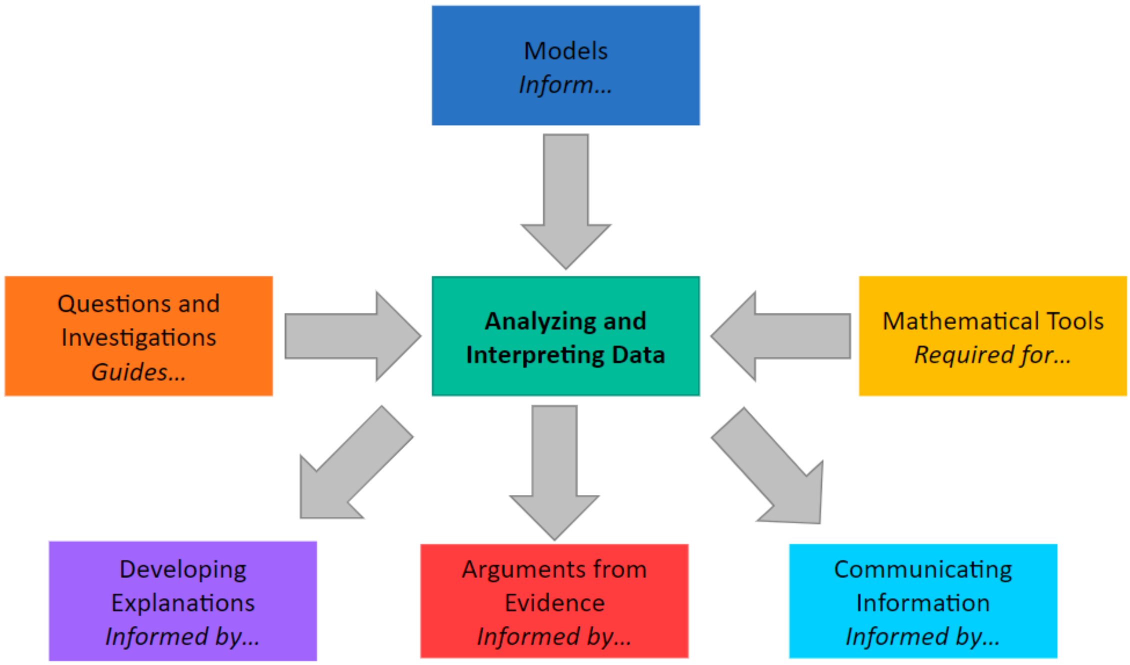
The *Framework for K-12 Science Education* provided an overview to guide the development of these new standards in K-12 science education. This framework identified and discussed a broad set of expectations for science learning which integrates 1) science and engineering practices, 2) crosscutting concepts that unify the study of science and engineering through common applications across fields, and 3) core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and application of science. The authors of the *Framework* explained that common among all domains of science is "a commitment to data and evidence as a foundation for developing claims." Subsequently, the science practices, identified in Table 1, stemmed from this commitment (p. 27).

Table 1. Science Practices

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

The science and engineering practice of analyzing and interpreting data is pivotal to other science practices. Analyzing and interpreting data connects information gathered during investigations to explanations, models, and arguments through the transformation of data into evidence. Obtaining evidence is the central purpose underlying data analysis and interpretation (Figure 1).

Figure 1. Analysis and Interpretation Related to Other Science Practices



(Thompson, 2021)

DRAFT Learning Pathway for Analyzing and Interpreting Data

Different states and organizations (e.g., Pennsylvania, Wisconsin, California State University East Bay, Achieve, AMSTI) have provided specific descriptions of what is necessary for students to demonstrate the practice of analyzing and interpreting data. These descriptions were used to identify criteria for the development of DRAFT Learning Pathways (grades 3-5 and 6-8) for *Analyzing and Interpreting Data* (see Appendix A). The criteria identified for the grades 3-5 DRAFT Learning Pathway included:

- Digital or analog tools
- Representation of data
- Make sense of phenomena
- Comparison
- Data
- Evaluation (for engineering)

The criteria for the DRAFT Learning Pathway grades 6-8 included:

- Linear/nonlinear relationships
- Temporal/spatial relationships
- Causal/correlational relationships
- Make sense of phenomena
- Statistics and probability
- Accuracy of data

- Comparisons
- Success criteria (for engineering)

The pathways for successfully demonstrating these criteria were structured with four levels: beginning, emerging, developing, and meeting. Each level included an asset-based description of how students typically learn and demonstrate the criterion. It is important to point out that these are DRAFT learning pathways and are intended for teachers to use to determine students' strengths and abilities in order to make instructional decisions. They are not intended to be used as an evaluation tool for scoring students' work.

Previous Exploratory Studies on Analysis

Given the pivotal role of the science practice of analyzing and interpreting data, it became clear that all science educators needed to understand its instructional and assessment implications. In prior years, Dr. Jeri Thompson, Center for Assessment, and the Pennsylvania Department of Education (PDE) conducted various studies related to 1) teachers' understanding of *analysis*, 2) how teachers instruct students to analyze text, 3) the extent that district curricular materials embed analysis expectations, and 3) the ways local assessment systems measure students' ability to analyze. These studies gathered information to support educators across the State in understanding the expectations of *analysis* in English language arts as identified in the *2014 Academic Standards for English Language Arts* (Pennsylvania Department of Education) and how students are expected to respond to a text dependent analysis prompt. Throughout these studies, district educators, and IU Consultants consistently identified a need for all content areas, including science, to embed analysis in their instructional and curricular programs with little consideration of how analysis may be different in other content areas, including the specific concepts that should be analyzed (Thompson, 2022).

Analysis, with respect to text dependent analysis in English language arts, has been defined as *a detailed examination of the elements or structure of text, by breaking it into its component parts to uncover interrelationships in order to draw a conclusion* (Thompson & Lyons, 2017). Prior to engaging in this science exploration study, it was necessary to first understand whether this definition of analysis could be applied to science content and the extent to which it applied to the science and engineering practice which expects students to *analyze and interpret data*. In 2012, NSTA defined analyzing and interpreting data as:

- **Data**: facts, statistics, or items of information
- **Analyze**: to study or determine the nature and relationship of the parts
- **Interpret**: to explain the meaning of

While these definitions are not identical to the definition used for English language arts, when combined, they are similar. Students are expected to conduct a *detailed examination* of data collected or provided from an investigation to uncover *an interrelationship of the parts* in order to explain their meaning or to *draw a conclusion*. However, the significant difference noted between the content areas are the stimulus material that students are expected to analyze—text in English language arts and investigation data in science.

Purpose of Current Study

Although different stimulus materials are necessary for analysis in the content areas, the common definition of analysis brought to the forefront the need to clarify how the expectations of analysis in science as related to the science practice, *Analyzing and Interpreting Data* is different than analysis in English language arts. Specifically, as district leaders, curriculum specialists, and IU Consultants seek to embed analysis into the science content area, there should be a focus on 1) the criteria necessary to analyze and interpret data, 2) the typical pathway that students learn and demonstrate the criteria for the science and engineering practice of *Analyzing and Interpreting Data*, 3) the manner in which students have classroom opportunities to learn and demonstrate this science practice, and 4) how teachers interpret and use the student work samples resulting from analyzing and interpreting data tasks.

These areas of focus were central to a six-month exploratory study which was conducted from October 2021 to March 2022 by the Center for Assessment, Pennsylvania Department of Education, and science educators across the State. The key research questions we sought to answer through this exploratory study were derived from these focus areas and included:

1. To what extent can educators create science lessons which engage students in the criteria for *analyzing and interpreting data*?
2. Can we create grade-span (3-5, 6-8) learning pathways for the criteria necessary for demonstrating *analyzing and interpreting data* in science?
3. Can educators validate the DRAFT grade-span learning pathways to recognize and describe how students demonstrate the criteria necessary for demonstrating *analyzing and interpreting data* and use the information to adjust instruction?

Participants

The science analysis exploratory study brought together a diverse group of 15 educators. Table 2 reflects the grade levels and/or positions represented by the educators in this study.

Table 2. Science Analysis Study Participants

Grade/Position	Number of Participants
Grade 4	1 Classroom Teacher
Grade 5	2 Classroom Teachers
Grade 6	1 Classroom Teacher
Grade 7	1 Classroom Teacher
MS (grades 6, 7, 8) & Department Chair	2 Classroom Teachers
MS (grades 6, 7, 8) & K-8 Director	1 Classroom Teacher
MS Technology and Engineering	1 Classroom Teacher
HS Technology and Engineering	1 Classroom Teacher
Elementary School STEM Coach	1 Educator
Middle School STEM Coordinator	1 Educator
Science Coordinator	1 Educator
Science Coach	1 Educator
College Instructor	1 Educator

The educators represented nine (9) school districts from western to eastern Pennsylvania and one college from central Pennsylvania. These educators were selected based on recommendations from the Pennsylvania Department of Education or district leaders. All participants were white, and eleven educators were female and four were male.

Meetings

Due to COVID-19, all six (6) sessions were conducted as three-hour virtual meetings during the 2021-22 school year.

The virtual meetings were conducted on the following dates:

- Meeting 1: October 18, 2021
- Meeting 2: November 16, 2021
- Meeting 3: December 10, 2021
- Meeting 4: January 11, 2022
- Meeting 5: February 2, 2022
- Meeting 6: March 23, 2022

Several tasks and outcomes were included in the meetings to support the educators' ability to validate the *Analyzing and Interpreting Data Learning Pathways* when examining student work samples. The first critical activity was to create a level playing field in understanding the meaning of three-dimensional science in Pennsylvania, including disciplinary core ideas (DCI), cross-cutting concepts (CCC), science and engineering practices (SEP), performance expectations, and science phenomena. These terms and explanations are defined in Table 3 (PA Integrated Standards, Appendix B-1; PA K-12 Inquiry and Design Science Practices).

Table 3. Explanation of Three-Dimensional Science Terminology

Three-Dimensional Science Terminology	Explanation
Three-Dimensional Learning	Developing and using elements of the three dimensions purposefully (i.e., to explain phenomena or design solutions to problems). Lessons and units aligned to the standards should be three-dimensional; that is, they should allow students to actively engage with the practices and apply the crosscutting concepts to deepen their understanding of core ideas across science disciplines while tending to appropriate dispositions.)

Disciplinary Core Ideas (DCI)	Core ideas in:
	• Physical sciences
	  ○ matter and its interactions
	  ○ motion and stability: forces and interactions
	  ○ energy
	  ○ waves and their applications in technologies for information transfer
	• Life sciences
	  ○ from molecules to organisms: structures and processes
	  ○ ecosystems: interactions, energy, and dynamics
	  ○ heredity: inheritance and variation of traits
	  ○ biological evolution: unity and diversity
	• Earth and space sciences
	  ○ earth's place in the universe
	  ○ earth's systems
	  ○ earth and human activity
	• Environment and ecology
	  ○ decision-making and action skills
	  ○ personal and civic responsibility
	  ○ earth's physical and living systems
	  ○ human systems
	  ○ environment and society
	  ○ skills for analyzing and investigating environmental issues
	• Engineering, technology, and applications of science
	  ○ applying, maintaining, and assessing technological products and systems
	  ○ core concepts of technology and engineering
	  ○ design in technology and engineering education
	  ○ history of technology
	  ○ impacts of technology
	  ○ influence of society on technological development

	◦ integration of knowledge, technologies, and practices ◦ nature and characteristics of technology and engineering
Cross-Cutting Concepts (CCC)	Concepts that unify the study of science and engineering through their common application across fields: • patterns • cause and effect: mechanism and explanation • scale, proportion, and quantity • systems and system models • energy and matter: lows, cycles, and conservation • structure and function • stability and change • sustainability
Science and Engineering Practices (SEP)	Description of how scientific and engineering knowledge develops: • asking questions and defining problems • developing and using models • planning and carrying out investigations • analyzing and interpreting data • using mathematics and computational thinking • constructing explanations (for science) and designing solutions (for engineering) • engaging in argument from evidence • obtaining, evaluating, and communicating information
Performance Expectations	• Pennsylvania Integrated Standards for Science Environment, Ecology, Technology and Engineering (Grades K-5) • Pennsylvania Integrated Standards for Science Environment, Ecology, Technology and Engineering (Grades 6-12)
Science Phenomena	An observable event or occurrences in the natural- and human-made world that can be observed and cause one to wonder and ask questions.

Educators engaged in discussing how the expectations of three-dimensional science learning needed to be embedded into instruction and formative assessments. Specifically discussed was the extent to which the formative assessments or tasks were designed including: 1) being grounded in real-world, phenomenon-based scenarios which provided students the time and space to work out solutions, 2) measuring student learning in relation to performance expectations and the associated dimensions (SEPs, CCCs, DCIs), 3) accessibility for all students, and 4) being designed for a specific purpose (Achieve, 2019). Assessments available from other states (i.e., Kentucky, New York) were examined by the educators to identify the three-dimensional science expectations. Following this introduction, a second critical task was to have the educators take a deep dive in examining the grade-span (3-5; 6-8) DRAFT Learning

Pathways describing how students learn and demonstrate the *Analyzing and Interpreting Data* SEP and to provide comments about the criteria and descriptors. The educators then examined specific lessons with embedded formative assessment to determine the extent to which students would need to learn this SEP in order to engage with the task. Using this understanding of three-dimensional science, a third task involved teams of educators creating lessons which included instruction and formative assessment of selected criteria aligned to analyzing and interpreting data. As previously described, the DRAFT Learning Pathways for *Analyzing and Interpreting Data* included multiple criteria and therefore, one lesson and formative assessment may not involve all criteria. Therefore, the educators were asked to select those criteria that fit the expectations of the performance expectations and the lesson's learning target. Each team was structured to ensure that at least one teacher would be able to implement the lesson and administer the formative assessment in the classroom. These teachers were asked to collect and upload student work. The final task and anticipated outcome were for teachers to annotate the student work samples to validate a grade-span DRAFT Learning Pathway and discuss how instruction would need to change to provide opportunities for students to learn.

Additionally, throughout the months of this exploratory study, teachers were asked to record classroom lesson activities related to analyzing and interpreting data, student responses, and their reflections related to the expectations of analyzing and interpreting data. The reflection questions focused on the ways in which the lesson activities expected students to demonstrate the underlying expectations of analyzing and interpreting data and how they could have changed the lesson or activity for students to demonstrate these underlying expectations. The intent of the *Lesson Catchers* (see Appendix B) was to ascertain how instruction and student responses changed throughout the school year as a result of their learning about three-dimensional science, and more specifically about the SEP, *Analyzing and Interpreting Data*. No specific number of lesson catchers to be created by each teacher was identified.

The specific content of each meeting is identified below:

Meeting 1: In addition to introductions and logistical information, this first virtual session laid the groundwork for understanding the meaning of three-dimensional science to ensure a level playing field with respect to terminology and underlying expectations necessary for instructing students in demonstrating analyzing and interpreting data. To support their understanding the educators reviewed the PA K-12 Science Practices, the NGSS K-12 Disciplinary Core Ideas, and the NGSS K-12 Cross-Cutting Concepts to determine which SEPs, DCIs, and CCCs could be included when instructing students on different Performance Expectations. Furthermore, the educators discussed the meaning of the SEP *Analyzing and Interpreting Data* and examined how this practice could be operationalized in a learning pathway.

Meeting 2: A quick review of three-dimensional science was conducted as well as the expectations, challenges, and considerations for creating formative three-dimensional science assessments. Table 4 lists the expectations, challenges, and considerations discussed.

Table 4. Expectations and Challenges of Creating Formative Three-Dimensional Science Assessments

Expectations	Challenges	Considerations
Tasks are driven by high-quality scenarios that are grounded in phenomena or problems.	Capturing the three dimensions in an assessment or task	May require tasks with multiple components, rather than a single question, even if each component captures a different part of the performance expectation
Tasks require sense-making using the three dimensions.	Using real-world problems and contexts	Phenomena-based scenarios should provide relevant information allowing for student engagement
Tasks are fair and equitable.	Developing tasks in which students with different backgrounds, needs, and levels of learning can engage and demonstrate mastery	Tasks can provide scaffolding to help students develop understand or solve a problem and by addressing the progressive nature of learning
Tasks support their intended targets and purpose.	Designed for a specific purpose	Decide what inferences are being made about students' science learning and how they can best show this learning

Additionally, teachers examined samples of lesson catchers that had been completed between Meetings 1 and 2, as well as two lessons and formative assessments developed by teachers in New York, to identify and discuss:

- the performance expectation being taught,
- the real-world phenomenon-based scenario and/or how the scenario could be enhanced,
- the way in which students were taught the criteria associated with analyzing and interpreting data, and
- the way in which the criteria associated with analyzing and interpreting data was being measured through the formative assessment process.

<u>Meeting 3:</u> During this meeting, educators discussed the guiding assumptions and instructional shifts necessary for implementing three-dimensional science in elementary, middle school, and high school grades (NRC, 2012). To further familiarize educators with the DRAFT Learning Pathways for *Analyzing and Interpreting Data*, they examined the student work samples from the completed lesson catchers to identify the evidence demonstrated and to determine which level of the pathway was best represented by the evidence. At the end of the meeting the educators discussed their findings, patterns noted, and implications for instruction and classroom formative assessment processes.

Meetings 4-5: During these two meetings, educators continued to explore three-dimensional science and the DRAFT Learning Pathways for *Analyzing and Interpreting Data* to create a lesson plan and formative classroom assessment measuring selected criteria for analyzing and interpreting data. A science lesson plan template (see Appendix C) was provided for the four groups of educators to use to support the first research question. The focus of the lesson and assessment for each group are identified in Table 5.

Table 5. Lesson Plan and Formative Assessment Focus

Group	Grade Level(s)	Disciplinary Area	Analyzing and Interpreting Data Criteria
1	4	Physical Science	Representation of data Make sense of science phenomena Comparisons Data
2	6-8	Life Science	Make sense of phenomena Comparisons
3	6-8	Physical Science	Linear/nonlinear relationships Temporal/spatial relationships Causal/correlational relationships
4	7-8	Physical Science	Causal/correlational relationships Comparisons Success criteria for engineering

The lessons were shared with the whole group and feedback was provided for consideration. Identified educators from each group were asked to implement their lesson and collect and upload student work samples into a designated Google folder prior to meeting 6.

Meeting 6: This meeting resulted in a key outcome of this exploratory study. Educators used the student work samples they collected and the DRAFT Learning Pathway for *Analyzing and Interpreting Data* to identify students' understanding and demonstration of the criteria identified on their lesson template. This information was critical in supporting understanding of our second and third research questions related to the development and use of a learning pathway for analyzing and interpreting data. Additionally, the educators were asked to reflect on the following questions:

1) Given what you have learned about Three-Dimensional Science and the Science & Engineering Practice of *Analyzing and Interpreting Data,* how will you change your instruction (including creating lessons, learning materials, etc.) and classroom assessments?

2) Given what you have learned about Three-Dimensional Science and the Science & Engineering Practice of *Analyzing and Interpreting Data,* what else do you still need/want to learn?

3) Given what you have learned about Three-Dimensional Science and the Science & Engineering Practice of *Analyzing and Interpreting Data,* what do you think will be beneficial for all PA science educators to know?

Data Analysis and Results

Qualitative data was collected throughout this exploratory study from three key sources: 1) instructional lessons and teacher reflections of their lessons from the lesson catchers, 2) an unstructured discussion during Meeting 6 in which teachers reflected on their learning throughout the year, and 3) examining student work samples resulting from a three-dimensional science lesson which embedded criteria from the SEP analyzing and interpreting data and using the DRAFT Learning Pathway for understanding how students demonstrated these criteria. These informal measures of this six-month exploration were used together to answer the three research questions.

Lesson Catchers

From October to March, eleven (11) educators submitted lesson catchers with between one and eight lessons for a total of 29 lessons. These lessons were examined to discern the extent to which educators were embedding three-dimensional science and more specifically, the SEP analyzing and interpreting data criteria, into their lessons and formative assessment practices. Table 6 reflects the information gained through the lesson catcher review.

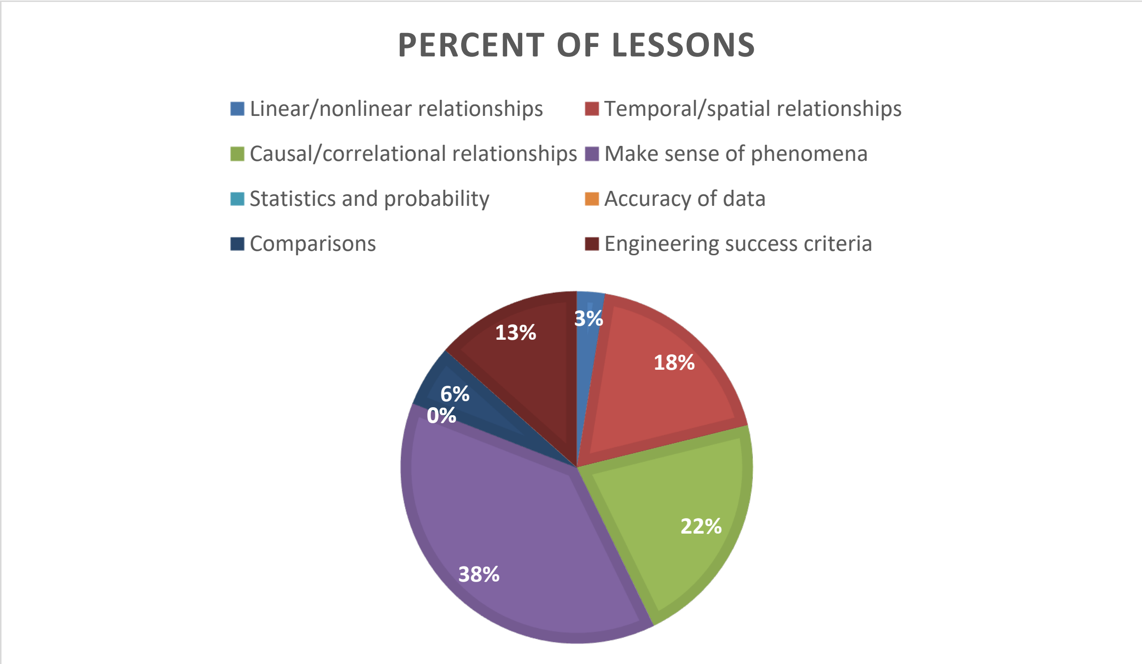
Table 6. Lesson Catcher Data

Grade Level	Lesson Catchers	Analyzing and Interpreting Data Criteria
Grade 3	1	Digital or analog tools
	2	Comparisons Make sense of science phenomena
	3	Make sense of science phenomena
	4	No evidence of criteria for analyzing and interpreting data
	5	No evidence of criteria for analyzing and interpreting data
	6	No evidence of criteria for analyzing and interpreting data
	7	Representation of data
	8	Representation of data
Grade 4	1	Digital or analog tools Representation of data Comparisons Data
	2	Digital or analog tools Representation of data
Grade 6	1	Make sense of phenomena Comparisons Temporal/spatial relationships
	2	No evidence of criteria for analyzing and interpreting data
	3	No evidence of criteria for analyzing and interpreting data
Grade 6	1	Engineering success criteria

Grade 7	1	Temporal/spatial relationships Make sense of phenomena
	2	Temporal/spatial relationships Make sense of phenomena
Grade 7	1	Causal/correlational relationships Make sense of phenomena
	2	Make sense of phenomena
Grade 7	1	Temporal/spatial relationships Make sense of phenomena
Grade 7	1	Temporal/spatial relationships Make sense of phenomena
Grades 6-7-8	1	Causal/correlational relationships Make sense of phenomena Engineering success criteria
	2	Causal/correlational relationships Make sense of phenomena Engineering success criteria
Grades 6-7-8	1	Temporal/spatial relationships Causal/correlational relationships Make sense of phenomena Comparisons
	2	Linear/non-linear relationships Temporal/spatial relationships Causal/correlational relationships Make sense of phenomena
	3	Causal/correlational relationships Make sense of phenomena
Grades 6-7-8	1	Temporal/spatial relationships Make sense of phenomena
	2	Causal/correlational relationships Make sense of phenomena Engineering success criteria
High School	1	No evidence of criteria for analyzing and interpreting data
	2	Causal/correlational relationships Make sense of phenomena Engineering success criteria

Due to the limited number of teachers in the elementary grades, it is unclear if there were any notable patterns related to the criteria selected to be embedded in lessons. Ten teachers were from grades 6 through high school, and Figure 2 shows that the criterion *Make sense of phenomena* was most prevalent in their lessons (74%). *Causal/correlational relationships* (42%) and *Temporal/spatial relationships* (37%) had the next highest percentage of criteria embedded in the lessons, while the *Statistics and probability* and *Accuracy of data* criteria were not embedded in any of the lessons reviewed.

Figure 2. Analyzing and Interpreting Data Criteria in Middle School Lessons



The educators were asked to reflect on the following questions related to each of the lessons:

1) In what way(s) do the activities expect students to demonstrate the criteria of *Analyzing and Interpreting Data*?

2) In what ways could you change a current lesson or classroom activity to allow students to demonstrate the criteria of *Analyzing and Interpreting Data*?

The reflections related to question one was provided in only one out of the ten elementary lesson catchers, and 18 out of the 19 lesson catchers in the secondary grades, for a total of 19 responses to this question. In 12 out of the 19 responses from both the elementary and secondary grades, the educators repeated the expectations of lesson (e.g., *Students document their data in a Google Spreadsheet*.), 5 of the 19 reflections provided additional information about lessons (e.g., *The experiment set up and reinforced what we were doing and talking about in class. It made them apply what they memorized about the photosynthetic equation into a "real-life" situation*.), and 2 of the 19 reflections clarified how the criteria were embedded in the lesson and formative assessment (e.g., *The activity expects students to relate the change in temperature to the amount of movement in particles* [causal/correlational relationships]).

Lesson reflections were also provided for the second question regarding how the lesson could be enhanced to reflect the *Analyzing and Interpreting Data* criteria. One reflection out of the ten elementary lessons was included, and 14 out of the 19 lesson catchers in the secondary grades had a reflection, for a total of 15 reflections to question two. Six of the 15 reflections identified a lack of knowledge regarding how to enhance the lesson (e.g., *I am unsure how to change this* *lesson to incorporate more data.*) and 9 of the 15 reflections specifically referred to how the lesson could enhance the *Analyzing and Interpreting Data* criteria such as:

- Causal/correlational relationships: *Students could have gone farther into the data to identify relationships between the data and the weather vocabulary. Students could have been split to collect [City] weather data from various days in the week, month, or year to make comparisons. Current weather data could have been collected from multiple cities to make comparisons and identify trends. Multiple cities over multiple days could have really dug into this deeper.*

- Accuracy of data: *If trends were decided upon as described above, there could have been a conversation about how accurate the trending data and conclusions were.*

- Linear/nonlinear relationships: *Relationships could have been identified if the data were graphed. It would have also assisted with any noticed trends.*

Overall, the reflections were not surprising given that this information is relatively new to the educators in which they have had few opportunities for purposeful planning related to the *Analyzing and Interpreting Data* criteria. It's important to note that only two lesson catchers were submitted after December 2021.

Unstructured Discussion about Overall Reflections

During Meeting 6 (March 2022), educators were asked to reflect on several questions:

1) Given what you have learned about three-dimensional science and the science and the science and engineering practice of *Analyzing and Interpreting Data*, how will you change your instruction (including creating lessons, learning materials, etc.) and classroom assessments?

2) Given what you have learned about three-dimensional science and the science and engineering practice of *Analyzing and Interpreting Data*, what else do you still need/want to learn?

3) Given what you have learned about three-dimensional science and the science and engineering practice of *Analyzing and Interpreting Data*, what do you think will be beneficial for all PA science educators to know?

The following themes emerged from these discussion questions:

- *There is a need to reflect on instruction and assessment practice:* Educators recognized that they had not previously considered the criteria related to analyzing and interpreting data in their instruction and assessment practices. Consequently, there was an indication that the use of the DRAFT Learning Pathways when planning lessons will be an important and necessary tool.

- *There remains a need for deeper understanding related to how the performance expectations (standards) embed the practices, and more specifically analyzing and interpreting data:* Educators recognized that they need to examine their current curriculum, lessons, and assessments to understand how three-dimensional science is currently embedded and in what ways they can be enhanced. Additionally, there was a desire to see examples of how three-dimensional science lessons and assessments should be developed.

- *Educators need support to understand three-dimensional science and the SEPs, and how to teach with these expectations in mind:* The educators believed that teachers and curriculum departments will need professional learning regarding what is meant by analyzing and interpreting data and how to enhance curriculum, instruction, and assessments, accordingly. More specifically, they believed that while current lessons, assessments, and curriculum potentially embedded the SEP *Analyzing and Interpreting Data* criteria, they needed greater clarity about what instruction is necessary for students to demonstrate the Meeting level expectations for each criterion on the DRAFT Learning Pathways.

Knowing what educators learned and continue to need for implementing analyzing and interpreting data criteria supports our belief that teaching three-dimensional science and the SEP *Analyzing and Interpreting Data* criteria is a necessary expectation. However, deep understanding requires continued professional learning and high-quality examples of instruction, curriculum, and assessments.

Student Work Samples and DRAFT Learning Pathway for Analyzing and Interpreting Data

The third source of qualitative data resulted from student work samples following a three-dimensional science lesson which embedded:

- the instructed performance expectation,
- the real-world phenomenon-based scenario,
- the criteria associated with analyzing and interpreting data, and
- the criteria associated with the SEP *Analyzing and Interpreting Data* which were measured through the formative assessment process.

These lessons were developed by the educators during meetings four and five. The educators were placed in groups based on grade-span, interest, and/or familiarity with the science dimension (physical science, life science, earth and space science). Each group had at least one teacher who was able and willing to implement the lesson, administer the formative assessment, and collect and upload student work samples. The resulting student work samples were reviewed by the educators during meeting six using the appropriate grade-span DRAFT Learning Pathway for *Analyzing and Interpreting Data* to validate a typical pathway science students follow to demonstrate the criteria for analyzing and interpreting data. As previously described, the pathway for successfully demonstrating the criteria was structured with four levels--beginning, emerging, developing, and meeting. The levels were intended to describe the typical path as seen in student responses as they move from novice to more sophisticated understandings of the underlying expectations of analyzing and interpreting data. The DRAFT Learning Pathways included descriptions of typical student work which characterized each level from a student beginning to demonstrate understanding of the criterion leading to one who is meeting the expectations. The DRAFT Learning Pathways were intended to be used by teachers to identify student strengths and needs based on what a student can do at a specific point in time. This informs the teacher's instructional decision-making about moving student knowledge and skills about the criterion to the next level within their zone of proximal development (Vygotsky, 1978). In other words, the intent of this review of student work samples was to determine if 1) the typical pathway in which students progress in demonstrating the criteria for analyzing and interpreting data is accurate, and 2) the expectations for the selected criteria are fully taught in the lesson and expected from the formative assessment. An example of an annotated work sample using the DRAFT Learning Pathway for Analyzing and Interpreting Data is found in Figure 5.

Figure 5. Annotated Student Response using the DRAFT Learning Pathway for Analyzing and Interpreting Data

Criteria	Beginning	Emerging	Developing	Meeting
Linear/nonlinear relationships	N/A			
Temporal/spatial relationships		Students fill-in chart and then use data to explain relationships between blade shape and voltage		
Causal/correlational relationships			Students analyzed patterns and trends about the relationship between blade shape and voltage to draw conclusions based on evidence	
Make sense of phenomena		Students explore connection between mechanical energy (turbine spinning) and electrical energy (voltage)		
Statistics and probability	Students describe data re: blade size and voltage in class/group discussion			
Accuracy of data		Students completed multiple trials of voltage readings for different blade shapes		

Comparisons			Students response to analysis question on p. 2 of worksheet describes interrelationship between blade shape and voltage output	
Success criteria {Engineering}		Students can identify which blade shape led to the greatest output, verbal discussion		

The annotations of student work samples revealed several salient points. Teachers were able to discern 1) the criteria associated with analyzing and interpreting data; 2) the level at which the student is demonstrating the criterion; and 3) when lessons are planned with analyzing and interpreting data in mind, the science practice criteria can be embedded in lessons and formative assessments.

Synthesis of Data

Based on the qualitative data, the results were synthesized, and organized by the research questions.

Research Question 1

To what extent can educators create science lessons which engage students in the criteria for *analyzing and interpreting data?*

The qualitative data indicates that when teachers gain knowledge about three-dimensional science, and more specifically, the criteria for analyzing and interpreting data, they can create lessons which embed the criteria in the instruction and formative assessment. The lesson plan templates, developed by the four groups, identified the criteria for analyzing and interpreting data that were included.

Two observations arose from the review of the lesson plans related to this SEP. First, the criteria noted on the lesson plan were not explicitly taught. For example, one lesson plan (group 4, grades 7-9) specifically identified the criteria to be included for analyzing and interpreting data as causal/correlational relationships, comparisons, and success criteria for engineering. However, upon review of the activities identified in the lesson, these criteria were not specifically taught, but rather were embedded as questions or activities. Secondly, educators were retrofitting previously developed lesson plans in an attempt to include the criteria for analyzing and interpreting data. In the lesson plan for group 1 (grade 4), the educators appeared to focus more specifically on the SEP *Planning and Carrying Out Investigations* while identifying the need to include questions about analyzing and interpreting data, rather than revising the lesson and purposefully including the necessary criteria. In other words, it appeared that the educators were aware of the need to embed the criteria for analyzing and interpreting data but were unsure how to include them as part of the instruction. It is unclear if this was due to insufficient time for developing the lesson, if additional knowledge about the SEP was needed, or a combination of these factors and/or others.

It's also important to note that throughout the six meetings and during the unstructured discussion in meeting 7, the educators believed that their current lessons, curriculum, and assessments embedded the criteria for analyzing and interpreting data. While this may be true, the review of the lesson plans indicated that educators may not recognize the need to move beyond exposing students to the criteria. Rather, teachers should instruct students on the meaning and expectations of the criteria, as well as providing them opportunities to practice and apply their knowledge and skills.

Research Question 2

Can we create grade-span (3-5, 6-8) learning pathways for the criteria necessary for demonstrating analyzing and interpreting data in science?

As previously described, the DRAFT Learning Pathways for *Analyzing and Interpreting Data* were developed using the Pennsylvania (2017) K-12 Inquiry and Design (Science Practices) document, and were informed using descriptions from Wisconsin, California State University East Bay, Achieve, and AMSTI. The pathways were developed prior to the exploratory study and were reviewed and modified based on recommendations by science advisors at the Pennsylvania Department of Education. During the study, participating educators also provided feedback and their recommendations were taken into consideration for modifying the pathways. Student work samples also aided in revising the pathways and validating the descriptions included at each level.

However, this study was very limited in scope and validating the pathways is dependent upon a comprehensive understanding of the SEP *Analyzing and Interpreting Data.* Given that this exploratory study was limited in time, number of educators involved, and the scope of information, the pathways should continue to be viewed as a DRAFT until further studies are conducted. These studies should include the review of additional lessons, formative assessments, and student work samples at various grades and science dimensions.

Research Question 3

Can educators validate the DRAFT grade-span learning pathways to recognize and describe how students demonstrate the criteria necessary for demonstrating analyzing and interpreting data and use the information to adjust instruction?

Educators were able to use the DRAFT Learning Pathways to describe evidence of the criteria found in the student work as demonstrated in Figure 5. As educators engaged in understanding three-dimensional science and specific criteria necessary for demonstrating analyzing and interpreting data, they were able to specifically identify the level on the pathway expected by the lesson, and whether individual students were demonstrating the expected level based on the description.

Two observations were noted from the educators' use of the DRAFT pathways. First, although the lesson plans identified which criteria for analyzing and interpreting data were included for instruction and formative assessment, the educators found evidence in the student work of all of the criteria. Specifically, Figure 5 annotations resulted from a student's work sample in response to the formative assessment associated with group 4 (grades 7-8). This lesson plan identified that the criteria to be taught and assessed included causal/correlational relationships, comparisons, and success criteria for engineering. When reviewing and annotating student work, the educators in group 4 annotated the student work for all the criteria on the pathway. Directions for annotating student work were discussed and were included on the annotation template as seen in Figure 6. It is uncertain whether the directions were unclear or whether the lessons and formative assessments actually embedded all criteria for analyzing and interpreting data.

Figure 6. Directions or Annotating Student Work

Annotating Student Work using the Learning Progressions

Goal: Annotate the extent to which students demonstrated the expectations of ***Analyzing and Interpreting Data*** based the descriptors in the appropriate grade span **Learning Progression**.

Directions:

1) Select approximately 2 pieces of student work from each teacher that you want to review and annotate. Since the student work samples have been uploaded and are PDFs in your folder, assume that the first work sample is #1, the second work sample is #2, and so on.
2) In the table below, identify the **teacher's name** (e.g., Thompson) and **which piece of student work** (e.g., #5) that is used for the annotation. This will assist us in matching the student work to the annotations after today's meeting.
1) Discuss the student student work sample and determine the extent to which the student demonstrated the expected criteria and describe using evidence from the student work.
3) Record the evidence and why you determined that the student demonstrates the criterion at that level.

For example:

Criteria	Beginning	Emerging	Developing	Meeting
Digital or Analog tools			The student independently selected the ruler to measure the growth of the plant over the two weeks. The student consistently required support and when used independently, the measurements were inaccurate.	
Representation of data		The measurements were recorded in a table but were not always placed in the correct column for the correct day. The student did not note that there were discrepancies with the data collected.		
Make sense of science phenomena				
Comparisons				
Data				

A second observation was that the annotations could be misleading with respect to how well students demonstrate the criteria associated with analyzing and interpreting data if the lesson and formative assessment did not expect the demonstrations at the Meeting level. Using the example in Figure 6, the annotation for the criterion Digital or Analog Tools indicates that the student demonstrated the expectations found in the description on grades 3-5 DRAFT Learning Pathway at the Developing level. However, if the lesson and associated formative assessment did not provide the student with the opportunity to demonstrate the Meeting level, there may be a misconception that the student is unable to fully demonstrate this criterion. Several implications for this observation include:

1) While in the midst of instruction, teachers may not plan to include the expectation that students demonstrate the full extent of the criteria associated with analyzing and interpreting data. This makes sense; however, they will need to be sure that this is noted on the annotation document to determine whether students are demonstrating the anticipated level. In other words, if the instruction and formative assessment expect students to demonstrate the criterion at the Developing level, teachers should use the DRAFT pathway to determine whether students are reaching this expected level, and if not, how should instruction be modified to ensure students understand how to demonstrate the expectation.

2) Teachers will need to monitor their lessons and formative assessments throughout the year to ensure that students have access and opportunity to demonstrate the Meeting level for each of the criteria. In order for students to fully demonstrate the SEP *Analyzing and Interpreting Data*, they need to learn and have multiple classroom opportunities that include the descriptions at the Meeting level of the pathway.

As noted in research question 2, these issues may be related to the limited exploratory research design and educators beginning understanding of the SEP *Analyzing and Interpreting Data.*

Limitations

While this exploratory study provided valuable training and learning about analysis in the science content area, and participants expressed appreciation for the information and resources, there were several limitations to the analyzing and interpreting data exploration.

1. The greatest limitation to this exploratory study was its structure. Meetings were three-hours in length, once a month for six months (October-March). This structure was created due to COVID-19 which inhibited in-person meetings from occurring and hiring full-day substitutes for teachers was discouraged by school and district leaders. We have learned from previous studies that teachers need sustained time (e.g., full days, multiple years) for engaging in this type of work and having opportunities to meet and talk to colleagues was critical. Educators need time to make meaning of the learning, to engage with the content, and to try new strategies in their classrooms prior to fully shifting their practice. The three-hour virtual structure of Zoom meetings stilted conversations, sharing of lessons, and examining student work samples. Educators were encouraged to set up times to meet and discuss the work in-between structured calls, but there is little indication that this occurred.

2. A second limitation of this exploratory study was the inconsistent and sparse information provided by teachers on the *Lesson Catchers*. It was anticipated that the information provided on these organizers would allow the researcher and PDE to understand how instruction and formative assessment opportunities changed throughout the year to

include three-dimensional science, and more specifically, the criteria for analyzing and interpreting data. However, few *Lesson Catchers* were created by each educator, and most were created early in the school year. One teacher submitted 8 *Lesson Catchers,* while the average number submitted was two. Additionally, not all teachers included reflections. Consequently, it is not clear the extent to which individual educators made a shift in their understanding of analyzing and interpreting data or how that was manifested in their lessons.

3. Another limitation was the number of educators (15) and districts (9) included in the study. Pennsylvania is a large state with over 500 districts representing rural, suburban, and urban districts. While it is not possible or desirable to include more teachers than were invited for this six-month exploration, the study should be replicated with other districts to ensure the results are accurate and applicable across the state.

4. A fourth limitation is the weak understanding of analysis in general, and the criteria necessary for students to analyze and interpret data. As the Pennsylvania Department of Education plans for releasing the revised science standards which embeds three-dimensional science, there is a strong need for professional learning across the state. As the standards are revised, so will the items on the state test be revised, and student success will depend on teacher understanding of the underlying expectations of three-dimensional science and the criteria for the SEP *Analyzing and Interpreting Data*.

5. A final limitation is related to the need for professional development for teachers to know how to embed the analyzing and interpreting data criteria into instruction and formative assessment, and how to use the DRAFT Learning Pathways to review student work and make instructional decisions.

Discussion

The science analysis exploration detailed in this report revealed that educators believe that analyzing and interpreting data is an important aspect of science instruction and assessment processes. They believe that the underlying criteria for this Science and Engineering Practice are currently taught in their lessons and curriculum, but they need to explicitly note these opportunities and supplement, when necessary. Overall, the teachers were able to make meaning of what they learned throughout the year to create a lesson and formative assessment that supports analyzing and interpreting data, and to annotate student work using the DRAFT Learning Pathways to assist with their instructional decision-making. The following sections provide insight into some of the instructional, curricular, and assessment implications from these findings and to discuss next steps in researching this SEP.

Curriculum and Instructional Implications

One of the key goals of this exploration study was to better understand the extent to which science educators understand, instruct, and assess the criteria necessary for analyzing and interpreting data. This goal was determined through the examination of lessons plans and corresponding formative assessments which included the expectations of three-dimensional science, and by annotating student work using the DRAFT Learning Pathways for *Analyzing and Interpreting Data.* Participants expressed the need for gaining deeper understanding of the criteria and how to embed them into their lessons. Given the impending release of the revised science standards, the Pennsylvania Department of Education (PDE) will want to engage IU Science Consultants and district science coordinators, department chairs, and coaches in creating an action plan for reviewing and revising current lessons and units to ensure that students are fully and explicitly instructed on these criteria. Creating a coherent K-12 structure will allow students to meet with greater success when analyzing and interpreting data in the science content area as they move through the grades.

Assessment Implications

While the PSSA science test has not changed yet, it will be revised to mirror the revised science standards. The lesson plans and student work resulting from the formative assessments developed during this study demonstrated that students are not expected to meet the full expectations of the criteria associated with analyzing and interpreting data. Consequently, it is unlikely that they will demonstrate the criteria in the summative assessment process. Engaging teachers in understanding the expectations of the criteria using the current version or future iterations of the DRAFT Learning Pathways for *Analyzing and Interpreting Data* will aid district leaders and educators to move beyond the low-levels expectations of the criteria that limit students' ability to demonstrate deep understanding of this SEP. As lessons and units of instruction are reviewed and revised, so too should the formative and summative assessment practices. The DRAFT learning pathways should be used by educators during Professional Learning Communities (PLCs), common planning time, or by individual teachers to make meaning of what students can demonstrate given appropriate instruction and to diagnose student strengths and needs with respect to analyzing and interpreting data to support student success.

Conclusion and Next Steps

The results of this exploration study can guide PDE's next steps with how to support educators across Pennsylvania in understanding three-dimensional science, developing lessons and formative assessments that embed the criteria for analyzing and interpreting data, and on using the DRAFT Learning Pathways for *Analyzing and Interpreting Data* to monitor and adjust instruction.

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Appendix A: DRAFT Learning Pathways for *Analyzing and Interpreting Data*

PA Science and Engineering Practices
Grades 3-5 Learning Pathway

Criteria *for Analyzing and Interpreting Data*	Beginning	Emerging	Developing	Meeting
Analyzing and Interpreting Data				
Digital or Analog tools	*Identifies different digital and/or manual tool(s) and their purpose.*	*Identifies and uses a digital and/or manual tool(s) when prompted and supported.*	*Identifies appropriate digital and/or manual tool(s) and uses with support.*	*When possible and feasible, identifies the appropriate digital tool(s) (e.g., computer, calculator, probe, sensor, scale, ruler, caliper), and explains why the tool is appropriate, and uses it/them independently.*
Representation of data	*Records and shares observations and data.*	*Makes measurements and/or observations, collects and records data, and describes the data noting patterns of similarities and differences.*	*Collects and displays accurate data in tables and graphs, and describes the meaning of the data (e.g., patterns of rates of change).*	*Independently collects, records, and represents accurate data in tables and/or appropriate graphical displays (e.g., bar graphs for comparisons, pictographs for statistical information, and/or pie charts for parts of a whole) to reveal and describe patterns that indicate relationships (e.g., cause/effect; scale, proportion & quantity).*

Make sense of science phenomena	*Describes objects, organisms, and/or observations, unrelated to a science phenomenon or system.*	*Uses observations and mathematics and/or computation (scale, size, quantity) to describe a science phenomenon or system.*	*Analyzes data to describe the interrelationship of variables and uses mathematics and/or computation (scale, size, quantity) as support for drawing a conclusion about a science phenomenon or system.*	*Analyzes and interprets data to describe the interrelationship among variables using logical reasoning (explanation and elaboration) and mathematics and/or computation (scale, size, quantity) as support for drawing a conclusion and determining implications about science phenomena or systems.*
Comparisons	*Examines one group's observable outcomes and data and describes what occurred.*	*Examines one group's observable outcomes and data and describes similarities or differences.*	*Examines data collected by distinct groups and describes similarities or differences in their findings.*	*Examines data collected by distinct groups and describes similarities and differences in their findings and makes a generalization.*
Data	*Identifies the data separate from the problem statement or proposed design of an object, tool, or process.*	*Describes the data in support of the problem statement or proposed design of an object, tool, or process.*	*Analyzes the data by describing an interrelationship between the data and the problem statement or proposed design of an object, tool, or process, and drawing a conclusion.*	*Analyzes data by describing and elaborating on an interrelationship between the data and the problem statement or proposed design of an object, tool, or process, drawing a conclusion, and making a logical refinement to the problem statement or proposed design.*
Evaluation {Engineering}	*Identifies the data separate from the design solution.*	*Describes the data in support of a design solution.*	*Uses data to evaluate the strengths and/or weaknesses of a design solution.*	*Use data to evaluate the strengths and weaknesses of design solutions and to refine the design solutions.*

Note: The red font represents the integration of cross-cutting concepts.

PA Science and Engineering Practices
Grades 6-8 Learning Pathway

Criteria *for Analyzing and Interpreting Data*	Beginning	Emerging	Developing	Meeting
Analyzing and Interpreting Data				
Linear/nonlinear relationships	*Constructs and/or identifies the x- and y- variables used in graphical displays of data.*	*Constructs and/or identifies the x- and y-variables and quantitatively describes the variables (i.e., identifying slope) used in graphical displays of data.*	*Constructs and/or quantitatively describes, analyzes, and interprets graphical displays of data and/or large data sets to identify, and describe the interrelationship of x- and y-variables (i.e., calculating slope, change in the x-variable and the relationship of the change in the y-variable) used in linear and/or nonlinear relationships.*	*Independently constructs and/or quantitatively describes, and analyzes and interprets graphical displays of data and/or large data sets, and draws a conclusion (e.g., causation v. correlation) about the interrelationship between the x- and y-variables used in linear and/or nonlinear relationships.*
Temporal/spatial relationships	*Uses graphical displays (e.g., maps, charts, graphs, and/or tables) of data sets to identify relationships.*	*Uses graphical displays (e.g., maps, charts, graphs, and/or tables) of data sets to identify and describe relationships.*	*Uses graphical displays (e.g., maps, charts, graphs, and/or tables) of small and large data sets to identify and describe temporal (i.e., time, sequence, logic) and/or spatial (i.e., physical position-above, below) relationships.*	*Uses graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify and describe patterns revealed by temporal and spatial relationships (e.g., distance-time, velocity-time).*

Causal/correlational relationships	*Identifies patterns in data (data that repeats in a recognizable way).*	*Identifies and describes patterns and trends (e.g., regular, irregular, cyclical) in data.*	*Identifies and describes patterns, trends in data, and draws a conclusion about the relationship of the data.*	*Describes the patterns, trends, and relationships in data (e.g., similarities and differences, causal and correlational, linear, and nonlinear) in graphical displays of data (e.g., scatter plot), distinguishing between causal and correlational relationships.*
Make sense of phenomena	*Identifies data that suggests evidence about a science phenomenon or system.*	*Identifies and describes data that suggests evidence about a science phenomenon or system.*	*Analyzes and interprets data by describing the interrelationship of variables as support for drawing a conclusion about a science phenomenon or system.*	*Analyzes and interprets data to describe the interrelationship among variables to provide sufficient and relevant evidence for drawing a conclusion and determining implications about science phenomenon or system.*
Statistics and probability	*Describes the data using mathematical terminology and probability to predict outcomes.*	*Applies a concept of statistics (including mean, median, mode, or variability) and probability (i.e., use probability models) to describe the data, using a digital and/or manual tool with prompting and support.*	*Applies concepts of statistics (including mean, median, mode, and/or variability) and probability (i.e., develop and use probability models) to analyze the interrelationships of variables, using digital and/or manual tools with support.*	*Applies concepts of statistics (measures of central tendency and variability) and probability (i.e., develop, use, and evaluate probability models) to analyze the interrelationships of variables and describes the general characteristics of the data (e.g., describing the center of a data set, variability or spread to describe the dispersion of data within the set, the skewness of the data, outliers in the data, stability of parameters of the data over time), using digital tools when feasible.*

Accuracy of data	*Identifies the need for accuracy of data and precision.*	*Identifies the limitations of data (e.g., incomplete data, unreliable data, quantity, format), and describes ways to improve accuracy and precision for a data set (e.g., check measurements and formulas, multiple measures, multiple trials).*	*Describes the limitations of data analysis (e.g., measurement error), with prompting and support, seeks to improve precision and accuracy of data with better technological tools and methods (e.g., check measurements and formulas, multiple measures, multiple trials).*	*Considers and describes the limitations of data analysis (e.g., measurement error), and independently seeks to improve precision and accuracy of data using the most appropriate technological tools and methods (e.g., check measurements and formulas, multiple measures, multiple trials).*
Comparisons	*Identifies similarities and differences in observations.*	*Identifies and describes similarities and differences from different trials and/or distinct groups.*	*Analyzes and interprets data by describing the interrelationships and variations in findings.*	*Analyzes and interprets data by describing the interrelationships and measurement variations in findings and determining how to address the variations.*
Success criteria {Engineering}	*Uses analyzed data to identify evidence of similarities and differences in features of the solutions.*	*Makes a claim based on the analyzed data for which characteristics of each design best meet the given criteria and constraints.*	*Uses the analyzed data to identify the best features in each design that can be compiled into a new (improved) redesigned solution.*	*Analyzes data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.*

Note: The red font represents the integration of cross-cutting concepts.

Appendix B: Lesson Catcher

Lesson Catcher

Teacher:

Date:

Analyzing and Interpreting Data
Lesson Activities
Student Responses **Either record oral responses, anecdotes or collect student work samples**
Reflection: In what way(s) do the activities expect students to demonstrate the underlying expectations?
Reflection: In what ways could you change a current lesson or classroom activity to allow students to demonstrate the underlying expectations of *Analyzing and Interpreting Data*?

Appendix C: **Science Lesson Plan Template**

Three-Dimensional Science Learning Plan Template		
Grade/Content		
Authors		
Number of Days		
DRAFT Standard/ Performance Expectation		
Disciplinary Core Ideas		
Cross-Cutting Concepts		
Science and Engineering Practices	Analyzing and Interpreting Data	
Science Phenomenon		
Instructional Pathway		
Activity	**Teacher Actions**	**Student Actions/Evidence**
Engage		
Explore		
Explain		
Elaborate		
Evaluate		
Classroom Assessment Name and Description		
Expected Student Response		