Summer 2017

NGSS and Science Museums: How Learning Progressions Can Inform Field Trip Lesson Planning for Informal Science Centers

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NGSS and Science Museums: How Learning Progressions Can Inform Field Trip Lesson Planning for Informal Science Centers

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B. S., Appalachian State University, 2010

Master's Project
Submitted in partial fulfillment of the requirements for the degree
Masters of Science in Natural Science
in the Science and Mathematics Teaching Center
at the University of Wyoming,
2017

Laramie, Wyoming

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Abstract

Many states, including Wyoming, have adopted the Next Generation Science Standards (NGSS) or a very similar version of science standards. Research shows that in order to remain competitive in the field trip market, science museums need to align their curriculum to the same standards (Anderson, Kisiel, & Storksdieck, 2006). The major challenge for museums engaged in this process is the gaps in content introduced to various grade levels across performance expectations. I propose that these gaps may be filled by creating a learning progression to inform the alignment process. Literature on cognitive development, informal learning, and previous learning progressions is used to create a physical science learning progression, scaffolded by foundational concepts and grade level. Next, I analyzed lessons from *The Science Zone* in Casper, WY to identify which foundational concept they addressed, then created a matrix to show which lessons were appropriate for each grade level. The final product is a suggested progression of physical science lessons for *The Science Zone* that is developmentally appropriate and aligned to the NGSS.

dedicated to Ric and Pam Jablonski, for their unwavering support and encouragement throughout my education

Acknowledgements

I would like to thank, first and foremost, my parents, Drs. Ric and Pam Jablonski. They took me to many science museums over the years, and always did everything in their power to support my academic growth and curiosity. They taught me that I could achieve anything I wanted enough to work hard for, and it is because of their never-ending support that I am where I am today. I love you both so very much. I would also like to thank my sisters, Marianna, Alice, and Teddy, for always being there for me no matter what.

I extend a great amount of gratitude to my Co-Chair Ana Houseal for her tireless hard work and guidance throughout this process, and well as Sylvia Parker and Rachel Sailor for their service on my committee. Working with the Science and Mathematics Teaching Center has been an honor and a privilege, and I appreciate all the people who work to make the program great.

To all my friends and colleagues at Teton Science Schools and the University of Wyoming, thank you so much for the comradery, collaboration, and commiseration. I am so blessed to have gotten to know each of you, and I will always treasure my time in this community.

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Chapter 1

Introduction

Background

Think back to elementary school. Did you ever go on a field trip to a science museum? If so, how much do you remember? Do you remember what class you were with? Who you sat beside? What you learned? Falk and Dierking (1997) asked these questions of 128 people and discovered that, not only could most of them remember a field trip, but also almost 100% were able to recall one or more things they learned. In the concluding remarks of their study, they attest that, "These findings strongly suggest that museum field trips - regardless of type, subject, matter, or nature of the lessons presented- result in highly salient and indelible memories. These memories represented evidence of learning across a wide array of diverse topics" (Falk & Dierking, 1997, p. 216). This evidence speaks volumes about the potential of science museums to make lasting and meaningful contributions to formal education. These field trips are more than just a fun day out of the classroom. They persist in the memories of the students, and for that reason, they have the potential to have an impact on a child's education.

Because field trips can be an integral part of the elementary school experience, it is important that the institutions offering informal science field trips, such as science museums, planetariums, and aquariums, offer programs that meet the needs and desires of classroom teachers. Anderson, Kisiel, and Storksdieck (2006) found that when looking at teachers' motivations to facilitate field trips, the field trip's connection to in-class curriculum is of utmost importance. Facilitating informal programs that are aligned with standards allows teachers to use these trips to extend learning beyond the classroom while also fulfilling school district requirements. Additionally, it allows teachers to engage with the topics before and after the visit without deviating from their school district's expectations.

In September 2016, Wyoming adopted a new set of science standards, called the 2016 Wyoming Science Content and Performance Standards (WyCPS) (Wyoming Department of Education, 2016). They are almost identical to the Next Generation Science Standards (NGSS), which were published by the NGSS Lead States in 2013 and have been widely adopted by many US states, but with a few state-specific guidelines added. This shift in standards for public schools means that institutions that cater to the public school audience must adapt as well. *The Science Zone* in Casper, WY has been providing educational programs for elementary classes in their local school district since the late 1990s. Many classes even hold memberships and bring students to the museum once a month. Unfortunately, for many students, this was their only exposure to science in school, as the local district was not enforcing science teaching time in the elementary schools within the district. When the new standards were introduced, Leah Ritz, Education Director at *The Science Zone*, recognized the need to update their curriculum to match the new standards. She contacted the Science and Math Teaching Center at the University of Wyoming to ask for guidance in doing so.

Statement of the Problem

Many science museums like *The Science Zone* provide engaging, hands-on lessons for field trips classes, but often they choose activities and subject matter based on educator preference or how exciting the activity is, and in this way, they are not necessarily informed by any standards. With the introduction of the NGSS, museums that decide to strive for alignment with the standards must now determine if and how their existing lessons align. Since many educational institutions also had to engage in this work, the Next Generation Science Standards team (at Achieve.org) developed the *Educators Evaluating the Quality of Instructional Products* (EQuIP) *Rubric*. This document "provides criteria by which to measure the alignment and overall quality of lessons and units with respect to the NGSS" (Achieve, 2014). This tool is thorough and very useful in a formal setting, as it takes into account the integration of the three dimensions of learning: the *Science and Engineering Practices*, *Cross Cutting Concepts*, and *Disciplinary Core Ideas*, that are central in the NGSS, as well as several facets of instructional support and authentic assessments. However, since it defines a lesson as "a set of instructional activities and assessments that may extend over several class periods or days; it is more than a single activity" (Achieve, 2014, p.2) it isn't a perfect fit for the one-contact lessons taught in science museums. Upon further investigation, I realized that there is no such tool for informal, one-time lessons. Nor is there clear guidance for how to structure curriculum in an informal education setting.

The NGSS are written as a "spiraling curriculum," which refers to the idea that, "a curriculum as it develops should revisit the basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them" (Lohani et al., 2005, p. FID-1). Thus, the NGSS are written so that each science topic is revisited several times throughout elementary school. However, there is such a large number of topics, or *Disciplinary Core Ideas* (DCI), that there is not enough time to cover each one every year. Instead, they are spread throughout the curriculum, with each DCI being covered every two or three years. This creates "gap" years for each DCI in which the subject is not covered in the classroom curriculum. This presents a challenge for science museums that are trying to align their lessons with the NGSS, because they have a hard time switching out topics, and need guidance in how to fill in during the “gap years” without going outside of the developmental needs of students, even in years where the content is not taught.

Purpose

The purpose of this project is to design a tool for helping science museums, such as *The Science Zone*, fill in the gaps and align their curriculum with the NGSS. I propose that learning progressions are the appropriate tool for this job. Learning progressions are “descriptions of successively more sophisticated ways of thinking about an idea that follow one another as students learn” (NRC, 2005, p. 3). Ideally, they are research-based and empirically tested, although some are published without these measures, and they help teachers understand the progression of concepts toward a particular learning goal. In order to investigate the efficacy of this idea, this project was guided by the following research question:

How can the literature on learning progressions help inform the process of aligning informal physical science lessons to the NGSS?

Chapter 2

Literature Review

Next Generation Science Standards

Since their publication, the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) have begun to revolutionize the way students and teachers approach science education. As of December 2016, 18 states and the District of Colombia have adopted the standards in their entirety, and several others, including Wyoming, have adopted versions that are over 95% similar to the NGSS. The 2016 Wyoming Science Content and Performance Standards (WyCPS) were informed by *A Framework for K-12 Science Education* and the NGSS, and also incorporated state-specific learning objectives (Wyoming Department of Education, 2016). They were designed and written to parallel the NGSS, and much of the language is the same. The physical science performance expectations, which are the focus of this paper, are identical in the WyCPS and the NGSS. Therefore, for the purposes of this research, I refer to the science standards as the NGSS because they encompass both the state and national guidelines.

The first major step towards the development of the NGSS was the publication of *A Framework for K-12 Science Education* (NRC, 2012), henceforth referred to as the *Framework*, by the National Research Council (NRC). The goal of the *Framework* is:

> To ensure that by the end of 12^{th} grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice,

including (but not limited to) careers in science, engineering, and technology. (NRC, 2012, p. 1)

Although previous attempts were made at designing and implementing inquiry based standards by the American Association for the Advancement of Science (AAAS) and the NRC, they were never widely adopted, and many teacher reverted to the older standards. These standards were merely a list of facts which students were expected to memorize. They were lacking in logical progressions, and did not incorporate basic knowledge of how science was actually conducted. Engineering was not included in the earlier standards. By narrowing the scope of core ideas and putting emphasis on practices and connections, they committee sought to help schools think about how to produce learners who are able to think critically about scientific ideas and engage with science and engineering throughout their lives (NRC, 2012).

In order to achieve these goals, a committee was assembled with representatives from the science, technology, engineering, and math (STEM) sectors. Together, these experts created a framework that is organized into three dimensions: Science and Engineering Practices (SEP), which are the processes involved in conducting science; Crosscutting Concepts (CCC), the big ideas that tie many scientific ideas together; and Disciplinary Core Ideas (DCI), which are the science content. These three dimensions, when taught in combination, help get students thinking and acting like scientists by emphasizing scientific processes over discrete facts. This helps students become more critical thinkers and highlights the *how* behind how scientific knowledge is constructed.

After the *Framework* was complete, the development of the NGSS was undertaken by a committee of STEM professionals and educators representing 26 lead states. The standards underwent many comment periods and revisions before their final publication in 2013 (NGSS

Lead States, 2013). The used the ideas from the *Framework* to develop Performance Expectations, or statements of what students should be able do to demonstrate understanding each standard. Each of these statements incorporates all three dimensions, and they are organized by grade level and theme (NGSS Lead States, 2013). Using the NGSS in science museums would allow informal educators to create lessons that are informed by the most current research and understanding of what high-quality science education looks like.

Fortunately, this new vision for science education is already well-aligned with the goals and competencies of informal science museum experiences. The *Framework* was based on a report called *Taking Science to School* (NRC, 2007). This report presents four "strands of proficiency" in science education from which the three dimensions were inspired. These strands include:

Strand 1: Knowing, using, and interpreting scientific explanations of the natural world.

Strand 2: Generating and evaluating scientific evidence and explanations

Strand 3: Understanding the nature and development of scientific knowledge.

Strand 4: Participating productively in scientific practices and discourse. (p. 36)

These strands place emphasis on action and inquiry, ideas that are heavily emphasized in the three dimensions of the NGSS.

Surrounded by Science: Learning Science in Informal Environments (NRC, 2010), is another guide published by the NRC explicitly for informal science educators and practitioners. It presents theories and case studies aimed at helping informal educators implement science education in the most engaging and effective ways. The authors used the same four strands and augments them with two additional strands that are specific to the strengths and opportunities of an informal science setting. These additional strands are:

> Strand 1: **Sparking Interest and Excitement**: Experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world.
>
> Strand 6: **Identifying with the Scientific Enterprise**: Coming to think of oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science. (p. 27)

This theoretical overlap creates the perfect conditions for aligning informal science lessons and activities to the NGSS.

Standards and Informal Science Education

Of course, even the best, most aligned lesson is useless unless someone is there to learn from it. More recently, informal science learning opportunities are increasing (Robelen, 2011), while at the same time, finding the time and funding to take advantage of them is becoming more challenging. It is important that museums and other informal education settings do everything they can to cater to the needs and desires of the students and teachers they are trying to attract. Many scholars have sought to decipher exactly what those important elements are (Anderson, Kisiel, & Storksdieck, 2006; Anderson & Zhang, 2003; Kisiel, 2005; Nabors, Edwards, & Murray, 2009).

Kisiel (2005) identified teachers' eight most common motivations for planning a field trip and found that they want "[to] connect with curriculum, provide a learning experience, promote lifelong learning, foster interest and motivation, expose to new experiences, provide a change of setting, provide enjoyment or reward, and satisfy school expectations" (p. 940). Among these, "connection with curriculum" was by far the most commonly reported, with 90% of teachers citing it as a motivation (Kisiel, 2005). Anderson, Kisiel, and Storksdieck's (2006) study that spanned across three independent studies in three different countries found that "classroom curriculum was the dominant consideration for the teachers surveyed" (p. 377). In Vancouver, Canada, 62% of teachers ranked "curriculum fit" as their highest priority consideration for planning and implementing a field trip (Anderson & Zhang, 2003).

Another important consideration is the need for classroom teachers to prove curriculum fit in order to get permission and funding from their administration. Unfortunately, there is a lack of quantitative research characterizing the nature of schools' field trip requirements, so the information that I was able to find is anecdotal and based on my experiences during my own six-years in the field of education. There is no over-arching state or federal policy that mandates that field trips must be aligned to the school's standards, therefore, districts and individual schools usually have their own policies. These policies vary greatly. Some schools do not require any proof of connection to curriculum, while others oblige teachers to provide written justification as to which standards the trip is meeting and how it will enhance the overall educational goals of the school year. My experience was that many schools' policies fall somewhere in between these two extremes. Although research has yet to support the importance of standards' connection to satisfy school requirements, it can be surmised from the presence of such policies that aligning field trips with standards does increase their value in the eyes of school administration.

Impacts of Informal Education on Formal Education Field Trips

While alignment is highly valued by teachers and administrators, it is by no means the only merit of school field trips. Unfortunately, there are several challenges inherent in assessing the long-term impacts of informal science experiences. This has created a significant gap in the literature. However, many researchers have addressed this question in various ways, and have provided evidence that informal science museum experiences do contribute positively to a student's education (Anderson, Storksdieck, & Spock, 2007; Behrendt & Franklin, 2014; Falk &

Dierking, 1997; Greene, Kisida, & Bowen, 2014; Wolins, Jensen, & Ulzheimer, 1992). To make these claims, researchers focused on the persistence of field trip memories and on-site assessments.

Theoretically, the novelty of being outside of the classroom can result in a more memorable experience for students. Wolins, Jensen, & Ulzheimer (1992) found that humans form two major types of memories in relation to events: *general scripts* and *specific memories*. *General script* memories are a compilation of all of one's memories of similar events. Take, for example, a school day. While one can usually remember what "a school day" consists of, they are likely drawing on several memories at once and would have a hard time distinguishing specific events on specific school days. When something novel happens, however, a *specific memory* is created. These memories are richer with detail and meaning. Therefore, "The more novel the experience, the more it deviates from the script, the more likely it is to be remembered" (Wolins et al., 1992, p. 18).

Falk and Dierking (1997) provided evidence for the theory that museum field trips are well remembered. In one of the few attempts that have been made at assessing long-term impacts of museum experiences, they conducted interviews with 128 subjects (34 elementary students, 48 middle school students, and 46 adults) about their memories of early-elementary field trips. They found that 98.4% could recall at least "one specific event or thing from the trip", with 80.5% recalling three or more (Falk & Dierking, 1997).

One of the major factors that increases retention of museum learning is reinforcement of the concepts either before or after the visit in the classroom (Anderson et al., 2007). Nabors, Edwards, and Murry (2009) conducted surveys with 38 "nationally recognized field trip sites" (p. 663-664) and found that educators at the sites reported that field trips were much more successful when students came prepared with background information relating to the site and the academic topic. Prior engagement with the content resulted in student groups that were more engaged and had higher retention of concepts (Nabors M., Edwards, L., & Murray, R, 2009). By teaching lessons that are tied to the standards, museums increase the chance that those concepts will also be addressed in the classroom, increasing the overall chances that the student will retain those concepts.

NGSS and Museum Learning

Based on the evidence previously presented, there is great benefit to both students and museums if the learning objectives at museums are aligned with the NGSS. In addition, the theoretical foundations of museum learning and the NGSS are parallel, which should make alignment a relatively straightforward process. However, as I discovered quickly after beginning this project, significant challenges exist.

The NGSS use a spiraling approach to their curriculum design. This means that content is introduced early in a student's education, then re-visited periodically. Each subsequent lesson builds on the previous lesson's foundation and adds complexity and depth, reinforcing the student's knowledge of the topic. Because there are so many DCIs in the NGSS, not every DCI can be addressed each year. For example, "Matter and Its Interactions (Physical Science 1 [PS1])" is introduced in 2nd grade, and then not revisited again until 5th. There are no NGSS performance expectations for PS1 in grades K, 1, 3, or 4. Having these breaks in the standards results in the museum educators having to decide between two courses of action. The first would be to only address those concepts as they are laid out in the NGSS, and the second is to find a way to address them in spite of the gaps. Filling in the gaps would allow the museum to have a full and robust curriculum, and to support student learning by appropriately scaffolding ideas and concepts continuously. Exposure to concepts during “off-years” could refresh the students’ knowledge and help support them for subsequent years.

This idea of scaffolding the concepts throughout grade levels, however, is only useful if the scaffolding is developmentally appropriate. Research on cognitive development has demonstrated that in many conceptual cases there is a relatively predictable sequence of ideas that learners progress through in order to fully understand a concept (Talanquer, 2009). While there are variations among learners, there is evidence across all disciplines that certain foundational ideas must be in place for the understanding of more complicated concepts (Salinas, 2009; Talanquer, 2009; Wiser, Smith, Doubler, & Asbell-Clarke, 2012). Therefore, the choice of when to present certain concepts to students has ramifications for whether the students will be able to truly grasp the concept. If ideas are presented out of order, they will likely be misunderstood or not understood at all. This suggests that how a museum chooses to structure their curriculum can have a huge impact on the amount and quality of learning that takes place.

Unfortunately, I found through conversations with many major science museums across the country that there is no consistent, research-guided protocol to help museums with this undertaking (see Appendix A for a list of museums contacted). Museums that are aligning their lessons with NGSS are doing so based mostly on their own ideas, or just assigning a new standard to an old lesson instead of updating their lessons and progressions to fit the new standards. For example, Vice President of Youth Education at the Houston Museum of Natural Science stated,

> When we start writing curriculum, we generally don’t start with the standards. For example, we have an activity teaching kids about the Roman aqueducts. We then tweaked it so that it is an engineering challenge involving petroleum pipelines and supply

management and cost/benefit analysis. (N. Temple, Personal Communication, April 2, 2011)

I propose that a better method to perform this task can be created using research on learning progressions that is grounded in empirical research.

Learning Progressions

Learning progressions are currently becoming more mainstream in the realm of K-12 education. Although there are a great many definitions presented in the literature, for this paper I will use the definition put forth by the NRC in *Systems for State Science Assessment* (2005). They define learning progressions as “descriptions of successively more sophisticated ways of thinking about an idea that follow one another as students learn: they lay out in words and example what it means to move toward more expert understanding” (p. 3). All learning progressions have some common features: they provide a sequence of successively more complicated ideas, are bound by top and bottom “anchors”, are framed around “big ideas”, and use assessment to validate their ideas (Hadenfeldt, Xiufeng, & Neumann, 2014).

Learning progressions are a powerful tool in science education because they focus on concepts instead of topics. Topics are much more akin to the “list of facts” model that many schools and standards creators are trying to move away from. While facts can be very engaging, they often lack conceptual foundations and connection with similar ideas, which can limit the amount of learning that takes place. By focusing on concepts instead, educators can carefully construct a strong foundation of ideas that build on one another and can be transferred to other topics (Wiser et al., 2012). A good example is a lesson on States of Matter. Many elementary teachers begin by describing the three states of matter and that materials can change among states. This “topic” is interesting, and can be taught using many engaging and hands-on lessons, but they neglect to address the underlying concepts that are essential to understanding how this occurs. An example of a conceptual approach to this lesson would be to have children first understand the “concept” of building blocks. That is, that matter of different materials is made up of many small particles. The movement of these particles can be used to explain why and how matter changes states. The “building block” concept can then be extended to other types of structures that are composed of building blocks, such as cells that make up a plant, or minerals that make up a rock. This approach to curriculum is more aligned with the NGSS, which prioritizes depth over breadth, and minimizes the number of concepts introduced per year. It also dovetails into the idea of the CCCs being overarching connections, or big ideas that apply across topics, which is one of the NGSS’ Three Dimensions.

Learning progressions are usually written as a sequence of levels, sometimes described with assigned numbers (Levels 1-5), and other times described using words (novice-advanced). This is important because it distinguishes them from progress maps, which are more closely tied to grade levels and standards. Salinas (2009) explains the differences between these two very similar concepts by saying, “learning progressions are descriptions of learning as it typically develops while progress maps are descriptions of what is the learning that is expected to be developed among students” (p. 11). While the NGSS include a very coarse-grained progress map for each DCI in Appendix E (NGSS Lead States, 2013), the sequence of ideas was based only on the committee’s own ideas, and was not grounded in empirical research (NRC, 2012). In order for this progress map to be a more useful tool for informing curriculum design, it needs to be broken down into a finer progression of ideas, based on empirically tested data.

Chapter 3

Methods

Matter in Physical Science

In order to explore my research question, I chose one discrete DCI strand from the NGSS: PS1: Matter and Its Interactions. Matter is defined as "anything that occupies space" (Hewitt, Lyons, Suchocki, & Yeh, 2015, p. 293), and units on matter commonly include discussion on the three states of matter and the atomic model. The concepts covered in this DCI are the precursors for chemistry, and deal with the physical and chemical properties of matter, and physical and chemical changes. I chose this topic after Leah Ritz, the education director at *The Science Zone*, expressed to me that the overwhelming majority of field trip requests are for physical science. It is her opinion that this is because many teachers do not feel comfortable with this subject and/or lack adequate materials to teach it in their classroom. Additionally, *The Science Zone* already has a lot of materials and equipment for teaching physical science that they would like to be able to use as much as possible (L. Ritz, Personal Communication, 11/14/2017). This is also a conceptually abstract topic, which makes it more difficult to understand how students are engaging with it. Therefore, I hope that by choosing this topic I will also increase the base knowledge of the concept of matter for my readers.

Research Synthesis

The first step in creating an NGSS aligned learning progression was to find and synthesize the learning progressions that were already created on the subject of matter. Fortunately, there are many suggested learning progressions concerning matter published within the last decade. After surveying available studies, I narrowed the scope to three publications. I chose these particular studies because each was backed by a large body of empirical research, and each is unique in how it structures the learning progression. Having these three unique structures allowed me to conceptualize the information from multiple vantage points, resulting in a more robust understanding.

Framing Students' Progression in Understanding Matter: A Review of Previous Research (Hadenfeldt et al., 2014) was chosen because it incorporates research from 82 peer-reviewed studies conducted between 2003-2012 and published in science education journals. It combines the data from these studies and organizes it into four "big ideas," each broken down into five levels. These are (a) Level 1: Naive Concepts, (b) Level 2: Hybrid Concepts, (c) Level 3: Simple Particle Concepts, (d) Level 4: Differentiated Particle Concepts, and (e) Level 5: Systemic Particle Concepts.

The second study, *Implications of Research on Children's Learning for Standards and Assessment: A Proposed Learning Progression for Matter and the Atomic-Molecular Theory* (Smith, Wiser, Anderson, & Krajcik, 2006) also breaks down the subject of matter into "big ideas," but then creates levels based on grades bands, similar to the NGSS (K-2, 3-5, 6-8, and 9-12). I used this study to verify that the Progress Map (NGSS, Appendix E) was aligned with empirical data, and it also was used to helped flesh out the vague progress statements on the Progress Map.

The third study, *On Cognitive Constraints and Learning Progressions: The Case of 'Structure of Matter'* (Talanquer, 2009), was chosen because it incorporates research spanning the longest time frame (30 years) of any of the studies (Hadenfeldt, et al., 2014) and identifies "cognitive constraints" instead of levels. Cognitive constraints are defined as "elements of a knowledge system that guide and facilitate cognitive processes as well as restrict their possible range" (pg. 188). This system of describing the common assumptions learners hold about matter and how they develop throughout one's education, allowed me to understand how to fill in the spaces between levels that existed in the other studies.

There are two commonly used modes for creating a learning progression: the *escalated approach* and the *landscape approach* (Salinas, 2009). The former uses a more linear design, while the latter shows connections between ideas in a more web-like format. For the purposes of this research, I chose the escalated approach, defined as, "a linear, escalating description of students' understandings about a topic over a span of time" (Salinas, 2009, p. 3). This approach calls for defining upper and lower limits, called *anchors*, and intermediate levels that describe benchmarks students should achieve as they progress towards mastery. It is more useful and straightforward for curriculum design than the landscape approach because it is linear, where in the landscape approach ideas can overlap and recycle. Overlapping and recycling ideas is a useful strategy for classroom instruction, but in this context it would be more difficult because of the short time-frame of the lessons and the fact that many students do not participate in multiple trips to the museum.

I used the 5th grade Physical Science DCIs for "Matter and its Interactions" (*PS1.A: Structure and Properties of Matter* and *PS1.B: Chemical Reactions*) as my upper anchor [1], as these statements are what students are expected to know at the end of 5th grade. The DCIs for 2nd grade were used as an intermediate level, and the bottom anchor was derived from Level 1 of Hadenfeldt et al.'s (2014) learning progression, which is described as students' thinking when they begin school. After setting these anchors, I aligned the NGSS Progress Map with Smith et.

[1] PS1.C was omitted because it is not addressed in elementary school

al’s (2006) learning progression. This allowed me to verify that the NGSS SEP’s were in agreement with the research-based learning progression. I found that the two were well aligned, and Smith et. al’s (2006) more thorough descriptions helped guide the rest of the alignment.

Next I layered Hadenfeldt et al.’s (2014) learning progression over my working model. I matched each of its “Levels” to the corresponding DCI and then distributed the intermediate levels across the remaining grade levels. I used Talanquer’s (2009) model to inform this distribution. The result is a learning progression that describes students’ understanding of matter during grades K-5.

As noted above, a learning progression, by definition, does not prescribe specific ages or grades to the levels they describe. Therefore, I had to convert my learning progression into a progress map that would allow me to assign specific lessons to specific grade levels. To do so, I assigned discrete “progress variables” to each grade level based on the sequence described in the learning progression. These progress variables describe specific, assessable concepts that students need to master before moving forward in the progression of ideas (Salinas, 2009). Then I assigned each progress variable a code. Progress variables for *PS1.A: Structure and Properties of Matter* are coded S-K through S-5. Progress variables for *PS1.B: Chemical Reactions* are coded R-K through R-5.

The next task was to identify which of *The Science Zone*’s existing lessons addressed these progress variables. I did this by analyzing each lesson for stated objectives and outcomes, as written in the lesson plan by the educational staff at *The Science Zone*. I also researched the lessons independently by referencing physical science text books (Hewitt et al., 2015) and online education resources to see if other educators were using them to demonstrate or teach other concepts. I assigned each of them one or more progress variable codes based on the concepts they addressed.

Finally, I created a matrix (see Appendix B) that displays each progress variable (by grade level) along the Y-axis, and each of *The Science Zone*'s activities along the X-axis, and indicates where they overlap.

Chapter 4

Results

The NGSS have two DCIs relating to Matter and its Interactions in elementary school: *PS1.A: Structure and Properties of Matter* and *PS1.B: Chemical Reactions.* For this reason, I organized my learning progression around these two topics.

PS1.A: Structure and Properties of Matter

The DCI for *Structure and Properties of Matter* relates to the atomic molecular theory, specifically the atomic model, and the physical properties of materials, such as weight, size, texture, etc. The lower anchors (Table 1) were taken from *Framing Students' Progression in Understanding Matter: A Review of Previous Research.*

Table 1

Lower Anchors for PS1.A (Adapted from Hadenfeldt et al., 2014, p. 193-195)

Concepts (Lower Anchors)	Reference
Students describe structures without the use of the particle concept.	Liu & Lesniak, 2006
They view matter as dividable but continuous.	Ayas et al., 2010; Papageorgiou, Grammat-icopoulou, & Johnson, 2010
Students do not have any model that allows them to describe physical properties and changes of matter scientifically. They describe only what they have observed.	García Franco & Taber, 2009; Liu & Lesniak, 2006
Students use prototypes to describe substance properties, e.g. water is a prototype for liquids.	Krnel et al., 2005; Othman et al., 2008

Note: The upper anchors (Table 2) for this topic are the 5th grade Performance Expectations (PE) 5-PS1-1 and 5-PS1-3.

Table 2

Upper Anchors for PS1.A (NGSS Lead States, 2013)

Concepts (Upper Anchors)	PE
Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter (particles that are too small to see) and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects	5-PS1-1
Measurements of a variety of properties can be used to identify materials. (boundary: mass and weight are not distinguished, no attempts is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation)	5-PS1-3

In order to define progress variables for each intermediate step, I used information from Hadenfeldt et al. (2014), Talenquer (2009), and Smith et al. (2006), including their descriptions of students' typical patterns of cognitive progression to determine the trajectory of concepts. I summarized this information to create the learning progression below.

PS1.A: Structure and Properties of Matter: Learning Progression

When students enter school, they begin to learn about different types of matter by learning how to recognize differences in structure and function. They often accomplish this by testing and sorting materials by their physical properties. At this stage, they still view matter as "continuous," meaning that materials are not divisible into smaller pieces. The next step is for them to break through that assumption and learn that objects can be constructed from many small parts. Once that idea is learned on a visible scale, students are ready to start translating that knowledge into the invisible scale, and learn that all matter is made up of small parts, so small that we cannot see them with the naked eye. By the end of 5th grade, students should understand that all matter is made up of these particles, but have not been introduced to the model of the atom. They also are able to understand that the properties of materials can be measured using tools such as scales, thermometers, and rulers.

PS1.B: Chemical Reactions

This DCI deals with chemical reactions and conservation of matter. Table 3 displays the lower anchors.

Table 3

Lower Anchors for PS1.B (Adapted from Hadenfeldt et al., 2014, p. 193-195)

Concepts (Lower Anchors)	References
Students do not have any model that is appropriate to describe or to recognize chemical reactions scientifically. In explanation approaches, they describe what they have observed	García Franco & Taber, 2009; Smothers & Goldston,2010
Students do not observe any conservation of mass in their daily life. They believe that the number of reactants changes with the mass in a chemical reaction because they do not have any particle perception.	Löfgren & Helldén, 2009
Thus, substances can disappear in chemical reactions and in physical changes.	Mohan et al., 2009; Rahayu & Kita, 2010; Smothers & Goldston, 2010

The upper anchors are presented in Table 4.

Table 4

Upper Anchors for PS1.B (NGSS Lead States, 2013)

Concepts (Upper Anchors)	PE
When two or more different substances are mixed, a new substance with different properties may be formed.	5-PS1-4
No matter what reaction or change in properties occurs, the total weight of the substances does not change. (boundary: mass and weights are not distinguished)	5-PS1-2

PS1.B: Chemical Reactions: Learning Progression

The first main concept that students must understand is that there are different states of matter (solid, liquid, gas), and that the same substance may exist in any of these three states. Then, they learn that heating or cooling the material can cause observable changes, some of which can be reversed (freezing and thawing water), and others which cannot (burning a piece of paper). Next, they must understand that matter still exists when it is broken down into particles too small to see. This concept is also addressed in the Structure and Properties DCI, but it is so integral to the understanding of both topics that addressing it twice is necessary. Next, students begin to learn about chemical changes, and that when two or more substances are mixed, a chemical change may occur in which a new substance with different properties may be formed. Finally, in this progression, they learn that, no matter what kind of change occurs, the same number of particles still exist, even if the new substance looks bigger or smaller.

Figure 1 is a visual representation of how these concepts progress and overlap. I have abbreviated each of the concepts in this table for formatting clarity. The full version (including citations) can be found in Appendix B.

Learning Progression. *PS1.A: Structure and Function of Matter*

	K	First	Second	Third	Fourth	Fifth
NGSS	n/a	n/a	Different properties. (2-PS1-2)	n/a	n/a	Too small to see. (5-PS1-1)
	n/a	n/a	Small pieces. (2-PS1-3)	n/a	n/a	Measurements. (5-PS1-3)
	n/a	n/a	Different kinds and states. (2-PS1-1)	n/a	n/a	n/a
Smith	n/a	n/a	Specific materials. Different kinds. Built from pieces.	n/a	n/a	Matter has weight. Different kinds and states. Too small to see.
	n/a	n/a	n/a	n/a	n/a	Materials have characteristic properties. Weight and Volume are additive properties.
Handenfeldt	No particle concept (1). Matter is continuous (2).			Particles are entities embedded in matter (3). Substance between particles (4). Students are not able to use their perception of particles to explain the structure of matter (5).		Particles are building blocks of matter (6). There is nothing between the particles (7).
	No physical change explanation (8). Use prototypes (9).			Categorize substances from physical properties (10). No particle explanation for physical change (11). Particles that are embedded in matter are often used in explanatory approaches (12).		
Talanquer	Continuity:			Granularity		
	n/a	n/a	Substantialism		Elementalism	
	n/a	n/a	n/a	Embedding		
	n/a	n/a	n/a	Inheritance		
	n/a	n/a	n/a	Static	Causal dynamic	

Progress Map. *PS1.A: Structure and Function of Matter*

Kindergarten	**First**	**Second**	**Third**	**Fourth**	**Fifth**
S-K. Matter has observable properties.	**S-1. There are different kinds of materials that serve different purposes.**	**S-2. Many objects can be made up from a variety of small pieces.**	**S-3. Matter is made up from pieces too small to see.**	**S-4. A variety of measurements can be taken to classify matter based on its properties.**	**S-5. Objects are made of particles moving around in space. Differences in particles and movement account for difference in materials.**

Figure 1: Abbreviated Learning Progressions and Progress Maps

Learning Progression. *PS1.B Chemical Reactions*

	Kindergarten	First	Second	Third	Fourth	Fifth
NGSS	n/a	n/a	Heating and cooling causes changes. Sometime reversible, sometimes not (2-PS1-4).	n/a	n/a	No reactions cause weight change (5-PS1-2).
	n/a	n/a	n/a	n/a	n/a	New substance may be formed (5-PS1-4).
Smith	n/a	n/a	Amount stays same despite physical changes.	n/a	n/a	New substance with different properties.
	n/a	n/a	Freezing and melting causes changes.	n/a	n/a	Matter and weight are conserved.
	n/a	n/a	n/a	n/a	n/a	Matter exists when broken into pieces too small to see.
Handenfeldt	Students do not have any model that is appropriate to describe or to recognize chemical reactions scientifically. In explanation approaches, they describe what they have observed (13).				Recognize chemical reactions through emergence of new substance (14).	
	No concept of conservation of mass (15). Substances can disappear (16).			Number of particles remains constant. Mass is dependent on state (17). Mass can increase when compressed. (18).		
Talanquer	Contact-Interactive		Contingent-Interactive			

Progress Map. *PS1.B Chemical Reactions*

Kindergarten	First	Second	Third	Fourth	Fifth
R-K. Matter can exist in different states.	**R-1. Heating and cooling substances causes observable changes.**	**R-2. Some changes are reversible, and some are not.**	**R.3 Matter continues to exist when broken into pieces too small to see.**	**R.4 When two or more different substances are mixed, a new substance with different properties may be formed.**	**R.5 No matter what reaction or change in properties occurs, the total weight of the substances does not change.**

Figure 1, cont.: A shortened version of the learning progressions and progress maps. For the full table including citations, see Appendix B.

The map itself is a very useful tool for educators who want to understand how students' conceptions of matter change throughout grades K-5. It can help them realize which concepts need to be addressed first, and can help them identify the appropriate timing for lessons and activities. In order to model how this process works, I used the existing physical science lessons from *The Science Zone*.

Using the Learning Progressions and Progress Maps

The first step one must take to use this learning progression as a tool for alignment is to code the existing lessons to the progress variables defined in the corresponding progress map. Based on my research, these are the progress variables I have defined for the two NGSS standards relating to matter:

Structure and Properties of Matter:

- **S-K (Kindergarten):** Matter has observable properties.
- **S-1 (First Grade):** There are different kinds of materials that serve different purposes.
- **S-2 (Second Grade):** Many objects can be made up from a variety of small pieces.
- **S-3 (Third Grade):** Matter is made up from pieces too small to see.
- **S-4 (Fourth Grade):** A variety of measurements can be taken to classify matter based on its properties.
- **S-5 (Fifth Grade):** Objects are made of particles moving around in space. Differences in particles and movement account for difference in materials.

Chemical Reactions:

- **R-K (Kindergarten):** Matter can exist in different states.
- **R-1 (First Grade):** Heating and cooling substances causes observable changes.

- **R-2 (Second Grade):** Some changes are reversible, and some are not.
- **R-3 (Third Grade):** Matter continues to exist when broken into pieces too small to see.
- **R-4 (Fourth Grade):** When two or more different substances are mixed, a new substance with different properties may be formed.
- **R-5 (Fifth Grade):** No matter what reaction or change in properties occurs, the total weight of the substances does not change.

With these progress variables in mind, I read through each of the lesson plans provided to me by *The Science Zone* to determine which, if any, of the progress variable they addressed. Many of the lesson consisted of several smaller activities, each of which illustrated a different concept, so the first thing I did was to break them down into individual activities so that I could code each individually. The next step was to reference the stated objectives as described in the lesson plan. If the objective matched one of the progress variables then I coded it to match that progress variable. If the activity had an objective that was not explicitly connected to one of my progress variables, I tried to find a connection based on my knowledge of the concepts. If I could find a connection, I coded the activity to that variable.

For example, the activity "Chocolate Test" was labeled for use in teaching the scientific method. Students are asked to make hypotheses about what will happen to different types of chocolate heated with a variety of heat sources. Because melting is a physical change, I decided that this activity may also lend itself to my purposes. I investigated other melting activities in elementary teacher resource guides (Pearson, 2012; Victor, 1993) and discovered that they were used to teach about the different states of matter as well as physical changes. Therefore, I coded this lesson with progress variables that addressed those topics (R-2: Some changes are reversible, and some are not; R-K: Matter can exist in different states).

Several activities addressed multiple progress variables, so I coded them for each one they address. For example, the first grade lesson titled, “Properties of Water” consists of two activities. In the first activity, educators have students test different materials, such as cotton balls, wood chips, and plastic beads to determine whether or not they absorb water. During the second activity, students are given a variety of materials, such as aluminum foil, paper towels, wax paper, and tape, and a stuffed animal. They are challenged to design a covering for the animal that will keep it dry when dunked in water. The lesson’s stated objectives (Engineering Performance Expectations directly taken from the NGSS) for this lesson are:

- K.2.ETS1-1- Ask questions, make observation, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.
- K.2.ETS1-2: Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.
- K.2.ETS1.3: Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.

However, I found that these activities can also be used to teach two of the progress variables in my progress map. The material testing activity could be used to teach the progress variables *S-K: Matter has observable properties, and S-1: There are different kinds of materials that have different properties*, and can also be used to reinforce S-5 (Objects are made of particles moving around in space. Differences in particles and movement account for differences in materials). The waterproofing challenge can be used to teach S-K and S-1.

Thus, I continued in this manner until each applicable lesson activity was coded to one or more progress variables. Next, I used this information to create a matrix that displays each of the progress variables along the x-axis, each activity along the y-axis, and where they align.

Educators can use this tool in two ways. If they are able to identify the objective(s) they would like to teach, they can choose the correct progress variable on the matrix, then follow the row to the right to see which activities are appropriate to use for that subject and grade level. For example, if they are planning a lesson for kindergarteners on the objective *PS1.1: Structure and Properties of Matter,* they would choose progress variable S-K, then use the table to find that the activities "Absorbency Test" and "Waterproof Challenge" should be developmentally appropriate. Figure 2 is a small sample of this matrix; the full matrix is in Appendix D.

	S-K	S-1	S-2	S-3
Silver egg		X		X
Baking Soda Art				
Elephant Toothpaste				X
Absorbency Test	X	X		
Waterproof challenge	X	X		

Figure 2. A Sample of the Matrix Tool.

Educators can use this tool to find activities that fit a certain grade level and objective or determine for which grade level and objective a certain activity is suited.

Chapter 5

Conclusion

Discussion

As more and more states move towards implementing the NGSS or similar standards, it is important that informal educational institutions update their programs and lessons as well. This allows them to attract more schools, because teachers place a high value on curriculum connection when planning field trips (Anderson et. al, 2006). It also increases the potential for retention of concepts, because it makes it easier for teachers to reinforce the ideas before and after the field trip in their classrooms.

Although aligning informal science lessons to the NGSS is important, clear guidelines for this process have yet to be established. I have presented one possible model for doing so with learning progressions. Using learning progressions allows educators to understand the usual series of concepts that a learner progresses through as they come to understand a process or idea. This information is valuable because it can help guide the selection of appropriate activities and lessons that are engaging for the student while also not being too complex to fully understand.

In the case of matter, many research-guided learning progressions were available to help me build a tool that could be used by *The Science Zone*. By comparing these ideas, I was able to construct a map that shows how these ideas progress. Then, I used that map to determine an order in which activities could be used to help students move toward mastery of the subject as efficiently as possible. Because I wanted this tool to be immediately useful to *The Science Zone*, I used their existing lessons to pilot test its utility. I found that many of their activities were well suited to teach at least one of the progress variables, if not more. This information can help educators plan a lesson comprised of several activities that is developmentally appropriate.

After creating the matrix, I discovered that some concepts were able to be taught by several activities, and some were not. For example, There were no activities in *The Science Zone's* current arsenal that explicitly addressed *R-3 Matter continues to exist when broken down into pieces too small to see,* yet there were eight appropriate activities each for *S-1: There are different kinds of materials that have different properties* and *S-3 Matter is made up from pieces too small to see.* By using this tool to identify strengths and weaknesses in their current collection of activities, the educators at *The Science Zone* will be able to determine where they should be focusing in terms of new curriculum development.

Limitations

This project was limited both by time and subject matter. If there were more time available, I would have liked to test my conclusions by putting this tool to use at *The Science Zone* by letting the staff there use it to build curriculum, rather than just evaluating what they have. It would have been informative to test it at other informal physical science institutions. Analyzing the effectiveness and developmental appropriateness of each lesson would help me discover if my hypothesized learning progressions and progress maps accurately described students' cognitive abilities. Without empirical data to support it, this tool remains untested.

The second limitation was the scope of the subject matter. I chose to focus on the topic of matter because research was readily available, and *The Science Zone* identified it as a priority area. However, in order to feel confident that this tool is more broadly applicable, it should be applied to several topics across a larger range of scientific disciplines. Some may not have such thorough research available, or certain topics might not progress so linearly in a student's conception.

In the case of *The Science Zone,* a large percentage of the classes that come sign up for a membership and visit the museum about once a month. As mentioned above, this is often the bulk of their science education during elementary school. In this context, the tool is very useful because the same students are returning to work through the progression year after year. This allows educators to be more confident that the necessary concepts have already been taught when they begin a lesson. In a less consistent museum context, such as museums that only see student groups once, this tool may be less useful because it is harder to know if the students have learned the foundational ideas that are necessary for a given lesson. One possible solution to this limitation would be to supply the learning progression and progress map to the teacher beforehand and allow them to identify where they believe their class falls on the continuum, and then choose a lesson for the next level.

Recommendation

The first step for determining the efficacy of this tool is to put it in to practice. *The Science Zone* could use this tool to plan lessons, and then use pre-and post-visit assessments to determine if students showed growth. The learning progressions and progress maps could also be distributed to teachers in the district, and feedback could be solicited about their opinions of the tools. As more information is gathered about how well this tool works in practice, updates should be made accordingly. This tool should also be tested in other subject matters to determine its efficacy across all scientific disciplines.

There may also be additional uses of this tool. As I discovered while compiling the matrix, this tool can help educators locate holes in their own activity banks. Just as I found that *The Science Zone* had no activities for teaching progress variable R-3, teachers or institutions could map their own lessons to the learning progression to identify areas in which they should prioritize curriculum development.

Another variation of use could be to supply this learning progression to teachers before their visit, and ask them to identify where on the progression they think their class lies. This information could be used to select the appropriate level of activities for the field trip. This would be especially useful for non-traditional or special education classes, where students may not fall within the typical range of student progressions.

Conclusion

The practices and requirements of science education in America are currently experiencing a modernization, and informal science centers are following suit. Schools use these institutions to expose their students to exciting, challenging, and cutting-edge experiences, and if they are operating from outdated techniques and standards, they will not be as attractive to teachers. From both the business and education standpoints, it is beneficial for science centers and museums to align their curriculum to the NGSS.

While there are many ways to go about this, I have presented one that I believe can be used broadly and adapted for different institution's needs. However, further research in the form of testing the tool with actual students, as well as applying the tool to different science topics, is needed. Every strong idea is built on a foundation of smaller concepts, and hopefully this tool will serve as one foundational piece to help build towards the integration of the NGSS in all informal science centers.

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Appendix A

List of Museums Contacted

- The Exploratorium, San Francisco, California
- The Leonardo, Salt Lake City, Utah
- Utah Natural History Museum, Salt Lake City, Utah
- Museum of Science, Boston, Massachusetts
- American Museum of Science and Energy, Oak Ridge, Tennessee
- Chicago Museum of Science and Industry, Chicago, Illinois
- California Science Center, Los Angeles, California
- SpectrUM Discovery Area, Missoula, Montana
- Buffalo Museum of Science, Buffalo, New York
- Science Museum of Virginia, Richmond, Virginia
- Houston Museum of Natural Science, Houston, Texas
- Orlando Science Center, Orlando, Florida

Appendix B
Learning Progressions and Progress Maps

PS1.A: Structure and Properties of Matter

Learning Progression. *PS1.A: Structures and Properties of Matter*						
	Kindergarten	First	Second	Third	Fourth	Fifth
NGSS	n/a	n/a	Different Properties are suited to different purposes. (2-PS1-2)(2-PS1-3)	n/a	n/a	Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. (5-PS1-1)
	n/a	n/a	A great variety of objects can be built up from a small set of pieces. (2-PS1-3)	n/a	n/a	Measurements of a variety of properties can be used to identify materials. (boundary: mass and weight are not distinguished, no attempts is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation) (5-PS1-3)
	n/a	n/a	Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties (2-PS1-1)	n/a	n/a	n/a

	Kindergarten	First	Second	Third	Fourth	Fifth
Smith	n/a	n/a	Objects are made of specific materials. There are different kinds of materials. The same kind of object can be made of different materials.	n/a	n/a	Objects are made of matter that takes up space and has weight. Solids, liquids, and air are forms of matter and share these general properties. There are many different kinds of materials. There can be invisible pieces of matter (too small to see).
	n/a	n/a	n/a	n/a	n/a	Materials have characteristic properties that are independent of the size of the sample (extends knowledge to less obvious properties such as density, flammability, or conductivity). The weight of an object is a function of its volume and the material it is made of. Volume is an additive property of an object that can be measured. Weight is an additive property of objects that can be measured (weight is sum of parts).

	Kindergarten	First	Second	Third	Fourth	Fifth
Handenfeldt	Students describe structures without the use of the particle concept (1). They view matter as dividable but continuous (2).			Students understand particles as entities embedded in matter (3). Between the particles is the actual substance (4). Students are not able to use their perception of particles to explain the structure of matter (5).		Students understand particles as a building block of matter (6). There is nothing between the particles. These particles are often described as the 'last divisible unit' which is why they are often described with macroscopic properties as the particles inherit these properties through this division process (7).
	Students do not have any model that allows them to describe physical properties and changes of matter scientifically. They describe only what they have observed (8). They use prototypes to describe substance properties, e.g. water is a prototype for liquids (9).			Students are able to categorize substances and to attribute characteristic properties to these categories (metals, non-metals and salts); therefore, students use 'actions' or 'similarities' to classify substances and matter (10). Students describe physical changes as modification of the original substance without using the particle model for a reasonable explanation (11). Particles that are embedded in matter are often used in explanatory approaches (12).		
	Continuity: "Matter is continuous, with no underlying structure."			Granularity: "Either learners think of a substance as made up of little pieces of the same material or they think of it as a continuous entity with embedded 'atoms' or particles of some generic kind."		
	n/a	n/a	Substantialism: "Learners' tendency to think of substances as the carriers of properties, such as color, smell, taste."			Elementalism- "All of the properties of substances are additive."
	n/a	n/a	n/a	Embedding: "Learners seem to presuppose the existence of some sort of material support in which the granules or particles are immersed."		
	n/a	n/a	n/a	Inheritance: "Granules or particles that comprise a substance have the same properties of a macroscopic sample of the material."		
	n/a	n/a	n/a	Static: "Particles in a substance are fixed in space."		Causal dynamic: "Particles will only move when they are forced to do so and that their movement will eventually cease. "

Progress Map. *PS1.A: Structure and Function of Matter*					
Kindergarten	**First**	**Second**	**Third**	**Forth**	**Fifth**
S-K. Matter has observable properties.	**S-1. There are different kinds of materials that serve different purposes.**	**S-2. Many objects can be made up from a variety of small pieces.**	**S-3. Matter is made up from pieces too small to see.**	**S-4. A variety of measurements can be taken to classify matter based on its properties.**	**S-5. Objects are made of particles moving around in space. Differences in particles and movement account for difference in materials.**

1. Liu & Lesniak, 2006
2. Ayas et al., 2010; Papageorgiou, Grammaticopoulou, & Johnson, 2010
3. Johnson, 2005
4. Papageorgiou et al., 2010; Talanquer, 2009; Tsitsipis, Stamovlasis, & Papageorgiou, 2012
5. Johnson & Papageorgiou, 2010
6. Johnson & Papageorgiou, 2010; Nakhleh et al., 2005
7. Adadan et al., 2010; Gómez et al., 2006
8. García Franco & Taber, 2009; Liu & Lesniak, 2006
9. Krnel et al., 2005; Othman et al., 2008
10. Krnel et al., 2005
11. Krnel et al., 2005; Smothers & Goldston, 2010)
12. Ayas et al., 2010

PS1.B: Chemical Changes

Learning Progression. *PS1.B: Chemical Changes*						
	Kindergarten	First	Second	Third	Fourth	Fifth
NGSS	n/a	n/a	Heating and cooling substances causes changes. Sometime these changes are sometimes reversible and sometimes they are not. (2-PS1-4)	n/a	n/a	No matter what reaction or change in properties occurs, the total weight of the substances does not change. (boundary: mass and weights are not distinguished) (5-PS1-2)
	n/a	n/a	n/a	n/a	n/a	When two or more different substances are mixed, a new substance with different properties may be formed. (5-PS1-4)
Smith	n/a	n/a	There are some transformations (reshaping, breaking) where the amount of stuff and weight is conserved despite changes in perceptual appearance.	n/a	n/a	Combining two or more materials can produce a product with properties different from those of the initial measurements.
	n/a	n/a	Freezing and melting changes some properties of materials but not others.	n/a	n/a	The amount of matter and weight are conserved across a broader range of transformations (melting, freezing, and dissolving).
	n/a	n/a		n/a	n/a	Matter continues to exist when broken into pieces too small to see.

	Kindergarten	First	Second	Third	Fourth	Fifth
Handenfeldt	Level 1: Naïve concepts: Chemical reactions Students do not have any model that is appropriate to describe or to recognize chemical reactions scientifically. In explanation approaches, they describe what they have observed (13).				Level 2: Hybrid concepts: Chemical reactions Students recognize chemical reactions through the emergence of a new substance with other properties than the reactants (14).	
	Level 1: Naïve concepts: Conservation Students do not observe any conservation of mass in their daily life. They believe that the number of reactants changes with the mass in a chemical reaction for they do not have any particle perception (15). Thus, substances can disappear in chemical reactions and in physical changes (16).			Level 2: Hybrid concepts: conservation Students understand that substances can not disappear and that the number of particles has to remain constant in chemical reactions or physical changes. Students believe that the mass of a substance is dependent on the position and on the aggregate state of a substance (17). The mass of a substance portion can increase when it is compressed. (18).		
Talanquer	Contact-Interactive- “Interactions between objects only occur when they meet in time and space.“		Contingent-interactive-Students ”condition the...interparticle interactions to other factors such as the temperature and the state of matter, or the type of process it undergoes.”			

13. García Franco & Taber, 2009; Smothers & Goldston, 2010

14. Liu & Lesniak, 2006
15. Löfgren & Helldén, 2009
16. Mohan et al., 2009; Rahayu & Kita, 2010; Smothers & Goldston, 2010
17. Othman et al., 2008
18. Treagust et al., 2010

Appendix C

Coded List of Activities (Taken from *The Science Zone*'s lesson plans)

The text for these activities was taken directly from *The Science Zone*'s lesson plans. Each lesson was broken down into its component activities, and each activity was coded separately.

Lesson	Activity	Description	Progress Variable Code
Chemical Reactions	Silver egg	Hold the egg near the candle, turning it until the entire thing is covered with soot. Next use the tongs to lower the egg into a glass of water. It will immediately turn to silver. How does this happen? The carbon in the soot repels water and holds a thin film of air next to the egg. This makes the egg appear to be silver. This is an example of a physical reaction.	S-3. Matter is made of particles too small to see. S-1. There are different kinds of materials that have different properties.
	Baking Soda Art	Have students draw a picture with glue. Sprinkle baking soda on the glue and dump off excess. Have students drip vinegar that has been colored with watercolors using pipettes. What happens? How does it change the baking soda and vinegar?	R-4. When two or more different substances are mixed, a new substance with different properties may be formed.

	Elephant Toothpaste	What is yeast? What is it used for? Place 4 oz/ 120 mL of hydrogen peroxide into a container with a small opening. (Place the container inside a larger bowl to catch overflow. Mix in a small amount of dish soap and food coloring. In a separate container mix 4 tbs of warm water with 1 package of yeast. Pour the yeast mixture into the other container and watch the reaction. What happened: The yeast released oxygen molecules from the hydrogen peroxide causing tiny bubbles that we see as foam. This is because hydrogen peroxide breaks down into water and oxygen. The oxygen escapes leaving water behind. The bottle also warms up because the reaction is exothermic.	R-4. When two or more different substances are mixed, a new substance with different properties may be formed. S-3. Matter is made up from pieces too small to see.
Properties of Water	Absorbency Test	Have kids test different objects and materials for water resistance. Each child will have a crayon mold tray or muffin pan with small amount of water as well as an assortment of materials. Let children dip items in water to see whether they absorb water or not. Using activity sheet and expo markers have kids place an “x” over items that absorb water. Discuss what the items that resisted the water feel like and are made of.	S-1. There are different kinds of materials that have different properties. S-K. Matter has observable properties.
	Waterproof challenge	Give each child a stuffed animal and allow them to choose a material to wrap the animal in, either plastic wrap, tinfoil or paper towels. After using tape and their chosen material let each child test their animal to see if they made it waterproof.	S-1. There are different kinds of materials that have different properties. S-3. Matter is made up from pieces too small to see.

Fibers	Paper Comparisons:	What the paper looks like depends on what it's made from. Most paper is made up of plant fibers, but what are fibers? Show students some microscopic images of paper fibers, but don't tell them yet which image goes to which paper. Lets' look at some paper that we use every day and see if we can find the fibers. Have students use large magnifying glasses to look at paper. Can they see fibers? Lets' see if we can see the fibers better by cutting the paper with scissors. Have students cut the paper and look at the edge they cut to see if they see any fibers. Next have them tear the paper and look at the edge again. Now we're getting somewhere. Show them the microscopic image of the paper they tore. Now have them tear the other samples of paper and examine them with magnifying glasses. Put microscopic images up as they do this so that they can compare what they see with their magnifying glasses to the image.	S-1. There are different kinds of materials that have different properties. S-3. Matter is made up from pieces too small to see. S-2. Many objects can be made up from a variety of small pieces.
Scientific Method	Chocolate Test	Melt chocolate with different heat sources	R-2. Some changes are reversible, and some are not. R-K. Matter can exist in different states.
Atomic Structure/ Crystals	Atomic Structure	Even though they cannot be split apart we can still see that atoms are made of smaller pieces. What are atoms made of? Electrons, neutrons and protons. Neutrons and protons are held together in what is called the nucleus of an atom because of positive and negative charges, similar to magnets. Electrons travel around the nucleus kind of the way the planets travel around the sun. Do you think that neutrons, protons and electrons are the smallest pieces of an atom? Neutrons and protons are actually made up of quarks which are almost impossible to see even with the strongest microscope.	S-3. Matter is made up from pieces too small to see.

	What are Crystals	Crystals are an organized group of atoms and molecules. They all have different properties and shapes. Show students different types of crystals using the ELMO to zoom in and enhance details. If possible, have samples for students to look at under magnifying glasses as you talk about them. For example: Show a salt crystal and talk about the shapes of a salt molecule and how it relates to the shape of the crystal.	S-K. Matter has observable properties.
	Make Crystals	Prepare Noosa containers beforehand by washing and taping instruction notes to the lid. Have students paint the inside of a clay bowl with glue. Sprinkle alum powder on the glue so that the entire inside is coated. Next have students mix 2 tbs. alum powder with ¼ cup of hot water and food coloring in a bowl. Place the clay bowl into a baby food jar and then pour the alum mix over it. If time permits allow glue to set more while you do the 2nd crystal mix. Have students use pipe cleaners to make their initials or their names. Make sure that they can fit their creation into a Noosa container. Next in a separate bowl have them mix 2 tbs. of borax into half a cup of hot water. (Water just needs to be hot enough for the borax to dissolve.) This may take quite a bit of stirring. Next they can place their pipe cleaner into the container and pour the mixture carefully into it so that it covers the pipe cleaner.	R-4. When two or more different substances are mixed, a new substance with different properties may be formed.
States of Matter	Molymod Molecules:	Have students build molecules using molymods	S-5. Objects are made of particles moving around in space. Differences in particles and movement account for differences in materials.

	States of Matter Movement:	States of matter change based on how fast the molecules are moving. Solids move very slow and close together whereas gases move fast with the molecules spread apart. Compare this to how we move when we get colder. To play the game have students stand close together without touching and move very slowly. This represents a solid. Now have them move a little faster and move further apart to avoid bumping into one another to represent liquids. For gas have them move as fast as possible while staying in the same spot and move further apart to avoid hitting each other. The game is sort of like red light green light. Students will have to adjust their movement and location in the classroom cased on the state of matter you call out. Do a few rounds.	S-5. Objects are made of particles moving around in space. Differences in particles and movement account for differences in materials.
	Water States of Matter	Give each student a glass of ice water, room temp water and hot water. Have them place a drop of food coloring in each cup and watch how fast or slow the color molecules move through the water.	R-1. Heating and cooling substances causes observable changes. S-5. Objects are made of particles moving around in space. Differences in particles and movement account for differences in materials. R-2 .Some changes are reversible, some are not

	What Cause Change	Pressure: Create an alcohol cloud by pouring a small amount of alcohol into a water bottle. Close and shake vigorously for about 30 seconds. Twist the bottom of the bottle to create pressure. Slowly release the cap (it may fly off) and an alcohol cloud forms. Temperature: Liquid nitrogen and water. (Pour boiling water into a bowl of nitrogen to make a huge explosion and discuss drastic temperature changes.) Chemical: Pour Red Bull or another soda high in citric acid into a glass of milk. The citric acid causes the milk to curdle. *** Have students tell you how the molecules changed during the different experiments.	R-4. When two or more different substances are mixed, a new substance with different properties may be formed. R-2. Some changes are reversible, and some are not.
	Alka-Seltzer Rockets	Have students make Alka-Seltzer rockets. Explain that solids that have gas trapped inside will release the gas when a liquid is added.	S-3. Matter is made up from pieces too small to see. R-4. When two or more different substances are mixed, a new substance with different properties may be formed. R-5. No matter what reaction or change in properties occurs, the total weight of the substances does not change. (boundary: mass and weights are not distinguished)

Mystery Powders	Observation of Molecules:	Give students samples of each of the white powders. They are going to work in groups of four. Can they feel the difference in substances? Do they smell and look different? What happens when you add water, have one of the students add water to their samples and the group can discuss changes. Repeat this with vinegar, starch indicator and iodine. Students can record any reactions on their recording sheet.	S-K. Matter has observable properties. R-4. When two or more different substances are mixed, a new substance with different properties may be formed. R-2. Some changes are reversible, and some are not.
	Properties of Molecules:	Substances that look the same often react differently to reagents. That is because even if they look the same the molecules are different. Show microscopic pictures of each substance. Double Bonds?	S-3. Matter is made up from pieces too small to see. S-1. There are different kinds of materials that serve different purposes.
	Model Molecules	Have students build molecules using colored marshmallows and toothpicks. Give examples of molecule structures of mystery powders. Discuss similarities and differences.(double bond) * $C_6H_{12}O_6$ (flour) vs. $C_{27}H_{48}O_{20}$ (corn starch) * $NaHCO_3$ (baking soda) vs. $KC_4H_5O_6$ (cream of tartar in baking powder)	S-3. Matter is made up from pieces too small to see. S-1. There are different kinds of materials that serve different purposes.
Rocks & Minerals	What's What?	Review different methods of identifying rocks and minerals. Mineral Identification: Students will work in groups to test 5 minerals using the Mineral Identification chart and record their findings. Rock Identification: Students will work in groups to identify each rock sample using their rock identification chart. They will record their findings.	S-1. There are different kinds of materials that serve different purposes. S-4. A variety of measurements can be taken to classify matter based on its properties.

Density and Flotation	Types of Liquid: 10-15 minutes	Combine different types of liquids in a container to see how their density differs. If there are differences in density of liquid will things float in other liquid that won't float in water?	S-K. Matter has observable properties. S-1. There are different kinds of materials that serve different purposes. S-4. A variety of measurements can be taken to classify matter based on its properties.
Properties of Pennies	Tear a Penny	Fill 3 plastic cups halfway, 1 with baking soda and water, 1 with hydrochloric acid and 1 with water. Place a small amount of ethanol into a fourth cup. Give a couple students a piece of sandpaper and a penny. Have them rub the penny on the sandpaper in 2 spots until they can see the zinc core. They can then place their pennies into the Hydrochloric acid. While the pennies soak in the acid go to second activity. After letting the pennies sit about 30 minutes, place the pennies into the baking soda solution, then the water and lastly the cup with alcohol. Dry the penny off and then it will tear easily.	R-2. Some changes are reversible, and some are not. R-4. When two or more different substances are mixed, a new substance with different properties may be formed.
	Cleaning Pennies:	Give each child three cups. How do they think that we should clean the pennies? Fill two with water and one with vinegar. Have the students mix soap into one of the water cups and salt into the cup of vinegar. Let them then place one or two pennies into each cup. Which solution do they believe will clean the best? After a minute of so have them take the pennies out and lay them onto a paper towel. Which solution works best?	R-2. Some changes are reversible, and some are not. R-4. When two or more different substances are mixed, a new substance with different properties may be formed. S-1. There are different kinds of materials that serve different purposes.

Atomic Matter and Structure	Atomic Structure	Atoms are the smallest pieces we can break matter into. Take a strip of paper and tear is in half. Now tear that half in half. Keep tearing the smaller halves in half until you cannot tear it anymore. These tiny pieces represent atoms, but even they are made up of millions of atoms. Even though they cannot be split apart we can still see that atoms are made of smaller pieces. What are atoms made of? Electrons, neutrons and protons. Neutrons and protons are held together in what is called the nucleus of an atom because of positive and negative charges, similar to magnets. Electrons travel around the nucleus kind of the way the planets travel around the sun. Do you think that neutrons, protons and electrons are the smallest pieces of an atom? Neutrons and protons are actually made up of quarks which are almost impossible to see even with the strongest microscope. When atoms join together they form molecules.	S-2. Many objects can be made up from a variety of small pieces. S-3. Matter is made up from pieces too small to see.

	Holey Atoms	Atoms are actually mostly made up of empty space, kind of like water. Show student a cup of water and a cup of alcohol. If you put them together, how much liquid will you have? It isn't two cups, because the alcohol fills in the empty space in the water. Water has empty space because it is made from molecules that are made from the atoms oxygen and hydrogen. Let's separate the two. Split class into pairs and give each pair two pencils sharpened on both ends. Have students poke the pencils through a strip of cardboard so that there is about an inch of space between them. Next, have students attach one end of a copper wire to each pencil and the other ends to a 9 volt battery. Next place the pencil ends that are not attached to wires into the water. The cardboards should hold them in place during the experiment. What is happening in the water? As the electricity passes through the pencils (electrodes) the water splits into hydrogen and oxygen gas. This can be seen through the bubbles around the pencil. For a variation, mix salt into the water beforehand. This creates chlorine gas instead of oxygen. This is because salt and water create hydroxyl ions. The oxygen is still present but stays combined with the chlorine gas that is released.	S-5. Objects are made of particles moving around in space. Differences in particles and movement account for difference in materials. S-4. A variety of measurements can be taken to classify matter based on its properties. R-5. No matter what reaction or change in properties occurs, the total weight of the substances does not change. (boundary: mass and weights are not distinguished)

	Penny Alchemy:	While the previous activity finishes take a beaker with water and place 30 g of zinc sulfate into 100 mL of water. Place the beaker on a burner and add mossy zinc and a clean penny. Let the solution boil for about 10 minutes. As the solution heats the zinc dissolves and releases electrons. Those electrons attach to the copper penny and give it a negative charge. (This is kind of like when we get a static charge.) The zinc then redeposits onto the penny giving it a silver color, which is actually white brass. Demonstrate how it is similar to static by charging a balloon and picking up a piece of paper and explain how the charged object is trying to rebalance itself. Rinse the penny off and then place it onto the hot plate. As the zinc coating is heated it diffuses into the copper and causes the brass surface to appear gold.	R-4. When two or more different substances are mixed, a new substance with different properties may be formed.

Appendix D

Matrix of Activities and Progress Variables

	S-K	S-1	S-2	S-3	S-4	S-5	R-K	R-1	R-2	R-3	R-4	R-5
Silver egg		X		X								
Baking Soda Art											X	
Elephant Toothpaste				X							X	
Absorbency Test	X	X				X						
Waterproof challenge	X	X										
Paper Comparisons		X	X	X								
Chocolate Test							X		X			
Observation of Molecules	X								X		X	
Atomic Structure				X								
What are Crystals	X											
Make Crystals											X	
Molymod Molecules						X						

	S-K	S-1	S-2	S-3	S-4	S-5	R-K	R-1	R-2	R-3	R-4	R-5
States of Matter Movement						X						
Water States of Matter						X		X	X			
What Cause Change									X		X	
Alka-Seltzer Rockets				X							X	X
Properties of Molecules		X		X								
Model Molecules		X		X								
What’s What?		X			X							
Types of Liquid	X	X			X							
Tear a Penny									X		X	
Cleaning Pennies									X		X	
Atomic Structure			X	X								
Holey Atoms					X	X						X
Penny Alchemy											X	

Key to Codes on Matrix

Structure and Properties of Matter:	
S-K (Kindergarten)	Matter has observable properties.
S-1 (First Grade)	There are different kinds of materials that serve different purposes.
S-2 (Second Grade)	Many objects can be made up from a variety of small pieces.
S-3 (Third Grade)	Matter is made up from pieces too small to see.
S-4 (Fourth Grade)	A variety of measurements can be taken to classify matter based on its properties.
S-5 (Fifth Grade)	Objects are made of particles moving around in space. Differences in particles and movement account for difference in materials.
Chemical Reactions	
R-K (Kindergarten)	Matter can exist in different states.
R-1 (First Grade)	Heating and cooling substances causes observable changes.
R-2 (Second Grade)	Some changes are reversible, and some are not.
R-3 (Third Grade)	Matter continues to exist when broken into pieces too small to see.
R-4 (Fourth Grade)	When two or more different substances are mixed, a new substance with different properties may be formed.
R-5 (Fifth Grade)	No matter what reaction or change in properties occurs, the total weight of the substances does not change.