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How Students Investigate: Understanding Students' Use of Scientific Schemas in Open-Ended Labs

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Abstract

Schema provides a theoretical framework for understanding the nature of science, inquiry, and open-ended labs. These topics have been emphasized in the state standards, especially in high school sciences. In this study the researcher took field notes, collected lab write ups, and conducted focus group interviews to understand students' use of schema related to open-ended labs. These data were analyzed with the constant comparative method to generate themes. The author describes the major findings with parallel narratives, one focused on a student's confusion and the other focused on a student's understanding. The author concludes by advocating for science teachers to provide open-ended labs with scaffolding for high school students by including sentence starters and reteaching the scientific process throughout the year.

How Students Investigate: Understanding Students' Use of Schemas in Open-Ended Labs

During college I took a lot of science classes. At first the classes seemed impossible as I wondered how I would ever remember all the organisms in biology, every chemical reaction in chemistry, and all the formulas I would use in physics. Over time, I learned the not-so-secret strategy for success in science: to make patterns out of the information I learned. That moment was a turning point for me; with that small shift in my thinking science transformed from an enormous set of facts into a process of how I thought about the world. As I taught my students to think like a scientist in a year-long clinical teaching placement for my M.Ed. in Teaching and Learning, I gradually pulled back the scaffolds to push my students from cookbook style labs, which come with every step of the procedure already set in stone, to an open-ended prompt for them to investigate. By the end of the school year students had dozens of chances to have that "Aha!" moment where the thinking patterns of science become intuitive. In this study, I share how students use the mental processes of science to investigate open-ended labs.

Purpose

The Texas Education Administration defines scientific inquiry as "the planned and deliberate investigation of the natural world using scientific and engineering practices" (Texas Education Agency, 2017). In the physics classroom, inquiry is the foundation of open-ended lab investigations. Rather than follow a series of steps which have been prepared by the teacher to get a result, inquiry-based or open-ended labs ask the student to use the scientific process. The mental work of connecting to new information then falls on the student. Open-ended labs are described by Dale et al. (2019) when they said, "The main goal of the experiment is not getting a highly accurate result, but being engaged in the experimental process" (Dale et al., 2019, p. 548).

As my students learned and practiced the scientific process over the course of the school year, they practiced recognizing the patterns and thought processes which make up the foundation of scientific investigations. Students used four steps for a scientific investigation: question, hypothesis, data collection, and conclusion. At the start of the semester students were given the first three parts and asked to discuss the result. The labs with every step of the procedure already set before beginning are sometimes referred to as "cookbook labs" because following the procedure is much like following a recipe. Over the course of the school year the scaffolding in the lab decreased, first asking students to come up with their own hypothesis, then their own procedure. By the end of the first semester students were given only the question. As these pieces of scaffolding were pulled back students were expected to adopt a scientific way of thinking, using similar styles of question, hypothesis, and procedure to reach a conclusion. In this study I investigated how students used their understanding of the scientific process to investigate an open-ended prompt. The purpose of this study was to examine and describe students' schemas when given an open-ended lab assignment. I focused on the following question:

> How do students use, or not use, the schema I have modeled for them when they are given an open-ended lab?

This study took place at my clinical teaching placement as I worked on my master's degree in a medium sized city in West Texas. The school I taught in was the smallest of the three high schools in town with only 320 students. The school was slightly less diverse when compared to the rest of the population with a composition of 52% white, .5% American Indian, 4% Asian, 5% Black, 35% Hispanic, and 3% two or more races. Compared to the district average of 67% economically disadvantaged, the school I taught in had only 44% economically disadvantaged. This school also had double the district percentage of students considered Gifted and Talented at 15%.

Literature Review

The shift from memorizing facts to understanding systems happens in any discipline as a student becomes proficient. One way to describe this shift in thinking is with schema theory, which says people learn patterns and develop organizational structures to understand information (Hughes & Cuevas, 2020). Some educators have theorized that by using the thinking patterns and common phrases of a discipline a novice can sound like a professional (Donovan & Bransford, 2005). A foundational study for schema comes from Chase and Simon (1973) when they found that professional chess players had a significantly better memory of the game board than a novice, but only when the pieces were arranged in a meaningful game. Their study showed that the expert understanding of systems at work allowed them to keep track of more individual pieces of information. When translated into the classroom, the value of learning the schema of science is that the skills remain the same when scientists make new discoveries, or when the chess masters see new game boards.

The schema related to science are clearly defined by educational organizations and fall in two main categories. These schema fall under the categories of inquiry or the nature of science, two common terms which have a significant overlap. Inquiry is a process of discovering information often included in discussions about the nature of science, which is the broader category containing all the scientific ways of thinking. The Texas Education Agency includes both these aspects in their standards in all science classes, from elementary through the 12th grade (Texas Education Agency, 2017). The Next Generation Science Standards have a thorough description of the nature of science and described it as “a variety of methods… based on empirical evidence… open to revision… a way of knowing… addresses questions about the natural and material world" (Next Generation Science Standards, 2013, p. 4). Several researchers have investigated how labs can be reworked to include more of the nature of science skills with great success, reporting positive effects on students' achievement, perceptions of science, self-efficacy, and creativity (Hasançebi et. al, 2021; Hughes & Cuevas, 2020; Koenig et. al, 2019; Wilcox & Lewandowski, 2016). Other researchers have developed tools to assess students' skills related to the nature of science and found that asking students to perform a critical thinking or scientific process task far more useful for predicting their future success in science courses than a multiple-choice test (Etkina & Van Heuvelen, 2001; Ludwig et. al, 2021; Walsh et. al, 2019). Since the nature of science and the skills used to perform scientific experiments are this valuable for learning, more classrooms would benefit from including inquiry-based labs.

The state standards for nature of science and inquiry are carried out in many ways in the high school science classroom, but the overwhelming majority is through lab investigations. Banchi and Bell (2008) describe the different levels of inquiry in a science class, ranging from a cookbook lab, where students are asked to confirm an already-known concept by following a set of instructions, to open inquiry, where students must generate their own question and plan to investigate it. This final level is what may be referred to as "open-ended labs," which can be used to meet these nature of science standards in high school classrooms (Banchi & Bell, 2008, p. 28). The defining feature of open-ended labs is the broad question or prompt, in contrast to list of steps featured in many classroom labs. Studies on open-ended labs found that students see both academic improvement and social benefits, like improving their writing and communication skills (Hoehn et. al, 2021; Holmes et. al, 2020; Kalender et. al, 2020).

Many of these studies are helpful to understand how to teach science in a high school classroom even though they took place on a college campus. However, high school students differ from students taking science classes in a university because many of my students do not want to go into a science career. While other studies have focused on one aspect of a high school lab, my study focused on the schema used by students throughout the entire process. Since there is a gap in the literature, my study aims to give a general understanding of ways high school students use scientific thinking.

Methods

Based on the research in the field, I designed this study to focus broadly on all parts of the open-ended lab. As I prepared for the study I worked with my cooperating teacher, my faculty advisor, and other teachers in my cohort to refine my idea. I included students in all three of my academic physics classes based on their assent to participate in the observations, artifact collection, and focus group interviews. This data collection focused on a single open-ended lab in the middle of the second semester of physics. Students were prompted to explain their reasoning at each of the four steps: question, hypothesis, data collection, and conclusion (see Appendix A). As they worked, I walked around the classroom to answer questions and take field notes. The simple open-ended lab prompt was, “Investigate magnetic fields.” Students branched from this goal into dozens of different questions, procedures, and conclusions.

Participant Selection

This study took place during my year-long clinical teaching placement in a high school physics classroom in West Texas. I invited all my students from three academic physics classes as well as my cooperating teacher to participate in this study (all names replaced with pseudonyms). Of the 53 students invited, 20 elected to participate in the study. The students in my classes were a part of the Brickhouse School and matched the overall racial makeup of the school district: 46% Hispanic, 35% Anglo, 13% African American, 4% two or more races, and 1.6% Asian/Pacific Islander/American Indian. Forty-four percent of my students were considered economically disadvantaged. I obtained consent and assent by sending an information letter and permission form home to parents or guardians, asking students to sign an assent form, and by providing an information letter and consent form for adult participants.

Data Collection

Data collection began early in the spring semester with an interview of my cooperating teacher. In this half-hour interview I asked questions about the schemas and scaffolds students had been taught throughout the year throughout each step of the lab: asking questions, making hypotheses, collecting data, and drawing conclusions. This conversation helped me prepare for the second period of data collection where I obtained the other three forms of data within a single week of instruction. On the day of the open-ended lab, I took field notes with a template and expanded on them after class (see Appendix B). On the same day I collected lab documents with students' work and explanations by scanning them digitally. Within five days of the lab, I conducted focus group interviews which were audio recorded and then transcribed (Hendricks, 2017). The focus group interviews involved four lab groups chosen for their high degree of participation with at least one from each of my three Physics classes. The focus groups lasted between 12 and 15 minutes, and followed the same interview protocol (see Appendix C). Only groups with full participation in the study were selected for focus group interviews.

Data Analysis

I used inductive coding and the constant comparative method to analyze my qualitative data from artifacts, notes, and interviews (Hubbard & Power, 2003). I began by processing the first 20% of the data into level 1 codes, which assign a specific topic to a chunk of data, then using those codes to label the rest of the data. After I generated the level 1 codes, I reviewed the data and organized them into three level 2 codes (Tracy, 2013). These level 2 codes synthesized the topics of the level 1 codes and helped me interpret the data. As I organized the level 1 codes into their level 2 parents, I wrote memos attached to them to keep track of why I made the decision to nest them together in this way. When my data was coded, I created a digital index to help find every instance of each level 1 and level 2 code. After coding and indexing all the data I created a codebook with a definition and example of each code to refer to when writing (see Appendix D).

Findings

Before any students walk into a lab, the teachers already have an idea of what they expect to happen. This imaginary student immediately knows a question to ask, a connection to make, and a solution. Unfortunately for teachers everywhere, this perfect student has never visited a classroom on the day of the lab. Instead, the real students in the lab fall into two general groups. One group approaches the ideal student; they can confidently use the tools they know at each step of the lab. The other group does not use the schema the teacher had in mind, either because they decided to use something different or because they did not have the mental tools available during the lab. These three stories of script, success, and struggle demonstrate the schema the teachers expect, and those which students use. These narratives which emerge from the data answer the question of what schema students use during an open-ended lab. Here I present three archetypal stories from the lab, first the perfect student in the teacher's imagination, then the real students who were successful, and finally the student who struggled to even complete the lab.

Some students moved between the two groups once or more over the course of the lab, but most stayed in the same group the entire time.

Starting the Lab: Scientific Questions

Our lab begins with supplies and a prompt. As the perfect imaginary student walks into class, she grabs her lab document from the door. When she reaches her lab station, she looks at the equipment in front of her. Today she sees a bar magnet, a piece of blank paper, and a clear box with metal shavings inside. She is already thinking about what she could investigate when the teacher introduces the prompt, “Investigate magnetic fields using the supplies at your station.” The perfect student starts thinking about connections to the previous unit and asks a question, “Electric fields depend on charge and distance; do magnetic fields work the same way?” She shares her idea with the group and listens to other ideas as the team decides what they will investigate today.

Meanwhile, real students fill the chairs of my classroom. Some students pick up the lab materials when they reach their station; one sticks the magnet to every piece of metal within reach. The prompt goes out and students start thinking about questions they can investigate. At this point in the lab the students launch off on two trajectories, one will lead to success, the other will end with frustration and confusion.

The successful student uses some of the strategies the teachers were expecting as well as a few general problem-solving skills to come up with a connection to start the lab. As he begins thinking about the lab, Elton starts by remembering the shape of a magnetic field from a video he saw online. Working backwards from the answer, he reaches his question, “How do we prove magnetic fields are circular?” Elton and his group agree that this question will lead to a good experiment. Several students use a connection to prior knowledge, remembering pieces of information which lead in dozens of directions. In all three classes, only two groups investigate the same question. Oscar and his group do not have a connection immediately, so they mess with the materials to figure out some ways they could collect data. They eventually ask which side of a magnet is stronger after they notice an apparent difference in how much of the metal shavings stick to each side of the magnet. Another group is curious about what kind of materials can become magnetized after noticing that the iron shavings did not seem to be magnetic on their own, but only in the presence of the bar magnet. After a moment of deliberation, they come to the teacher with a list of other materials to test. Each of these approaches to the prompt gives the group a direction and a next step, makes a connection, and sets the group on the path to learn something they are curious about.

Unfortunately, not everyone has such an easy time coming up with what they will investigate. As her group gets started, Ellie is overwhelmed by the number of steps she has to figure out with her group. At the beginning of the lab, she furrows her brow and stares at the magnet for a few minutes as she tries to force ideas to appear. Eventually someone in her lab group takes the lead, leaving her and the other two teammates behind as they try to figure out what the leader means. At another station, Beth asks the teachers questions about the lab supplies. “How will this be graded? Do I have to use everything? What question should I ask?” After talking to the teacher for a few moments, Beth explains how she chose her question by writing down, “Because the teacher said so.” After the lab these students both remarked that they were more concerned with their grade than anything else since they did not believe that they were smart enough to discover anything new. These students have used different schema in their first phase of the lab than the successful students, but it is not too late for them to get back on track (see Figure 1).

Figure 1

Schema Used by Three Types of Students

The Imaginary Student	The Successful Student	The Confused Student
Makes a connection to their past experience Asks a scientific question	Messes with materials to make a connection Works backwards from the answer they know Asks a creative question Shares their thoughts with the group	Makes up a question without a connection to past experiences Plays with materials just for fun Works alone

Note. While not necessarily exclusive to the group they are in, these schema were most prevalent in the group they are listed under.

These two groups of students have already separated themselves based on the connections they made in asking a question. While one group is ready to collect specific data, the other group is stuck behind a barrier of writing a question. The groups that struggled the most at this step may have an issue with planning, but they also struggle to articulate their ideas. These groups are quiet, at least about the lab prompt, as they struggle to make sense of what they are seeing in front of them. One of the most helpful tools to give this group of students as I walked around the class was a sentence stem like, "Why does… do…" These stems helped some students get on the right track. Once they had words to communicate their idea, they were successful on the rest of their lab. This scaffold was less helpful to those looking for a way to make the perfect grade as the class moved on to the next part of the lab, making a prediction.

Writing a Hypothesis

Question in hand, the imaginary student now makes a hypothesis. He remembers the two parts of a good hypothesis from every other lab. First, every hypothesis is formatted as an if-then statement. Second, a hypothesis can be disproven. To answer his question, this imaginary student now predicts what will happen when they collect data. “If the strength of a magnetic field depends on distance, then the amount of shavings picked up by the magnet will decrease as it gets farther away from the box.” His hypothesis says exactly what kind of data he will collect so the imaginary student moves on to the next step quickly and painlessly. As the real students enter the next phase of the lab, the gap between them grows wider. Those who have a clear direction from their question can write a hypothesis with clarity, but the groups still wandering without a goal make things even harder on themselves by coming up with impossible or meaningless tests. As the confident group refines their process, the confused groups make a wild guess.

While not identical to the ideal student, the confident group follows the same process. Elton describes the hypothesis as the simplest part of a lab; it is a connection between the data they collect and the question they asked. After making connections and discussing their goal as a team, it is a simple come up with an if-then hypothesis. These students have already thought about the process of testing their hypothesis even before writing it down. Beth wrote, “If the metal shavings are attracted to the magnet, then the magnetic field is shaped the same [as the metal shavings].” While the real hypotheses from students are not as neat or precise as the teachers’ perfect hypothetical, they still have the two key components of a testable answer. In many successful groups they spent a few minutes discussing which of multiple hypotheses to select for their experiment. As they worked together to come up with potential tests, they refined the process of data collection. All on the same page, these students now have a plan which enables them to work together with their own role in the group.

Only a few feet over, the hypothesis is an intimidating challenge to those who are less clear on their direction. Rather than working together to figure out a plan, one student tells Ellie what test they are going to do. Beth and her team make a guess, hoping it is what the teacher is looking for when their labs are graded. These groups did not include an if-then statement in their hypothesis and most of the time made a claim that was completely untestable like, "Magnetism comes from subatomic particles." While these ambitious predictions might sound good at first glance, they lead groups into a frustrating data collection process when they were too nebulous to pin down.

Each of these experiences in the hypothesis stage of the lab continues in the trajectory set at the beginning. The students who made a strong connection to their previous understanding of the world keep making progress as they add specific details into their plan for data collection. Those who were confused at the beginning are still struggling to find direction, predicting results that would be impossible to measure. At this crucial stage in the lab process students are unlikely to get back on track before the end of class.

Drawing Conclusions

After the imaginary lab group has their hypothesis, data collection is clear. They collect the data they predicted in the hypothesis and interpret their result. As the imaginary students begin their data collection, they are looking for how much of the metal shavings sticks with the magnet at different distances from the box. As they collect data these students can tell from the first test what their conclusion will be, each additional test only adds confidence to their answer. "Magnets behave in a similar way to an electric charge; they attract the most strongly when they are close to the shavings." These students draw on the data to inform their conclusion and write an explanation tying everything back to their original question. In the real classroom the group mentality really breaks down at this step as students are finished collecting data and begin drawing their conclusions. The conclusion is more writing than the previous steps, so students take on the challenge as individuals. At this point, students in the real class make some connections all the way through while others rush to give shallow answers.

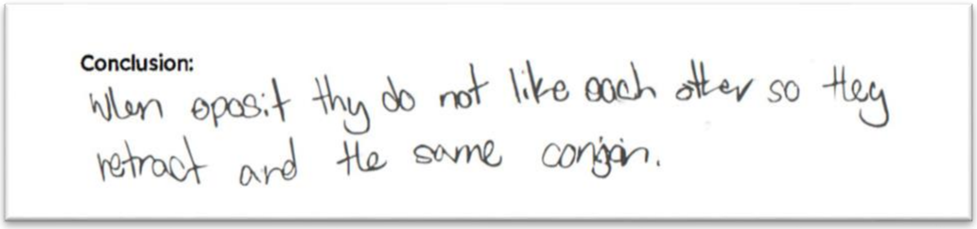
Since Elton's lab group worked backwards from their conclusion to the question, they reached this part of the lab and knew exactly what they were looking for. They described the cohesive goal that ran through the entire lab in their conclusions, emphasizing the data that were most relevant to their question. After debriefing the lab in the focus group, this lab group went into detail about the further questions they were now curious about for the rest of the unit. This group not only learned something on the day of the lab, but they also got ready for the rest of the unit.

Collecting data took a long time, so Oscar and Patrice feel rushed to get a conclusion on the lab document. They felt good about each of the steps in the lab so far but reaching the end suddenly they think about their grade. Patrice just wants to put something simple down and, after conversing with Oscar, she writes a simple sentence to summarize what she learned. Oscar is more anxious; instead of a single sentence he fills up the rest of the page with words about the experiment. Despite being thorough, his summary is hard to understand. As they come in for a landing, Oscar and Patrice show how well they have made the connection between their data and their question by efficiently communicating their result.

Meanwhile, Annie did not understand why the data her group collected was helpful to answer their question. Without a connection to the data, Annie decides to put down an answer anyway (see Figure 2). She explains that she reached this conclusion, "By doing test to get my answer." This result is as much a guess as her hypothesis was, so after finishing the experiment Annie is as confused as she was at the onset.

Figure 2

Annie's Conclusion



Note. According to the focus group interview, her single sentence conclusion reads, "When opposite they don't like each other so they retract to the same conjunction."

At the end of the lab students either learned something or confused themselves. Some groups had a cohesive line of thought that ran through all three phases, a few ran out of time and rushed their conclusion, and others were completely confused by the time they were asked to make meaning from their data. The schema at the conclusion of the lab are either making a connection or making something up. The most successful groups used time management skills to get through the data collection with time to spare and could come up with a strong conclusion.

Implications for Teachers

Students used a wide variety of schema to do their labs for three main purposes. In the first phase of the lab, the schema focused on making a connection, either with the materials provided or to past experiences. In the second phase of the lab the schema focused on testing a hypothesis, like using an if-then statement. The schema used during the final phase of the lab focused on interpreting the data to get meaning. Students handled each of these steps with varying degrees of success, partly from their understanding of the lab process and partly from other factors.

After watching students struggle with the language skills involved in the open-ended lab, I made several adjustments to my classroom teaching. The two biggest areas where I adjusted instruction were by including linguistic prompts for labs and by reteaching concepts periodically. When implementing open-ended labs these adjustments can give struggling students enough direction to reduce their frustration and help the grade-conscious students move past their stress. Throughout the interviews I was surprised to hear students from both the successful and struggling groups say they preferred the freedom of open-ended labs to their more procedure-oriented counterparts, so I included more of them in the weeks since conducting interviews.

Language prompts like sentence starters can solve some of the roadblocks students faced in this open-ended lab. Two ways of including prompts are on the paper and prompt charts. To include the prompt on the page is as simple as providing the first few words of a sentence, providing the two key words of a hypothesis followed by a blank, or including a word bank of prompts. These inclusions are especially helpful for students who struggle to write complete sentences with scientific vocabulary. Another option is to hang a chart with a few sentence stems for each part of the lab on the wall. The main source of frustration based on interviews was being unsure of the direction the lab was going; these stems can give just enough scaffolding for students to articulate what they are trying to do in the lab.

Other than having the language to engage with the lab I noticed the other major hurdle for students was their stress about their grade. Some students wrote the same reason for a question, hypothesis, and procedure, “Because the teacher said to.” This showed me that students were not engaged with answering the material with what they learned, preferring to say what they thought would get them the best grade with the least work. They relied on the teacher to do the thinking for them, using the schema of offloading the work to make it easier. While I would love to develop a growth mindset in my students overnight, I can use thorough feedback within the first weeks of class to help fix gaps before they become habits. When students have a clear understanding of my expectations for them, they will know how they are doing when it comes to their labs and can spend more time on the thoughts that will be the most helpful to their learning.

While some students were reluctant to engage in the mental work that goes into an open-ended lab, all the students I interviewed preferred open-ended labs to their traditional counterparts. They had positive things to say about stretching what they know to learn something new, overcoming a challenge and feeling successful, and feeling like they are important to their groups. These students responded with feedback about why some open-ended labs are hard, which all boiled down to whether they understood the goal. When students had a goal in mind with their lab, they felt successful. When they did not, they felt lost and confused. For subsequent labs I included more direction in the prompt. Rather than "Investigate magnetic fields," I prompted students to, "Determine whether light has interference like a wave or travels in a straight path like a particle."

After using multiple open-ended labs in my classroom during my year-long clinical teaching placement, I would recommend this type of activity for every science classroom. These kinds of inquiry-fueled investigations are useful at the beginning of a unit to inspire curiosity before getting into more specific content when students have been taught the scientific process. I also recommend providing the equipment, like magnets and iron filings in a box, for these investigations rather than giving students access to everything the lab has to offer.

Students in my class used many of the schema presented to them in labs over the school year, including the topics of a scientific question, the if-then format for a hypothesis, and drawing conclusions based on observed data. These simple tools are the foundation of the scientific discipline. This study only looked at 20 students in moderate depth. In the future I would be interested in tracking students across a school year as they start learning these concepts and have more opportunities to put them into practice. The difference between the successful and the struggling groups came down to making connections more than anything else so future investigation could focus on how to teach students to make connections like those in the successful groups. Further research could also look at whether students can still accurately use the scientific process they learned the year before in the next class, with collaboration from biology, chemistry, and physics teachers working together to investigate.

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Appendix A

Lab: Magnetism

Question:

How did you come up with your question?

Hypothesis:

How did you decide on a hypothesis?

Procedure, setup, and data:

How did you decide on a procedure?

Conclusion:

How did you reach your conclusion?

Appendix B

Note-Taking Template

Period:	Class:	Date:

Lab Prompt:

Student questions

Student Hypotheses

Procedures

Reflection

Appendix C

Interview Protocol for Use with Student Focus Groups

Set up 2 recording devices.
Instruct students how to be part of the interview:

Speak one at a time.

Answer like I don't know you and have never been in class with you before.

If you think of something while one of your lab partners is talking, write it down on the notecard in front of you. If you have something you do not want to say out loud, you can use the notecard to write that down as well.

What happens during labs in physics?
What steps do you follow when you are doing a lab?
How do you come up with a question in lab?
How do you come up with a hypothesis in lab?
Tell me about your hypothesis for this lab.
How do you decide on a procedure to follow in lab?
Tell me about your procedure in this lab.

Appendix D

Codebook

Code	Level	Definition	Example
Drawing Conclusions	2	This parent code contains the significant data relating to the results and conclusion section of the lab.	*"If you have an understanding of what you're trying to do it doesn't matter whether you have a lot of instructions or an open-ended setup, you can reach a good conclusion." FG4*
Cohesive thoughts	1	This code is for when students make a connection throughout different sections of the lab.	*"If you start them out saying you're going to make this connection, I expect to see this connection, then they will work to make the connection." Teacher Interview*
Connection to data	1	This code marks where students have made a connection between data they collected and their conclusion.	*"We put all the fillings on one side and used the middle of the magnet to try and move them, but they didn't move." 6th Period Labs*
Depth of thought	1	This code marks places where students had a particularly deep thought or a particularly shallow one.	*"Explain how you reached your conclusion. -By thinking about magnets." 1st Period Labs*
Showing your work	1	Talking about showing work or actually showing calculations in the lab.	*"I have five steps that I give them that I expect anytime they show any work." Teacher Interview*
Generating a hypothesis	2	This parent code contains significant themes that primarily arose in the second step of the lab, the hypothesis.	*"My professors of methodology in graduate school laid into us for about four weeks that a hypothesis should always be an if-then statement." Teacher Interview*
Disproving the hypothesis	1	The goal of a hypothesis is to be able to disprove it, and this code marks instances where that goal appears.	*"Coming up with hypotheses is interesting because a lot of times after you conduct the experiment what you wanted to try to learn from the experiment… and what you actually learned can be very different."*
Wait, what?	1	Something is either so convoluted or difficult to interpret that it takes several	*"-Yeah, questions just flourish new ideas over time? -It's like, it's like what would happen if we did this?"*

Code	Level	Definition	Example
		passes to glean the meaning.	*Focus Group 1*
If… then hypothesis	1	A hypothesis is a disprovable if… then statement.	*“It needs to have a definite structure. If this, then this.” Teacher interview*
Refining the process	1	After collecting some data, it may be useful to go back and make the process a little more accurate.	*“I would test it every time I finished it to see what I needed to add on stuff.” FG1*
Specifically worded descriptions	1	Rather than relying on drawings, students sometimes rely on words to explain their thinking.	*“1. Take the little box and the magnet. 2. Put the magnet on the box and see which side attracts more metal. 3. Compare the south, north, and middle.” 1st Period Labs*
Thinking in pictures	1	Students draw what they are thinking.	*“Figure 1.” 1st Period Lab*
Wild guess	1	With little background knowledge to rely on, students instead make a wild guess as to what will happen.	*“Because we don’t actually know what it would do or how it would relate to each other.” 1st Period Labs*
Scientific Questions	2	This parent code contains the first major piece of the lab process.	*“That's kind of what scientists are generally trying to do, which is like figure how things work.” FG4*
Because I said so	1	Instead of thinking for themselves, students sometimes just write what the teacher said.	*“I was force to answer the question.” 1st Period Labs*
Creative thinking	1	Students rely on materials, tools, or concepts outside of the ones mentioned.	*“How strong is the magnetic field forms something that isn’t already magnetic when we put a magnet on it?” 4th Period Labs*
Group work	1	General sentiments on group work for labs and projects vary, but this code holds them all!	*“Where you can get like… instead of one interpretation of what's going on, you get a bigger picture, because there's a bunch of different ideas.” FG2*
I work alone	1	Sometimes when working with a group it is easier to	*“A lot of the times my group didn't really like to do much.” FG2*

Code	Level	Definition	Example
		do everything yourself and share answers later. After all, their grade is their problem.	
Messing with the materials	1	When you don’t know where to start, start messing around with what you have.	*“it's really fun to mess with. But if you really get into thinking about it, there's like a lot of questions and like theories you can make about it.” FG3*
Prior knowledge	1	Recognizing a pattern that connects to a video you saw a year ago can give a lab a specific goal.	*“Use the knowledge that you have to say... Like reach more knowledge or try to learn from what you know.” FG2*
Working Backwards	1	Rather than starting with a question, starting with an answer you already know can help give the rest of the lab purpose.	*“After we could figure out why ourselves it worked, we could then ask a question, and we worked backwards from the answer in a way.” FG4*