COMBINING INQUIRY-BASED ACTIVITIES WITH VIRTUAL SIMULATIONS IN FIFTH GRADE SCIENCE: AN ACTION RESEARCH STUDY

By

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To my family and friends – thank you for always believing in my goals

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I truly would not have accomplished this feat without the huge community around me, supporting me and believing in me every step of the way. I am forever grateful.

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NGSS	Next Generation Science Standards – These are the three-dimensional standards covering core ideas, cross-cutting concepts and engineering practices that are taught by many districts across the United States.
STIR	Science Teacher Inquiry Rubric – developed by Bodzin and Beerer (2004), which is used by teachers to evaluate their instructional practices, determining whether or not they are inquiry-driven and focus on student-centered or teacher-centered instruction.

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By

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Chair: Kara Dawson
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This action research study aimed to find ways to adjust my practice by incorporating inquiry-based, science activities and virtual simulations to improve student conceptual understanding of physical and chemical changes. A multi-lesson, curricular intervention combining inquiry-based activities and virtual simulations was developed using research-based best practices and implemented in three 5th grade classrooms. A self-reflective journal, the Science Teacher Inquiry Rubric (STIR), and student interviews were used to study my teaching practice. Exit tickets, student interviews and surveys, and classroom artifacts were used to study changes in students' conceptual understanding of the content. Data were collected from a purposeful sample of twelve fifth-grade students and analyzed using Process, In Vivo Coding, and Pattern Coding.

Integrating virtual simulations and inquiry-based learning led to a more student-driven experience. During the study, students provided feedback through exit tickets, and shared that inquiry-based activities and virtual simulations positively impacted their understanding of physical and chemical changes. Students demonstrated new learning of physical and chemical changes using inquiry-based activities and virtual simulations

in small groups and during individual assessments. Yet, only a small number of students reported feeling confident in explaining the scientific models they developed to others. While the results were primarily positive, there are adjustments I need to make to this curriculum. For example, I need to reconsider the timing of the virtual simulations within the instruction. I also need to consider issues related to the limited time students must use the free versions of virtual simulations since paying for full access is not an option for me.

This study offers ideas for integrating inquiry-based learning and virtual simulations in an elementary science classroom and provides specific details regarding the impact these methods have on teaching and student conceptual understanding. Given that most work in this area occurs in high school or post-secondary science classrooms, this study contributes important insights and suggests that elementary science classrooms can successfully combine inquiry-based science activities and virtual simulations.

CHAPTER 1
INTRODUCTION TO THE STUDY

Background Research conducted by Kirschner et al. (2006) suggests that inquiry-based learning (IBL), using active, experiential learning to understand scientific phenomena, might strain a learner’s cognitive load too much. The authors explain that teachers can reduce learners' cognitive load by using virtual simulations to scaffold the IBL process. In my fifth-grade science classes, I find it challenging to demonstrate various scientific phenomena in a classroom due to the nature of the idea or concept. In addition, I do not feel equipped with the proper tools for addressing more abstract ideas on macro and micro scales in the classroom. For example, one particularly challenging component within the “Matter and its Interactions” unit is teaching students the Law of Conservation of Mass using matter particles. Fifth graders struggle to consider particles of matter at a molecular level. This study aims to design and pilot test a unit on Matter and its Interactions that integrates inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding.

Researchers have studied the combination of simulations and inquiry-based activities for over fifteen years. The balance of both methods is essential for understanding challenging concepts (Olympiu & Zacharia, 2012; Yuliati et al., 2018 Zacharia, 2007; Zacharia, 2015). Combining these methods has also improved student engagement, attitudes, and motivation (Mutlu & Sesen, 2020; Wen et al., 2020). Both methods were effective, and students did not prefer one method over the other; therefore, combining methods could be the key to success (Pyatt & Sims, 2012). The integration of multiple methods for instruction, such as blending inquiry-based activities and virtual simulations, supports differentiation in the classroom which is essential for a wide range of learners (Kubicek, 2014; Olympiu & Zacharia, 2012; Wu & Krajcik, 2006; Zacharia, 2015; Zacharia et al., 2015).

Currently, there is a gap within the research surrounding the use of simulations and inquiry-based activities in elementary education, as most studies focus on using both strategies with high school or undergraduate students. Based on my problem of practice and the current gap in the literature, I will be able to collect and analyze qualitative data, identify overall patterns, reflect upon my practice, and determine the next instructional steps after implementing a new intervention.

Context

The context of the study was a fifth-grade classroom with students in a suburban town and working without a curriculum while trying to follow the Next Generation Science Standards. My colleagues and I have created four different units using a free science curriculum called Phenomenal Science that we have adapted to fit the needs of our students. This study focused on the Matter and its Interactions unit. Students understand physical and chemical changes through inquiry-based activities, however, they struggled with understanding the differences between these two changes on a molecular level. Similarly, students found it challenging to explain the law of conservation using the idea that matter is made up of particles too small to be seen. For these reasons, the Matter and its Interactions unit provides opportunities for students to combine inquiry-based activities with virtual simulations to enhance their conceptual understanding.

Purpose Statement and Research Questions

The purpose of this qualitative study was to find ways to incorporate both inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding. The research questions for this study include:

1. In what ways do I adjust my teaching with inquiry-based activities and simulations to facilitate student learning of physical and chemical changes?

2. In what ways, if any, will using virtual simulations and inquiry-based activities improve students' conceptual understanding of physical and chemical changes?

Research Approach

A qualitative research approach was used for this study. Specifically, an action research design was used to explore groups of students in three science classes. According to Dana and Yendol-Hoppey (2020), action research is the process of systematically and intentionally studying one's practice to gain insights into improving teaching and learning. By using an action research design, I learned about my current teaching, reflected upon the use of new interventions, and made plans for the next steps in my instruction.

During my work in the doctoral program, I have started to understand the ongoing role of action research in my career as an educator. Action research can be defined as a practice in which professionals take the time to ask questions, research, plan, act, change, and reflect upon their practice (Greenwood & Levin, 2006; Yendol-Hoppey & Dana, 2020). Teaching is constantly evolving, and educators need to collaborate, plan, test, and reflect on lessons, activities, and assessments to fit the needs of the students. Action research seamlessly fits into the teaching mold and is encouraged by professional learning communities. As action research becomes more of a common practice in education, it is also important to consider the implications of the findings beyond the four walls of a classroom.

Action research provides teachers with the opportunity to amplify their practice, however, the results could have a stronger impact if they are shared to promote educational reform. Ultimately, this study had two purposes. First and foremost, to address the research questions and identify best practices when combining virtual simulations and inquiry-based activities. In addition, a second purpose was to share the results of this study with the academic community to begin to fill the gaps in K-8 science education. While developing, transforming, and teaching the content using the Next Generation Science Standards, inquiry-based activities and simulations, my role as a teacher allowed me to gain insights that are not readily available to researchers outside of education. This study not only improved my professional practice as an educator, but it fills in missing components within research, and even encourages other professionals to contribute their expertise beyond their classrooms.

Significance of the Study

This study was beneficial for my instructional practice, my students' learning, and my departmental colleagues. After teaching fifth-grade science using the NGSS curriculum guidelines for the past five years, there are gaps within my instruction and opportunities for growth when teaching both macro and microsystems. After completing this research, I was able to reflect on my teaching and continue to make improvements to enhance instruction for my future science classes.

Additionally, my students were provided with diverse learning opportunities that impacted how they understood the world beyond our classroom walls. My fifth-grade science department was also able to learn from my findings about the strategies and methods that worked and those that did not work while implementing this intervention. This could move us forward with planning for future units and finding virtual simulations that could be beneficial to use throughout the school year to reduce cognitive load.

The final missing piece in the literature is the use of a similar intervention in elementary science classes. Most of the recent research focuses on high school students or undergraduate students. This research is important because students are just beginning to understand their learning through inquiry, therefore, it is important to balance the cognitive load so they can continue to benefit from both simulations and inquiry-based activities throughout their science educational career.

Table 1-1. Summary of research questions, data collection methods, and data analysis methods.

Research Question	**Data Collection**	**Data Analysis**
In what ways can I incorporate virtual simulations and inquiry-based activities within my instruction?	Documents/ Artifacts / Student Work Curriculum used (without simulations) Simulations used Create student work portfolios including assignments, assessments, screenshots of simulations, projects	Process Coding Pattern Coding
	Reflective Journal Weekly journal entries (running document) Reflections on curriculum, simulations, IB activities, student discussions, etc.	Process Coding Pattern Coding
In what ways, if any, will using virtual simulations and inquiry-based activities in my instruction improve my students' conceptual understanding?	Interviews Informal interviews- Asking questions during a lesson (take notes) Formal interviews- Small groups of students – specific questions about activities when both methods were incorporated	In Vivo coding Pattern Coding
	Observations Record video or audio during lessons Take brief notes during student independent work time	In Vivo coding Pattern Coding

CHAPTER 2
LITERATURE REVIEW

As elementary classrooms transition to a 21st-century learning environment, the use of simulations in science class has demonstrated many advantages in student achievement, motivation, and has improved attitudes toward science content. The research for this study focused on the use of virtual simulations in science classes along with best practices in teaching science. During the research process, a few key ideas surfaced. These themes included inquiry-based science, the use of a 5E learning model, Next Generation Science Standards, the use of virtual simulations, and combining virtual simulations with inquiry-based activities.

Variables and Definitions

Inquiry-based learning is a common phrase used in K-12 education today. Many definitions have been developed and different approaches have been established within this instructional method, therefore, it is important to define this phrase in this study. The most common and relevant definition within the research literature was developed by Pizzolato et al. (2014) stating, "Inquiry-based learning views students as active thinkers who build their understanding of interactions with phenomena, the environment, and other individuals" (p. 2). Experiences provided through this approach allow students to have autonomy in their learning as they work through lessons and experiments (physically or virtually), through collaborative learning.

Another phrase that will be used regularly in this study and was identified in most of the current research is virtual simulations. Many terms and phrases represent this concept such as virtual experiments, virtual science, computer-based modeling, and virtual labs. In this study, virtual simulations will be defined as technology-based simulations used to help students visualize, model, manipulate, test, and experiment with different scientific phenomena. Virtual experiments have shown many advantages, specifically with addressing abstract concepts that are usually difficult to teach in a traditional classroom setting.

Prior Research

Inquiry-Based Science

One of the most influential topics in science education is inquiry-based learning. Therefore, it is not surprising that this was one of the first significant themes identified in literature. IBL improves student achievement, attitudes, and provides seamless integration with technology. Inquiry-based learning uses a student-centered design to encourage student initiation of learning resulting in a significant impact on long-term memory and cognitive development (Ojo, 2020). Students take on the role of a scientist and ask questions, develop hypotheses, create experiments, and collect and analyze data. A study by Howes, Lim & Campos (2009) explains that inquiry shouldn't be considered pedagogy and instead it should be looked at as developing student skills. They emphasized how inquiry-based learning supports student questions about the world and engages students in data collection and analysis to answer those questions (Howes, Lim & Campos, 2009).

The advantages of inquiry-based learning have been well distributed throughout the research. IBL has a positive impact on achievement specifically involving comprehension, laboratory experience, problem solving and processing, cognitive development, and confidence in science (Kim, 2016; Zacharaia, 2003). It also develops connections between the classroom and real scientific investigation, or authentic learning (Kubicek, 2014; Qablan & DeBaz, 2015). Inquiry-based learning increases scientific literacy when students can design experiments with proper scaffolding and guidance (Wen et al., 2020). By combining the constructivist approach, IBL, and simulations, there is a push for more cognitive conflict, resulting in increased growth and understanding over time (Huang et al., 2017; Qablan & DeBaz, 2015; Schellinger et al., 2019; Yulalti et al., 2018; Zacharaia, 2003). Inquiry-based science provides opportunities for students to use their prior knowledge to push their thinking, and can promote students to challenge these preconceptions, allowing for more cognitive dissonance in which there is a deeper understanding and significant growth in learning happens (Qablan & DeBaz, 2015; Schellinger et al., 2019).

One common sub-theme identified regarding inquiry-based learning was the impact it has on students' attitudes toward science. Inquiry-based learning improves engagement for students who might normally struggle with scientific concepts (Wen et al., 2020, p. 10), and it increases and maintains positive student attitudes toward science (Kim, 2016; Zacharia, 2003). Research shows that IBL can preserve student interest by allowing students to further investigate their interests within a lesson or experiment (Kim, 2016; Mutlu & Sesen, 2020). Students prefer IBL no matter what format (physical or virtual) (Mutlu & Sesen, 2020; Pyatt & Sims, 2012). This finding aligns with the idea that students have a more positive attitude based on the teaching approach, such as inquiry-based learning, rather than based on the content (Kim, 2016). By providing student-centered learning using the IBL approach, not only will students improve their understanding of the content, but they will also become more excited about the scientific process (Kim, 2016).

When using IBL, the teacher presents a problem, and students use self-directed methods for solving the problem (Song & Kong, 2014). Incorporating IBL is not necessarily easy for all teachers and classes, but one study by Hakverdi-Can & Dana (2012) found that more humanistic teachers tend to use inquiry in science classes through collaboration, discussion, and student-driven experimentation. The goal is to balance factors of scaffolding to meet the needs of a wide range of learners (Wen et al., 2020) while limiting the "cookbook" procedures found in a traditional method of science education (Song & Kong, 2014). Guided inquiry increases learning efficiency and conceptual understanding (Wen et al., 2020). In a study by Moon and Brockway (2019), students learning through guided inquiry did significantly better than students using an open inquiry approach because they could see some of the more complex relationships between variables that were not apparent for the students that used open inquiry. Students typically struggle with open inquiry because they tend to change more than one variable at a time during an experiment. Planning and proper use of technology are essential for following the guided inquiry approach in the classroom.

Another component of inquiry-based learning addressed was the discussion of the inquiry learning environment. Donnelly & Linn (2014) thoroughly discussed the structure, impacts, and goals of using an inquiry learning environment. They shared that ILE's use powerful visualization to explore meaningful and authentic scientific concepts. Inquiry learning environments encourage collaboration and the development of autonomous, metacognitive learning practices. The goal of using an inquiry learning environment is to ensure scaffolding that allows students to work in their zone of proximal development (Donnelly & Linn, 2014). Since this is a newer method within inquiry-based learning, more research is needed to identify trends when using an inquiry learning environment.

Finally, there are a few challenges to consider as I conduct my research. One of the common issues found when teachers used inquiry-based activities was that students struggled to connect data to the guiding question (Soonjana & Kaewkhong, 2022). As I developed and reviewed my lessons for this unit, I needed to ensure that students start with a driving question, and circle back to the question following the experiences in the classroom. Studies by Bodzin & Beerer, Forbes (2011), Qablan & DeBaz (2015) and Soonjana & Kaewkhong (2022) provide helpful questions to consider, suggestions on adapting a curriculum using inquiry-based learning, and inquiry-strategies scales and rubrics to evaluate the overall implementation.

5E Learning Model

Science instruction revolves around authentic phenomena and allows students to question, investigate, and explain the world around them. The 5E model developed by the Biological Science Curriculum Study (BSCS) led by Rodger Bybee (1987) provides an organized method for this type of instruction. The 5E model includes different stages of learning including engage, explore, explain, elaborate and evaluate. In the engage phase, teachers use a driving question connected to the real world to peak student interest and allows students to develop related questions for further exploration in the lesson or unit. This helps to increase student motivation which promotes more conceptual change (Garcia et al., 2021). The explore stage encourages students to make claims about the phenomena, and then test their hypotheses using different activities or experiments through guided inquiry (Garcia et al., 2021). Following exploration, the class moves onto the explain stage which includes direct and formal instruction and helps students organize the information they have gathered during the exploration phase. Students try to make sense of the data and identify patterns to provide a solid claim with supporting evidence and reasoning. The elaborate stage continues to push student thinking through transferability by using what they have learned and applying it to new concepts or new experiments. Finally, the evaluate stage is a meaningful learning opportunity that has clear assessment goals and will allow students and teachers to reflect upon the overall learning (Garcia et al., 2021; Nasr, n.d.).

The 5E model is supported by research, designed for conceptual change, creates cognitive conflict with preconceptions, activates prior knowledge, promotes positive attitudes towards science, increases general achievement and is better for teaching states of matter (Garcia et al., 2021). Additionally, research shows that there are statistically significant differences in understanding before and after the use of 5E learning model in the short term and five years later (Garcia et al., 2021). This learning model can be used to enhance curriculum to allow for a more student-centered learning experience (Scott et al., 2014). Students prefer this method of learning because it promotes active learning which allows for conceptual change. For this model to be effective, the teacher must provide time for addressing and reflecting upon student prior knowledge (Garcia et al., 2021).

Use of the 5E model in an elementary setting must be thoughtfully planned and must include some flexibility as students are overcoming preconceptions. The planning process should be student-centered, promote a constructivist mindset, and include real-life application for authentic learning. By using exemplary studies by Nasr (n.d.) and Garcia et al. (2021), I will be able to ensure proper alignment of the 5E model within my lessons for this unit.

Next Generation Science Standards

Over the past decade, the National Research Council has worked on improving science education by looking specifically at the National Science Education Standards. In 2013, the Next Generation Science Standards (NGSS) were introduced to educators across the United States. Developers shared the numerous benefits of the standards including the improvements to instruction and student learning outcomes and focusing learning using the lens of a scientist and how they understand the world. Prior to NGSS, the NSES allowed students to ask questions, plan investigations, gather data, and communicate learning. This instructional approach followed a more linear scientific method, while the Next Generation Science Standards allow for more flexibility and movement across different stages (Merritt., Chiu, Peters-Burton, & Bell, 2018). Additionally, the NGSS incorporates science and engineering practices that were not incorporated into the original NSES inquiry standards (Smith & Nadelson, n.d.). Overall, the Next Generation Science Standards were developed to establish more reform across districts using content standards, cross-cutting concepts, and science and engineering practices (Smith & Nadelson, n.d.).

Some of the current research explained the integration of the Next Generation Science Standards and teacher perceptions of the implementation in their elementary science classrooms. One study found that teachers sometimes have difficulty obtaining questions that can be tested based on the standards (Merritt., Chiu, Peters-Burton, & Bell, 2018). This is important for use of the NGSS, but also guiding questions drive inquiry-based activities which is a focus of this study. Studies also found that teachers struggled to transition from the teacher as an expert (direct instruction) to the students becoming experts with the teacher being a facilitator (Haverly et al., 2022). Students must have opportunities to ask questions, make, explore and explain predictions, and focus on the learning process with a scientific mindset rather than the correctness of predictions (Merritt., Chiu, Peters-Burton, & Bell, 2018). Studies by Krajcik (2014) and Smith & Nadelson (n.d.) include steps on how to properly integrate and analyze the NGSS in K-12 classrooms. The study by Merritt, Chiu, Peters-Burton, & Bell (2018) offers reflection questions to consider while implementing the standards to ensure that all three components of NGSS are included in lessons.

Virtual Simulations

In this literature, the most popular topic in science education was the integration of virtual experiments or simulations into a classroom setting. Many advantages have been identified regarding the use of simulations in science lessons. Virtual experiments have been shown to open possibilities for experiences that could not be done with a class demonstration. On a broader scale, virtual experiments provide multiple representations of phenomena (Gonczi et al., 2016; ; Lye et al., 2014;Smetana & Bell, 2012) and promote higher order thinking skills while emphasizing problem-solving (Smetana & Bell, 2012). Students may never get the opportunity to experience these real-life phenomena, so simulations give them the chance (Chen et al., 2019; Isman et al., 200; Mutlu & Sesen, 2020; Smetana & Bell, 2012; Waight & Abd-El-Khalick, 2012; Xie et al., 2018;). A literature review conducted by Smetana & Bell (2012) synthesized 61 studies that focused on the use of virtual simulations in science classrooms.

Smetana & Bell (2012) explained the advantages of virtual simulations and stated that they help students confront preconceptions, allow students to pose and test hypotheses, they cater to learner's needs allowing for differentiation, and they have even shown to specifically help students with lower cognitive abilities.

They also allow for the demonstration of abstract phenomena covering micro and macro environments (small scale - unable to see, large scale - unable to reproduce in a lab) (Gerard et al., 2016; Gonczi et al., 2016; Herga et al., 2014; Kubicek, 2014; Olympiu & Zacharia, 2012; Smetana & Bell, 2012; Herga et al., 2014; Kubicek, 2014). Some examples of these phenomena include ecosystems (Dickes et al., 2019), friction (Evangelou & Kotsis, 2019), solar heat (Xie et al., 2018), atoms, electrons and photons (Yulalti et al., 2018), systems-based learning (Brigas, 2019), space systems (Schwarz, Meyer, & Sharma, 2007), global warming and greenhouse effect (Özcan, Çetin, Koştur, 2008), electricity (Unlu & Dokme, 2011), and submicroscopic conditions (Herga et al., 2014).

Not only do virtual experiments provide the chance for students to discover unimaginable phenomena, but they also provide opportunities to work with tools or chemicals that are unsafe for classroom use (Chen et al., 2019; Herga et al., 2014; Isman et al., 2007; Olympiu & Zacharia, 2012; Pyatt & Sims, 2012;). Students have shared that virtual experiments can be more user-friendly and less intimidating than laboratory experiments (Pyatt & Sims, 2012). They also increase motivation, engagement, and comprehension when using portable devices and gaming (Chang et al., 2020; Chen et al., 2019; Ching & Hagood, 2019; Gonczi et al., 2016; Mutlu & Sesen, 2020; Özcan et al., 2008; Smetana & Bell, 2012;).

The final advantage to using virtual experiments is their ability to save time. Simulation trials take less time and allow for flexibility, so more data can be collected in a shorter time as compared with physical experiments (Klahr et al., 2007; Mutlu & Sesen, 2020; Smetana & Bell, 2012). Faster data collection allows for more data manipulation, analysis, and discussion (Dickes et al., 2019; Herga et al., 2014; Kubicek, 2014; Nicolaou et al., 2007; Olympiu & Zacharia, 2012; Pyatt & Sims, 2012). This, in turn, provides more time for teachers due to less laboratory preparation (Xie et al., 2018).

On the contrary, few studies have focused on the disadvantages of simulations or virtual experiments in the classroom. Of the studies completed, one disadvantage shared was that identifying variables and relationships can be a bit more challenging with simulations (Kubicek, 2014). Another study explained that students felt overwhelmed by simulations that were too advanced for them. Specifically, some of the special features and explanations made the simulation confusing and distracting at times (Paul, Podolefsky, & Perkins, 2013). Virtual simulations should be a supplement to, not replace, current instruction (Smetana & Bell, 2012). Teachers need to be mindful of their implementation, as simulations should be used at different times for different purposes. For example, if the goal is for the students to understand the scientific process, then it is crucial for students to use simulations prior to completing hands-on explorations. If the objective is for students to improve conceptual understanding, then simulations should be used after hands-on explorations (Smetana & Bell, 2012). Incorrect implementation can lead to further confusion or misconceptions for students. In addition to the order of use of simulations, teachers also must provide proper guidance for the simulation to be effective. Teachers must use modeling and implicit scaffolding techniques with simulations to help reduce cognitive load (Gonczi et al., 2016; Paul, Podolefsky, & Perkins, 2013; Smetana & Bell, 2012). Although the use of virtual simulations has shown an overwhelming number of advantages in science education outweigh the few disadvantages, it seems that further research is necessary to make a true analysis.

Combining Virtual Simulations with Inquiry-Based Activities

Combining both physical and virtual experiments has had a positive influence on science education. From an academic perspective, combining methods has increased academic achievement (Unlu & Domke, 2011), produced higher test scores than virtual laboratories or physical laboratories alone (Jaakkola & Nurmi, 2008; Unlu & Domke, 2011; Zacharaia, 2007), promotes systems thinking, conceptual change and a need for modeling (Schwarz et al., 2007). The balance of both methods is essential for understanding challenging concepts (Olympiu & Zacharia, 2012; Yuliati et al., 2018); Zacharia, 2007; Zacharia, 2015 such as electricity (Jaakkola & Nurmi, 2008; Unlu & Domke, 2011; Zacharia, 2007) and rustproofing (Song & Kong, 2014).

Combining these methods has also shown improvement in student engagement, attitudes, and motivation (Mutlu & Sesen, 2020; Wen et al., 2020). Both methods were found to be effective, and students did not prefer one method over the other, therefore the combination of methods could be the key to success (Pyatt & Sims, 2012). This instructional approach has also benefited a wide range of learners. The integration of multiple contexts and methods for instruction supports differentiation in the classroom

(Kubicek, 2014; Olympiu & Zacharia, 2012; Wu & Krajcik, 2006; Zacharia, 2015; Zacharia et al., 2015).

Combining these methods help students develop science laboratory skills (practice) and open opportunities for students to see beyond the classroom (Crompton et al., 2016; Nicolaou et al., 2007; Zacharia, 2015). Research shows they also can allow students to think of alternative methods for problem-solving (Olympiu & Zacharia, 2012; Yuliati et al., 2018). Most importantly, combining physical and virtual experiments closes the gap between theory and reality (Jaakkola & Nurmi, 2008; Zacharia, 2015). This was one of the more insightful findings in the research when discussing physical and virtual experimentation.

Studies combining physical and virtual experiments were thoughtful and visionary for teachers. In a systematic review, Zacharia (2007) shared that many studies were mindful of the Clark (1983) perspective and ensured that the curriculum was taught the same way within the control and experimental groups, and that the only difference was adding the technology. This helped put the focus on the tool, rather than the method of instruction. Teachers can use virtual formative assessments to meet the needs of their students individually (Gerard et al., 2016). Educators can benefit from this instructional method because it helps narrow the focus of the lesson and eliminate distractions for students (Olympiu & Zacharia, 2012). An interesting study by Zacharia (2003) explained how teacher preparation programs tried the combined method and pre-service teachers felt both had advantages to their learning. This is a helpful way to allow teachers to see the impact of combining methods because they can learn through experience. More research using this method is necessary to result in generalizations regarding teacher perspectives.

Combining these methods can be addressed by using a computer-supported inquiry learning environment (CoSIL). CoSIL environments were addressed a few times in the research when discussing simulations in science classrooms. Computer-supported inquiry learning environments push students to develop research questions, hypotheses, experimental design and conduct their experiments for analysis and discussion (Kim, 2016; Kubicek, 2014). This teaching approach has been identified as one of the most influential methods for teaching various scientific concepts because they balance physical advantages and virtual advantages (Zacharia et al., 2015). This environment allows students to re-see abstract phenomena through various methods (virtual and physical experiences) (Zacharia et al., 2015). CoSIL environments have been studied in higher education, however, there is room for research in the elementary and middle school science classrooms.

Conceptual Framework

The conceptual framework shown in Figure 2-1 below, emphasizes the important aspects of the study. This action research study will blend inquiry-based activities and virtual simulations within the NGSS curriculum, specifically Matter and its Interactions. Ultimately, the combination of these methods will lead to overall growth in two ways. First, student conceptual understanding could improve by using the combination of methods. Second, the work, analysis and reflection upon combining inquiry-based activities and virtual simulations will encourage growth in my teaching and using researched-based evidence to support instructional practices.

Research Gaps

In the field of educational technology, there are plenty of studies combining inquiry-based laboratory experiments with virtual experiments in higher education. However, there is a lack of research on the benefits of combining these methods in elementary education. As a result of the gap in current research, this study's research questions were established to further investigate this topic. Recent research focuses mostly on high-school and undergraduate students. Evangelou and Kotsis (2019) identified a need for studies that include educators teaching different phenomena to primary (elementary) students using virtual and physical experiments. Many prior studies include the combination of instructional methods but specifically look at physics concepts (Ben Ouahi et al., 2021; Evangelou & Kotsis, 2019; Hamed & Aljanazrah, 2020).

Other areas that are missing from the current literature include explanations of difficulties when integrating simulations (Smetana, & Bell, 2012; Wen et al., 2020), change in conceptual mastery using PhET simulations (Yuliati, Riantoni, & Mufti, 2018), and qualitative analysis with reflections on how teachers and students use simulations alongside authentic inquiry (Herga, Grmek & Dinevski, 2014; Huang, Ge & Eseryel, 2017; Stegman, 2021). Additional areas of concern include the guidance and scaffolding necessary for the integration of both inquiry-based activities and simulations (Zacharia et al., 2015), and the triangulation of data including student surveys, interviews, and teacher reflections (Smetana, & Bell, 2012). The improvements based on prior research will be addressed and included in the methodology section.

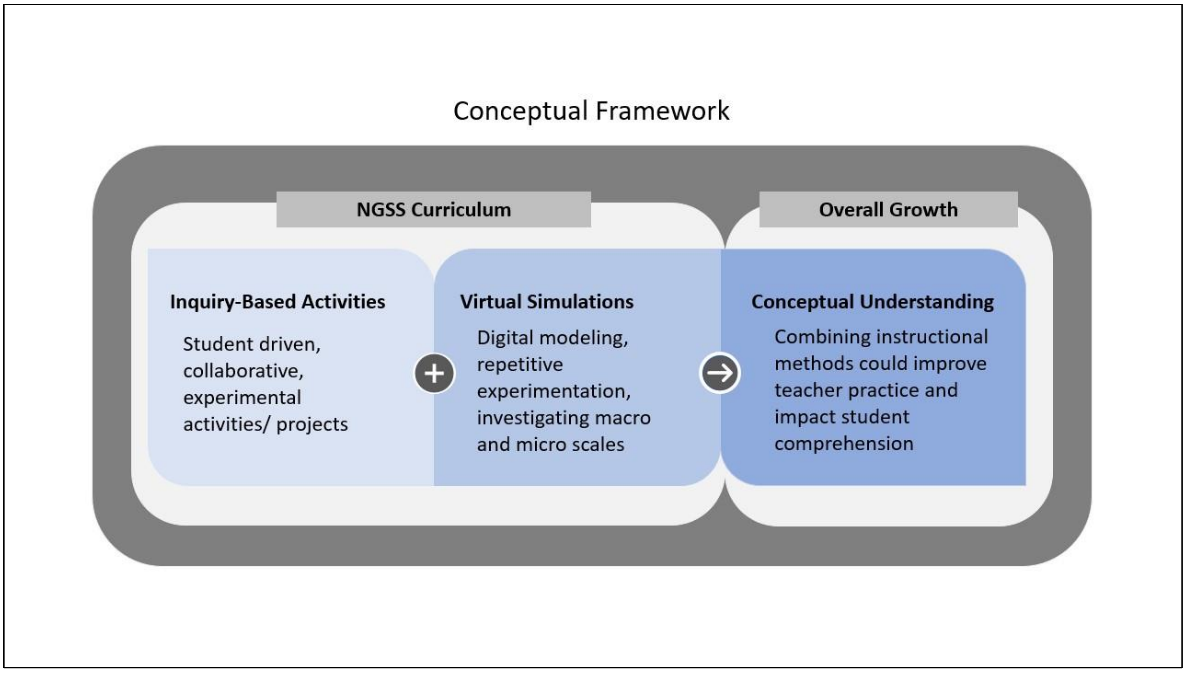


Figure 2-1. The diagram above shows the overall process of the study using inquiry-based activities and virtual simulations alongside a NGSS curriculum to monitor student growth in understanding and student attitudes toward science.

CHAPTER 3
INTERVENTION

Background

In my 5th grade science classes, students are learning how to model scientific phenomena for the first time. Due to the strong emphasis on math and literacy in elementary school, students have not had many experiences with science, therefore, scaffolding is necessary to encourage guided inquiry in my classroom. The unit for this study, Matter: It's What's for Dinner focuses on Matter and Its Interactions from the Next Generation Science Standards. The specific Next Generation Science Standards covered are as follows (NGSS, 2013):

5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.

5-PS1-2. Measure and graph quantities to provide evidence regardless of the type of change that occurs when heating, cooling or mixing substances, the total weight of matter is conserved.

5-PS1-3. Make observations and measurements to identify materials based on their properties.

5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Covering four standards within one 9-week unit has its challenges. One specific challenge is fitting in numerous inquiry-based opportunities for students to explore and experiment to better understand the phenomena. Therefore, after reviewing the current literature, I decided to combine inquiry-based activities with virtual simulations as one efficient and practical way to offer students a variety of ways to learn the concepts. Wen et al. (2020) studied the use of guided inquiry with virtual simulations in eighth grade science classes. Authors found that the treatment group using combined methods out-performed the control group on delayed-post-tests. This means that the combined methods could be helpful for long-term learning.

Currently, students are following the 5E learning model as facilitated by the teacher, and complete anywhere from 2-5 activities for each standard. Table 4-1 shows the current breakdown of each standard aligned with the activities.

Table 3-1. Overview of core standards for the unit along with specific activities aligned to those standards.

Standard	Activities
5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.	Activity 5: Solids, Liquids, and Gasses Activity 11: Air - is it Really There?
5-PS1-2. Measure and graph quantities to provide evidence regardless of the type of change that occurs when heating, cooling or mixing substances, the total weight of matter is conserved.	Activity 6: Everyday Examples of Physical Changes Activity 8: Is it a New Substance? Activity 11: Air - is it Really There? Activity 12: Law of Conservation
5-PS1-3. Make observations and measurements to identify materials based on their properties.	Activity 2: Determining Physical Properties Activity 3: Classification of Properties Activity 4: The Science of Lunch
5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.	Activity 7: Changing Matter Activity 8: Is it a New Substance? Activity 9: What's the Matter? - Physical vs Chemical Changes

When identifying which activities align with each standard, it is apparent that there are fewer lessons that focus on 5-PS1-1: Develop a model to describe that matter is made of particles too small to be seen. Part of the reason for this is that the standard covers a very abstract concept, which is difficult to address in a classroom setting. Therefore, the intervention used for this study involved adapting the curriculum to incorporate virtual simulations into lessons for more opportunities to understand the concept. Olympiou et al. (2012) found that virtual simulations enhanced understanding of abstract concepts for students with limited prior knowledge. Additionally, they explained that as students learn more abstract phenomena, they need concrete representations to help students move forward with modeling. Using the prior research on proper implementation and use of inquiry-based activities alongside virtual simulations in science instruction, integrated these two approaches and determine whether these changes improve student conceptual understanding.

Curriculum Design

As I reviewed my current curriculum and lesson plans, I used a backward design approach, looking at the four power standards that were to be covered in the unit. Before specifically aligning the activities with each standard, I considered what was most difficult for students in lessons and assessments in previous years. The biggest point of contention has consistently been having students model matter as particles that are too small to be seen. Typically, students can identify materials based on their properties, and end the unit with a thorough understanding of physical and chemical changes. But when looking at the microscopic level, students of varying abilities have struggled to successfully understand, model, and explain these matter particles.

The concept map for the unit, Matter, It's What's for Dinner, is included below in Figure 3-1. This figure outlines the main disciplinary core ideas that are the focus of the unit and shows connections across concepts. For this study, the focus is on the unit of Matter and Its Interactions. The specific standards that are being addressed involve modeling matter demonstrating that it is made of particles too small to be seen, and the process of using measurement and graphed evidence to determine the mass before, during and after physical or chemical changes to ensure that it remains the same.

These concepts are bigger ideas that need to be broken down into smaller steps. For example, modeling matter is broken into first identifying properties of matter and the use of scientific modeling. Throughout the unit, students participated in lessons and activities that encourage them to observe matter in different ways and ultimately helped them learn how to define different types of properties of matter. Alongside this work, students modeled the matter they observed to build their understanding and work towards continued use of explaining properties or changes based on particles of matter.

On the other side of the concept map, the focus is on collecting observable data and using measurements and graphs to better understand the law of conservation of mass. Students looked at both changing and conserving matter. When matter is changed, it can be through a physical or chemical change. Also, students learn about conserving matter as they start learning more about physical and chemical changes. This was done through different activities where students weigh the substances used before, during, and after the change, to determine if their data supports the law of conservation.

The curriculum for this unit was based on a previous study in a program called Phenomenal Science. After working with the original version of this unit, my colleagues and I adapted the curriculum to fit the needs of our learners, along with the resources available to us. Additionally, a unit overview is included in Appendix A. Each activity is broken down into 5E learning model components, an overview of the lessons, NGSS alignment, objectives, supplemental materials (videos, readings, etc.), specific assignments and activities, applicable virtual simulations, and assessments.

Activities 1, 2, 3, and 4 focus on determining physical properties, classifying and categorizing properties, and making observations. Following the foundational activities, the next two, Activities 5 and 6 take it a step further and begin building on physical properties by looking at physical changes and phase changes. This is the point where students must begin creating models demonstrating particles of matter. Activities 7-9 bring in the concept of chemical properties and chemical changes, and ultimately help bridge the gap in distinguishing between the two types of changes. Activity 10 encourages students to create a cooking experiment where they apply their knowledge using experimental design and they must identify and explain different properties and changes happening while cooking. The following activity moves into a discussion of air being made of particles of matter. Students explore different stations and test their ability to model and explain how they know air is everywhere Finally, in Activity 12, students began working on different experiments and activities that push their thinking through the law of conservation. This concluded the unit and led them to their final assessment, Cooking with Experimental Design.

The first component considered when reviewing the curriculum was each activity's alignment with inquiry-based learning. After reviewing the literature, I found a few beneficial tools to help evaluate the lessons. The Factor solutions for Inquiry Strategies Scale (IS) was shared by Soonjana and Kaewkhong (2022) and allowed me to briefly overview activities within lessons to determine whether they included inquiry strategies or non-inquiry strategies. The second rubric was suggested by Forbes (2011) and is the Inquiry Scoring Rubric for Lesson Plans. This rubric was used prior to instruction to ensure best practices were considered in relation to inquiry-based learning. The scores from these two rubrics can be found in Appendix B.

One of the biggest challenges of incorporating virtual simulations within this curriculum is that most scientific simulations are intended for use by high-school or undergraduate students. Another challenge with using simulations is accessibility and cost. Therefore, I had certain criteria that were considered when choosing simulations for each activity. During this process, my goal was to find simulations incorporating interactivity, examples, labels, explanations, and multiple application forms. Based on previous experience, some simulations are limited in these areas, which makes it difficult for students to make connections between class activities or concepts and online simulation. Not all simulations come from the same website or program due to these constraints.

Figure 3-1. This concept map provides an overview of the core standards covered within this study. It includes specific skills needed to meet the learning goals, and connections between subjects.

Lessons

This study focuses on combining both inquiry-based activities and virtual simulations to positively impact student learning. The lessons that needed the most improvement include:

- Activity 5: Solids, Liquids, and Gasses
- Activity 7: Changing Matter
- Activity 8: Is it a New Substance
- Activity 9: Physical vs Chemical Changes

Each of these activities required students to model particles of matter during physical or chemical changes. Table 3-2 shows the progression of student learning as the class moved across activities in the unit. When teaching these lessons previously, I would start by using the *PhET States of Matter: Basics* simulation to help students visualize phase changes. Beyond that, students had few opportunities to use simulations to help with further visualization to help with scientific modeling. This section outlines the lessons that incorporated the intervention, how gaps were identified in each lesson, and the reasoning behind making changes to the curriculum.

Table 3-2. Overview of the lessons covered throughout the unit and the learning goals for each activity.

Lesson	**Learning Goal**
Activity 5: Solids, Liquids and Gasses	Students will be able to explain physical changes using water molecules changing from a solid to liquid and gas.
Activity 7: Changing Matter	Students will be able to compare/ contrast physical and chemical changes using examples from prior learning and define each type of change based on categorized examples.
Activity 8: Is it a New Substance?	Students will be able to properly identify a physical and chemical change by making a claim, supporting it with evidence from the activities, and providing reasoning to enhance their argument.
Activity 9: What's the Matter?	Students will be able to demonstrate their understanding of physical and chemical changes through scientific modeling at a molecular level and provide explanations of what happens during each type of change.

Activity 5: Solids, Liquids and Gasses

Originally, this lesson was incorporated to review basic states of matter and phase changes with students prior to comparing physical and chemical changes. Students completed a state of matter reading as a whole class and answered comprehension questions with partners. Following the reading, I would model how to use the *PhET States of Matter: Basics* simulator, helping students to see how particles of matter changed in shape and movement during different states of matter. Students were then given time to try out the simulations. Once students had time to practice, they would sketch models of each state, identifying particles of matter. After studying previous research, I have learned that it is essential to incorporate simulations alongside inquiry-based activities, rather than replacing them. Herga, Grmek & Dinevski (2014) shared that it is important to incorporate inquiry-based activities prior to virtual simulations when the focus is conceptual understanding.

This lesson was successful in some ways but lacking in others. Students were engaged with the *PhET States of Matter: Basics* simulator and were able to explain particles of matter, their movement, and follow up with a conversation about phase changes. These were all good starting points, but it was missing connections to inquiry-based experiences, and a further push with students explaining different phase changes using their models as formative assessments.

To improve this activity, students will participate in an inquiry-based activity using ice cubes, food coloring, and a Ziplock bag. Students will be challenged to identify the most efficient ways to change the solid ice cube to a liquid and a gas all while collecting observations. They will be answering analysis questions using the data collected during the experiment. Once students have fully analyzed and discussed the inquiry activity, they will move into modeling using the *PhET States of Matter: Basics* simulator. Figure 3-2 below shows a screenshot of the simulator which demonstrates water at the solid state. The *PhET States of Matter: Basics* simulator allows students to visualize water molecules at each state (solid, liquid and gas) and encourages student interaction to move through the phases of matter by increasing or decreasing the temperature. Students created a Flipgrid™ screencast while using the *PhET States of Matter: Basics simulator,* explaining each state, discussing particles of matter, and make direct connections to the inquiry-based activities from earlier in the lesson.

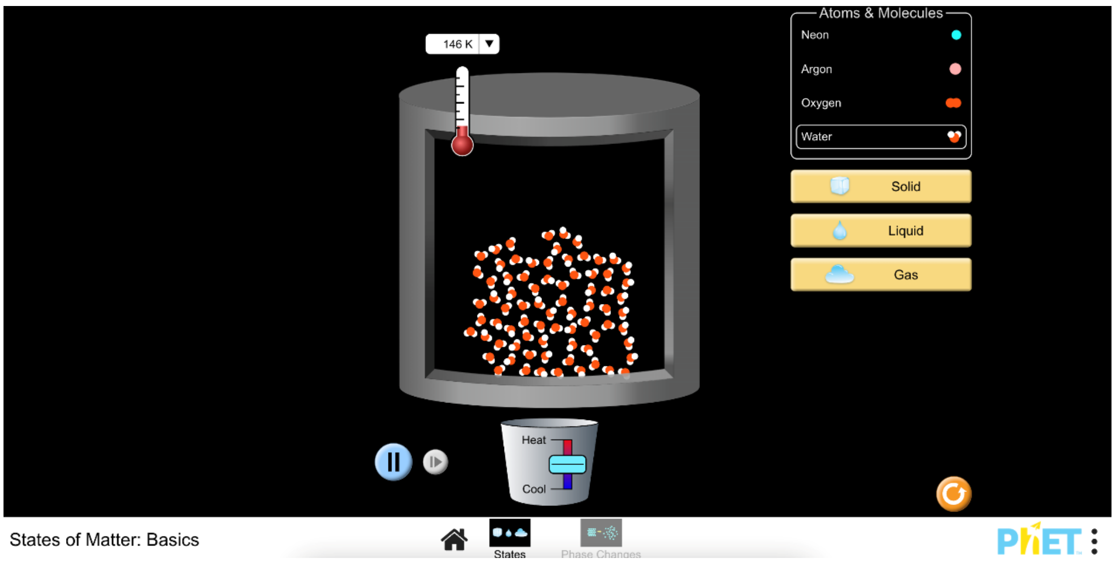


Figure 3-2. Screenshot of the PhET simulation used by students to explain phase changes and the molecules at each state of matter. Photo courtesy of author.

Website used: https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html?utm_source=google&utm_medium=cpc&utm_campaign=pmax-macc&gad=1&gclid=Cj0KCQjw-pyqBhDmARIsAKd9XIPLSbatavvhmCRJbQ1DzEX6H7w4bAtsKi3D5HQTxAR_MQCb99YPv20aAoJ4EALw_wcB

Activity 7: Changing Matter

The initial lesson used in the curriculum for Activity 7: Changing Matter was well-designed for inquiry-based learning. It is led by the guiding question, “What happens to the properties of substances when mixed, heated or cooled?” In this lesson, students work in groups/ pairs to investigate and record observations and answers to discussion questions about changing matter. They use four examples; warm water and salt, water and food coloring, water + glue + borax, and baking soda and vinegar. Students determine what changes occur and whether it is physical, or chemical based on the properties before and after mixing substances.

At first glance, this lesson is engaging, collaborative, and inquiry-driven, however, it is missing a big component of the Next Generation Science Standards, scientific modeling. Prior to the intervention, students did not have to explain the changes in terms of particles of matter. This is a big leap from the phase changes discussed in Activity 5: Solids, Liquids and Gasses. However, after taking time to identify beneficial simulations, I am hopeful that students will be able to connect their lab experiences with simulations to create a scientific model.

In addition to the inquiry-phase of the activity, I am now going to incorporate the use of a simulation following the original exploration. For this part of the investigation, I will begin by modeling the use of a Chemical Changes simulator by Gizmos. Figure 3-3 shows a screenshot of this simulator, which allows students to interact with different substances that would be too dangerous for the classroom. Not only does it allow students to look at different reactions between substances, but it shows the mass throughout the experiment. This would help students begin to see the conservation of mass for future lessons. Also, some of the questions within the simulator push students to begin thinking about what qualifies as a chemical change, and what is the specific evidence of this happening. Previously, students would state that a chemical change represents an irreversible change. I am hoping with the use of the simulator, students will be able to use specific evidence such as a gas being produced or temperature changes to qualify something as a chemical change.

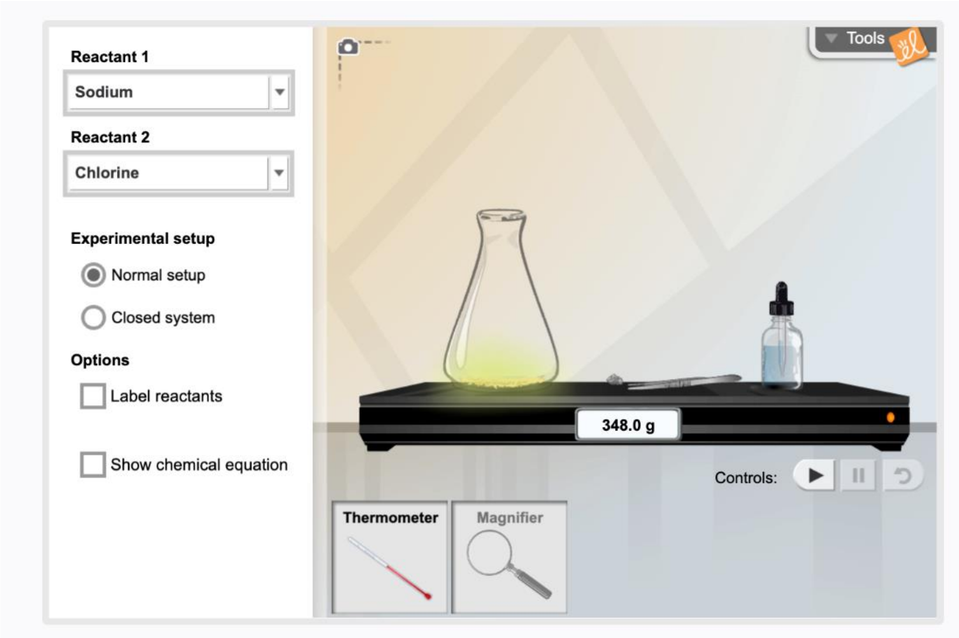


Figure 3-3. Screenshot of the Gizmos simulation used by students to learn about properties and identifiers of chemical changes. Photo courtesy of author.

Website used: https://gizmos.explorelearning.com/find-gizmos/lesson-info?resourceId=1060

Activity 8: Is it a New Substance?

When developing this unit with colleagues, Activity 8: Is it a New Substance? was always a driving force for our unit. To introduce the lesson, I show students an empty pot and have a student fill it with water, and another student adds in a tablespoon of salt. On a hot plate, I boil the water, and allow students to make predictions, and discuss what is happening in the demonstration. Students draw a before and after model of salt and water in their observation box and take notes. This is followed up with an inquiry-based activity, where students use their learning to try to explain physical and chemical changes with eggs. Teachers provide a hard-boiled egg and a frozen egg to each group. Students make predictions, collect observations, and determine which type of change has occurred with each egg based on their data.

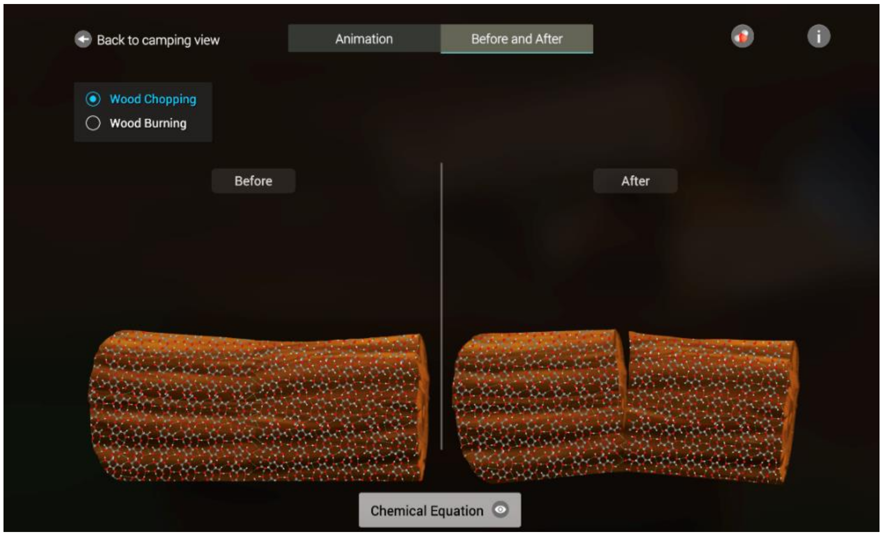
Each of the components within this lesson are engaging and encourage the curiosity of students. However, when it comes to the scientific modeling of salt water and the two types of eggs, students end up with a very basic representation of the change. This lesson could be amplified by incorporating a simulation at a molecular level to help students see physical versus chemical changes.

One website that allows students to see this is eduMedia and their Dissolution of NaCl in Water demonstration. This simulator runs a slow-motion video of the experiment, which then zooms into the particles of matter, specifically Sodium Chloride molecules and water molecules showing how they can connect when salt and water are mixed. This representation does an excellent job of showing that salt and water are only connected, rather than creating a new substance. It demonstrates how easily these two can be broken apart to their original states. By using this simulation in addition to the successful activities used previously in this lesson, students may be able to better understand and model the particles of matter within physical and chemical changes.

Activity 9: What's the Matter? (Physical and Chemical Changes)

At this point in the unit, students have had plenty of practice with identifying and explaining physical and chemical changes. During this “elaborate” activity, students will work in groups to find new examples of physical and chemical changes. Our focus for this unit has been on examples from cooking, but in this activity, students will work on finding videos of different examples (inside or outside of the kitchen). Groups will then add videos of each to the Venn Diagram while filling out similarities and differences between the examples they found. Students really enjoy finding physical and chemical changes on their own, however, they only explain the change in basic terms. Based on the goals of this unit, I would like for students to be able to represent physical and chemical changes using particles of matter in addition to the terms used throughout the unit.

To improve this activity, I found a CK-12 Foundation simulator that is a part of their Exploration Series focusing specifically on Chemical and Physical Changes in a campsite. Figure 3-4 below shows how students can click on different components of the simulator, such as a piece of wood, and choose what change they would like to happen. For example, a piece of wood can either be cut or burned. Whatever the student chooses, they can view an animation of the change occurring, or simply see a before-and-after model incorporating the particles of matter. If students want to learn further, they can use tools such as the molecule explorer or view the chemical equation. When using this simulation, I would like for students to create a model of their own on paper, or using their device, and organize a brief Claim Evidence Reasoning (CER) response for a physical change and a chemical change. They will incorporate and use evidence from their models and explain why each is an example of a physical change or a chemical change.



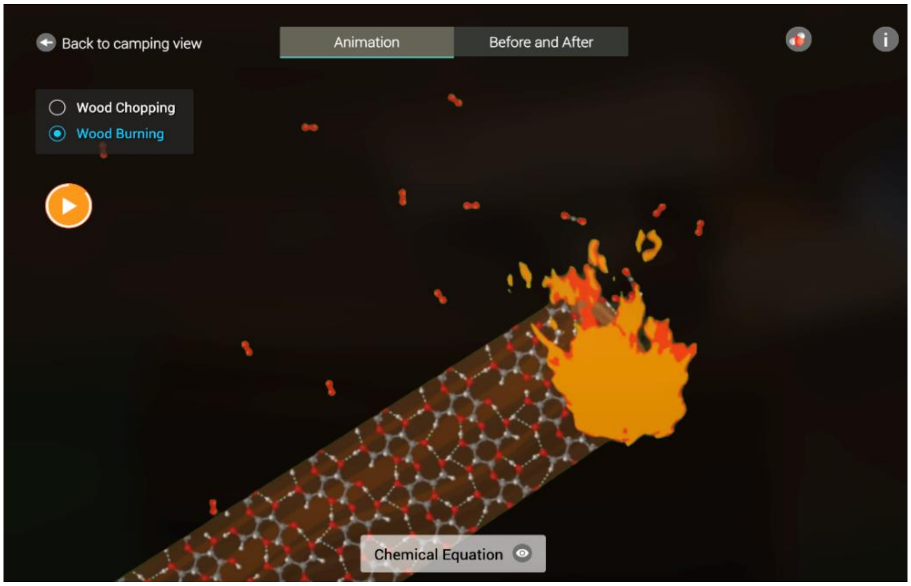


Figure 3-4. Screenshot of the CK-12 Camping Physical and Chemical Changes simulation used by students to explain examples of each type of change, looking specifically at the molecular level. Photos courtesy of author.

Website used:
https://interactives.ck12.org/simulations/chemistry/campout/app/index.html?lang=en&referrer=ck12Launcher&backUrl=https://interactives.ck12.org/simulations/chemistry.html

CHAPTER 4
METHODOLOGY

Introduction

The goals of this action research study include answering two research questions (1) In what ways can I incorporate virtual simulations and inquiry-based activities within my instruction and (2) In what ways, if any, will using virtual simulations and inquiry-based activities in my instruction improve my students' conceptual understanding? This chapter will outline the methods, tools, and data-driven strategies used to help answer these questions.

Qualitative Methodology

Qualitative research focuses on the "how" or the "why" of a phenomenon. Data collection can include interviews, observations, field notes, documents, artifacts, etc. In qualitative research, the goal is to find patterns or themes within the data. This type of research allows for flexibility in data analysis through coding methods and discussion of findings. The results of a qualitative study are not generalizable but can help answer questions about a particular phenomenon.

Study Participants

This study included 12 students, four from each of the three classes taught by the researcher. It occured in a suburban school district in the Midwest, with an enrollment of around 57.4% white and 42.6% minority students. The students switch classes every hour and have one 48-minute science class daily. Students are equipped with one-to-one devices, and the district uses Google Suites for Education. The participant selection criteria below explain how groups were chosen and the importance of this data for the study. All participants in this study were provided with the University of Florida's IRB-approved consent documents shown in Appendix D prior to conducting the study.

Participant Selection Criteria

With the goals of this study focused on improving instruction using inquiry-based activities and virtual simulations, I encapsulated the bigger picture of what was happening while the intervention is used in my classroom. Therefore, I identified specific qualifiers for students I collected data on within the study. These learner profiles are explained further based on the qualifications of a typical 5th grade student.

Average Science Students

I focused on average 5th grade science students in this study. Participants selected had grades that were A's or B's in science and demonstrated an average understanding of concepts throughout the school year. Four students per class (12 students total) were chosen to be part of this study. Data were collected on these 12 students through documents, surveys, and interviews. All participants (and parents/ guardians) completed informed consent documents before starting the study.

Research Design

The overall design of this study incorporates the transformed curriculum covering Matter and Its Interactions, the use of an intervention – combining inquiry-based activities with virtual simulations, and methodological triangulation of data sources to identify patterns or themes across data sources.

The first component considered when reviewing the curriculum was each activity's alignment with inquiry-based learning. After reviewing the literature, I found a few beneficial tools to help evaluate the lessons. The Factor solutions for Inquiry Strategies Scale (IS) was shared by Soonjana and Kaewkhong (2022) and allowed me to briefly overview activities within lessons to determine whether they included inquiry strategies or non-inquiry strategies. The second rubric was suggested by Forbes (2011) and is the Inquiry Scoring Rubric for Lesson Plans. This rubric was used prior to instruction to ensure best practices were considered in relation to inquiry-based learning. The scores from these two rubrics can be found in Appendix B.

Following my lessons, I used the Science Teacher Inquiry Rubric (STIR) created by Beerer and Bodzin (2003), to reflect upon my instruction using both inquiry-based activities and virtual simulations.

Data Collection

Data Sources

I collected five forms of data collected for this study: (1) teacher reflective journals, (2) student exit tickets, (3) Science Teacher Inquiry Rubrics (4) pre/post scientific models and reflections, and (5) interviews. Combining these different data collection methods for this study helped promote reliability using methodological triangulation.

Reflective Journal

Due to the nature of action research, it is important that I collect data in the form of a reflective journal for my study. Considering the first research question, it seems that a reflective journal would be very insightful to identify strengths, challenges, and questions I consider as I work through the new lesson format. The prompts that will be used in the reflective journal will be:

- What worked well in the lesson?
- What were the struggles students had in the activity?
- How did the use of simulations seem helpful?
- What could be improved?
- How did the activity impact their model?
- Other notes/ observations

This journal will provide a space for me to discuss some key realizations while I work through different components of the lessons. This reflective journal will be collected and organized using Google Docs as shown in Figure 4-1. By using this format, I will have easy access immediately after lessons to scribe notes to and eventually reflect upon in more detail at the end of the day.

Activity 5: Solids, Liquids, and Gasses

What worked well? Why?	What didn't work so well? Why?	What do I need to change and why?

Figure 4-1. This is a screenshot of Google Doc that will be used to take reflective notes after each lesson in the unit. Since the researcher is also the teacher, this table format will be essential for fast, efficient notes, and will be further expanded on at the end of the day.

Science Teacher Inquiry Rubric (STIR)

Beyond collecting general thoughts and questions from the lesson, I will also include an analysis of each class period using the Science Teacher Inquiry Rubric (STIR) created by Beerer and Bodzin (2003). This rubric provides a scale to measure the alignment of inquiry-based learning in the lesson, along with a measurement of student-centered vs teacher-centered education. Even though this rubric focuses on inquiry-based learning, it will also be used to investigate the authentic implementation of virtual simulations within the lesson. The addition of virtual simulations within the lessons should not hinder the use of an inquiry-based learning approach. These should connect naturally, and work to fill the gaps within the two learning formats.

Pre-post Scientific Models

In the beginning of the unit, students complete a pre-test including original models with explanations of physical and chemical changes and the law of conservation. These reflections were completed by the students at the end of the unit.

Additionally, students will be submitting three smaller assignments throughout the unit that will help to give a more comprehensive overview of the impact of inquiry-based learning in the unit. The first will be during Activity 5: Solids, Liquids, Gasses when students are expected to use what they have learned to develop models of each state of matter by showing and explaining the particles of matter that are too small to be seen. The second assessment that will be reviewed is during Activity 8: Is It a New Substance when students are writing a CER response in which they share whether a new substance has been created. Students must provide evidence using models from previous activities to discuss changes in particles of matter to fully demonstrate their knowledge.

Act. 1: Introduction to Unit

I can use prior knowledge to model the differences between physical and chemical changes.

Investigation Question: How does cooking change our food?

____

____

____

Based on your prior knowledge, create a scientific model of both types of changes below.

Physical Changes	Chemical Changes

Figure 4-2. This figure shows the set-up of the student lab notebook when introducing the unit. Students will use their prior knowledge of developing scientific models and their background knowledge of physical and chemical changes to create scientific models of each concept.

Student Exit Tickets

Another form of data collection will be the use of student exit tickets. These exit tickets will be collected through Google Forms after each activity. All students will complete the exit ticket form, but only the identified students' responses will be analyzed. The Google Form will include a Likert scale and will focus on the questions shown in Table 4-1 below.

Table 4-1. Overview of the exit ticket questions broken into common questions across activities and activity-specific questions.

	Exit Ticket Question
Across Activities	1. I learned something new in this activity. 2. The inquiry-based activity (within lab notebook) was helpful for my learning. 3. The virtual simulation (online scientific model) was helpful for my learning. 4. The whole group discussion was helpful for my learning. 5. The claim, evidence, and reasoning (CER) response was helpful for my learning.
Activity-Specific Questions	At the end of the activity, you had to make a model showing __________ (dependent on activity). 6. I understand how the activity connects with my model. 7. I can explain my model to someone else. 8. I used ideas from the virtual simulation to make my model. 9. I used examples from the inquiry-based activity (within lab notebook) to make my model. 10. I need more information to complete my model.

Interviews

It will be helpful to conduct formal interviews to gauge student understanding outside of the classroom setting. These interviews would take place at the end of the unit during my planning hour and may consist of individual conversations or small focus groups based on student availability. As previously mentioned, action research aims to improve one's teaching practice. Therefore, it is important to dire from the student's perspective to see where they struggled and what was most beneficial to them throughout the unit. This Interview protocol was established through the guidance of Castillo-Montoya (2016) using The Interview Protocol Refinement Framework. The interviews took about 10-15 minutes long and included one-on-one interviews with students from each class. Below is a list of questions that were asked during the interview:

- How do you feel you learn best? (Experiments, simulations, group work, discussions, etc.)

- What are some things you enjoy doing in your core classes?
- Why do you enjoy these activities?
- Throughout the unit, we used different activities and tools to help you learn. What was most helpful and why? (Inquiry-based activities, simulations, discussions, CER)
- At the end of the unit, you had to make a model showing physical changes and chemical changes.
    - What helped you create that model?
    - Why was that important for creating your scientific model?
- What was your favorite part about the unit? Why?
- Could any part of the unit be removed? Why?

Data Analysis

The qualitative data analysis methodology used is the four-step process created by Dana and Yendol-Hoppey (2020). This four-step model includes the following steps; description, sense-making, interpretation, and implication. The description step will help to clarify observations and initial insights. Next, I used In Vivo Coding (Saldana, 2016) for the focus group transcripts and Process Coding (Saldana, 2016) for the student documents and the reflective journal to extract overall categories. During the second cycle of coding, I used pattern coding to begin pulling out themes from the In Vivo and Process Coding results (Saldana, 2016).

Afterward, the sense-making stage allowed me to use methodological triangulation by comparing results from the pattern coding, student documents, and the reflective journal. In the interpretation stage, I used the results to begin identifying themes across data points specifically narrowing the focus to student conceptual understanding and student attitudes toward science. In the implication stage, I communicated the final themes, and next steps for my instructional practice. These pre-tests were compared to the final representations of the phenomena to reflect on student growth.

Process Coding

When reviewing classroom observations and my reflective journal, I used Process coding to focus on coding actions and interactions between myself and the students in my classroom. Saldana (2016) explains that in Process Coding, the reviewer uses one code per line and specifically uses gerunds to summarize the actions in each line (p. 111). In this study, Process Coding started with analytic memo writing and was followed by a second cycle using Pattern Coding. By using this method and learning more about the interactions between myself and students, I gained a better understanding of the change in learning over time.

In Vivo Coding

According to Saldana (2016), In Vivo Coding is one of the best coding methods for action research because it is more likely that the researcher will be able to encapsulate the real meaning behind participants' words (p. 106). With the lessons and intervention of this study being created and led by the evaluator, it is important for the researcher to see the data from an outside lens. In Vivo Coding is a reliable method for data analysis of interviews in this study. When conducting this type of coding, I identified codes within quotation marks to follow proper protocol. This proposed memos or categories directly from transcripts of interviews and observations. Following the first cycle of In Vivo coding with analytic memos, I followed up with a second cycle of Pattern Coding to help look beyond basic themes and potentially find “dimensions of categories” as discussed by Salanda (2016, p. 108).

Pattern Coding

To further analyze the results from Process and In Vivo Coding, I used Pattern Coding for my second cycle coding method. Pattern Coding takes the memos or categories identified in the first cycle of coding and pulls out larger themes for a final explanation (Saldana, 2016, p. 238). When using Pattern Coding, I followed the recommendations by Gibson and Brown (2009) and use “super coding” through a Computer Assisted Qualitative Data Analysis (CAQDAS) program. This approach helped me search for these bigger relationships within each data set. Once these themes were identified, I moved forward with a final analysis of the coded reflective journal, interviews, and classroom observations.

Establishing Trustworthiness

Rigor

In this study, multiple methods were used to ensure rigor in the research. This was completed by using “big-tent” criteria discussed by Sarah Tracy (2010) to guide my study. First, incorporated a worthy topic. This study was relevant because at the time our district was currently working without a set curriculum and was not up for renewal for a few years. Therefore, finding ways to enhance student conceptual understanding was key to improving my instructional practices, and eventually could influence other teachers in my district.

Another way I will established rigor wasthrough credibility. To establish credibility, the research will be conducted through methodological triangulation of data sources. With my understanding of the content, school climate, and timeline I can focus on the use of the intervention and determine impacts as they come to life.

The final objective for promoting rigor in this study is to include resonance in my research. Even though this is a case study and focuses primarily on fifth-grade science classes, I believe the results of this study could be beneficial to most science educators that are using the Next Generation Science Standards and hope to find tools to enhance their instruction. Currently, there is a gap in the research when looking at elementary science education and combining these instructional methods. This could help push future research by identifying the benefits of conceptual understanding and provide a glimpse into student perceptions of the intervention.

Delimitations

As previously mentioned, there are multiple units in need of improvement when addressing large and small-scale systems in my science classes. To keep the study on track, I will only focus on one unit, Matter and its Interactions, for my research. This will be difficult to maintain as I move on to other units throughout the school year, but it is important to keep the study within my timeline.

Limitations

There are some limitations to this study. First, students may not have been open to sharing their opinions about the class during the interviews, as I was the teacher for the course. Participants used for artifact collection might be absent for certain lessons or might move during the unit. Each class was run a bit differently due to the diverse student population and will was accounted for when reviewing and analyzing the data. Finally, with different events happening throughout the school year, the timing in this study was not perfectly aligned. Students that are part of focus groups or that are being used for document collection might be absent for certain lessons or might move during the unit.

Ethical Considerations

Reflexivity

First, I used reflexivity to be transparent about my connections, interpretations, and potential biases of the research in this study. In educational research, there is no way of completely separating yourself from the study. Therefore, I appropriately positioned myself in my study (Creswell & Poth, 2018) by explaining my experiences and how they might influence my interpretation of the data, while also collecting reflective notes, I will be able to be straightforward with my analysis.

Procedural Ethics

Since this study collects data from a public elementary school, it is important to align the research with procedural ethics for the safety and privacy of all participants. Before conducting this study, I was approved by the University of Florida's Institutional Review Board (IRB) and the superintendent of curriculum in my school district to conduct the study and guarantee I followed the expected protocols and procedures required by the university, and district. I worked with minors in this study ; therefore, I recieved informed consent documents from both the students and their parents or guardians before starting my study.

Relational Ethics

This case study takes place in the school that is my current employer, which means it is of utmost importance that I consider relationships with colleagues and students throughout this study. Sarah Tracy (2010) explains that relational ethics should recognize the connection between the researcher and the participants. By including member reflections in the study, I will be able to view the data from all angles and perspectives which will help balance the study.

Subjectivity Statement

My background as a science educator has a strong influence over my bias towards the subject of finding best practices in science education. In this study, I analyzed multiple instructional methods including the use of inquiry-based activities and virtual simulations in an elementary science setting. Throughout this research, I studied my teaching practice. The research I complete for this study is something that would potentially impact my personal instruction, my colleagues' teaching, and even my overall district's decisions on curriculum. With that in mind, I need to be conscious of how I address my research and others within my work setting as I complete this study.

Another aspect of my study that will have an impact on my research is that I will be using my students as participants. This can be challenging as I must ensure that students are all receiving the same instructional approaches and have equitable opportunities throughout the study. Therefore, I will be using the combined methods of instruction with all my students, no matter if they are participating in the study. Students who were in the study were chosen based on particular criteria established prior to the start of the study. These students will know they were chosen when they are asked to participate in interviews at the completion of the school year.

Throughout my teaching career, I have worked with a diverse group of students both from an urban and suburban setting. My passion for finding equitable learning opportunities for all students drives my motivation to identify the best teaching practices. As a white female working with a diverse population of fifth grade students, I must be mindful of how the strategies, programs, and teaching practices might influence student conceptual understanding in different ways based on their backgrounds. I will also need to be aware of the various learning styles and levels of students in my classes as I move forward with this research.

With each of these aspects in mind, I must tread carefully while continuing with this study. Not only does this research topic impact my teaching currently, but it will also influence how my department moves forward with instruction. As I learn more about combining inquiry-based activities and virtual simulations while teaching physical and chemical changes, I will share what I have learned with those in my district but work hard not to push any agenda for curriculum in our building. Finally, I hope to use what I learn to promote a beneficial learning experience for students.

Table 4-2. The data collection table below highlights the different data collection methods, the amount of time each will take, and details and descriptions for each method.

Data Collection Method	Timing	Details
Documents	March - April 2023 Duration: 5 weeks	Pre/ post scientific models Screenshots of virtual simulations to compare with models Student models and responses following each activity.
Exit Tickets	March – April 2023 Following each activity: Activity 5 Activity 7 Activity 8 Activity 9	Following each activity in the study, students will complete an exit ticket through Google Forms. Students will be answering questions about the activity using a Likert scale. This will be used to determine next steps for instruction.
Interviews	March - April 2023 At the end of the unit	The interview for this study will be conducted with students in my science classes. By using informal conversational interviews, I believe that I will get more information about the feelings and beliefs surrounding the use of the intervention. In addition, this will allow students to participate in an open-ended conversation with questions tied to the research questions.
Reflective Journal	March - April 2023 Duration: 9 weeks	I will record daily notes surrounding the instruction across the three class periods. Then, at the end of the week, I will combine the notes in a reflective summary based on using the intervention, student conceptual understanding, my instructional findings, and student perceptions.
Science Teacher Inquiry Rubric (STIR)	March - April 2023 Following each activity: Activity 5 Activity 7 Activity 8 Activity 9	The STIR will be used after each activity from the study to review alignment with inquiry-based practices and student engagement.

CHAPTER 5
FINDINGS

The purpose of this study was to find ways to incorporate both inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding and answer the following research questions:

1. In what ways do I adjust my teaching with inquiry-based activities and simulations to facilitate student learning of physical and chemical changes?
2. In what ways, if any, will using virtual simulations and inquiry-based activities improve students' conceptual understanding of physical and chemical changes?

Research Question 1 – Teaching Adjustments

Coding Cycles

The first coding cycle focused on the initial research question and was done through MAXQDA (2022), looking specifically at the reflective journal, STIR, and student interview questions. These data were analyzed through descriptive coding following strategies from Saldana (2016). Table 5-1 outlines the codebook for research question #1, explaining each code used and the frequency of the codes from the first coding cycle.

During the second coding cycle, I followed the pattern coding method from Saldana (2016). Due to the seamless connections and codes across data points, I was able to identify themes that help answer the research question (See Table 5-2).

Themes

Theme 1: Integrating virtual simulations and inquiry-based learning led to student learning across activities, but there are components I need to adjust because students still struggle with certain concepts.

The first identified theme clarifies the impact of implementing combined instruction methods on student learning. The intervention was positively discussed in the reflective journal and in student interviews. Additionally, there were shifts in the Science Teacher Inquiry Rubric as lessons moved from teacher-centered to learner-centered activities.

Changes to Instruction

An important aspect that arose regarding student comprehension was the fact that by adjusting my teaching, and incorporating inquiry-based activities and virtual simulations, I was able to slow down, force students to dig deeper, and cultivate their learning rather than just providing them with the answers. These changes to my instruction led to big moments in student comprehension, clarification, and overall learning. One of the most apparent changes that led to significant growth was the overhaul of Activity 9: Physical vs Chemical Changes. From a strictly data-driven standpoint, the growth in the activity according to the STIR rubric was immense. Before the intervention, the activity was slightly student-driven, but not necessarily inquiry-based and scored an average of a 0.5 on the rubric. Following the intervention, the activity jumped up to an average score of 3.2 on the rubric due to the increase in opportunities for learners to formulate, evaluate, and justify conclusions about an activity.

When looking at this activity through the reflective journal, it was apparent that the changes from the intervention helped identify student strengths and areas for growth as they completed the formative assessment. Previously, students would work with groups to find examples of physical and chemical changes and place them in a Venn

Diagram. Now, students use that to build more evidence prior to completing the formative assessment. Students had to demonstrate their knowledge of the two types of changes by using a simulator that included a variety of each type of change. They had to model and explain the change from the campsite simulator, but then also needed to explain the change through a molecular model. This was a huge jump in student understanding as they needed to understand what happens to different molecules during a physical and chemical change.

In my reflective journal I noted, “This was a great tool for student self-assessment, but also helped me identify glaring issues in student comprehension” (Reflective Journal, Entry #4, 4/12/23). Without this additional component of the activity, I would not have identified this challenge students faced, “One example from the simulation tripped up a significant number of students in 6th hour. About 8-10 students thought that filtering water was a chemical change. This was eye-opening because they thought that the filter was creating a new substance once the water went through it” (Reflective Journal, Entry #4, 4/12/23). This example redirected my instruction and allowed me to reconnect with students before moving forward in the curriculum. We were able to have whole-class discussions about this type of change, and students who struggled with this concept saw the example in a new light.

Changes in Student Learning

First and foremost, it was apparent that the changes in my teaching methods led to immediate observations of student growth and learning when compared to the previous curriculum. When students were presented with a problem, like turning an ice cube into a liquid and gas, in Activity 5, they had to demonstrate critical thinking skills as they worked together to develop a solution. In the reflection for Activity 5, I wrote that students were “creative and showed a better understanding when they came up with ideas themselves” (Reflective Journal, Entry #1, 3/15/23) as opposed to me providing definitions, descriptions and examples of solids, liquids, and gasses for students in a lecture-style format. One example of students developing a better understanding was when a group used their knowledge from the virtual simulation to come up with a plan to change the state of matter of the ice cube. In the reflective journal, I wrote,

> “Before starting the activity, one group of students reflected on their knowledge from the States of Matter virtual simulation and shared what they remembered about phase changes. Group members recalled that to change states of matter, they had to increase the temperature of the ice cube to get the water molecules moving faster” (Reflective Journal, Entry #1, 3/15/23).

In comparison with the previous version of this activity, students had enhanced opportunities for higher-level thinking through collaboration compared to the prior lecture-based format. Students were able to build their background knowledge from the simulator explaining the process through Flipgrid™ and then use what they learned to come up with an evidence-based strategy for changing the state of matter of the ice cube.

A major component of the Science Teacher Inquiry Rubric is the opportunity for students to formulate, support, justify, and communicate their conclusions from an inquiry-based experience. The ability to make conclusions is a higher-level thinking skill that students need to develop as they experience different phenomena. By incorporating the inquiry-based activity in Activity 5: Solids, Liquids and Gasses, students had the opportunity to not only hypothesize, but also test out methods and collect data when changing the ice cube from a solid, to liquid and gas. At the end of the activity students were able to come up with conclusions based on their findings.

An example of this was when students started Activity 5: Solids, Liquids, and Gasses by making a prediction about the investigation question that asked, “What happens to matter particles when you change states from solid to liquid to gas?” Once students made the predictions, they tested their theories using the States of Matter Simulation and collected observations using the simulator. Students then created Flipgrid™ videos explaining what they were observing using the simulation, discussing the changes between states of matter. Student videos and notebooks show that this was the point in which students began to realize that they needed to add heat to a solid to turn it into a liquid or, eventually, a gas. During the following inquiry-based activity, they discussed what they had learned through the simulation with their group members and found that they had observed similar traits when changing states of matter. Many students used this knowledge to come up with a plan for changing their solid ice cube into a liquid and then into a gas. In their lab notebook, one student shared,

> “Our group decided to add heat to the ice cube to melt it. We remembered from the simulation that when the ice was heated, the water molecules spread out and moved faster, making it a gas. We added heat by putting the ice cube under a lamp and melted it. Then once it melted, and put it over a fire, and it quickly evaporated” (Student Document, 3/15/23)

This shows the interwoven connections students made when using the States of Matter simulation and the inquiry-based activity to learn more about phase changes and their real-world applications.

Similarly, students were able to draw conclusions in Activity 7: Changing Matter, with support from the front-loading simulation as students manipulated chemical changes on the Gizmos simulation. Figure 5-1 shows an example of a chemical change on Gizmos, which helped them pinpoint identifiers to decipher between physical and chemical changes.

In the past, I had provided students with the vocabulary terms, examples, and non-examples, but the growth truly happened when students were able to find these patterns with the simulation and inquiry-based activity and share their findings with one another. This allowed them to form conclusions by distinguishing between physical and chemical changes at the end of the activity.

The idea of using evidence and experience to support findings carried on into Activity 8, when students had to complete a Claim, Evidence, Reasoning (CER) response. This additional CER response required students to use their observations and other evidence to complete a written response, which was not previously part of the curriculum. Figure 5-2 shows a student example of the CER response.

This student successfully used their observations from the inquiry-based activity to provide explicit evidence for the physical and chemical changes. Following their use of evidence, the student pulled from other activities in the notebook in which they defined physical and chemical changes and used that to support their answer in the reasoning portion. Additionally, when reviewing the chemical change example, the student referenced some examples of chemical reactions they saw when using the Gizmos simulation in their lab notebooks. Students needed the inquiry-based activity for experience but additionally needed the simulation to help build background knowledge to ultimately establish strong claims and back them up with evidence and reasoning.

The incorporation of virtual simulations played a significant role in enhancing student learning. Simulations also brought more opportunities for students to learn in a classroom setting. In Activity 7: Changing Matter, I shared that the “Gizmos simulator was an important experience for students to define a chemical property and a chemical change” and “most students were able to find 5-6 examples with the simulator” (Reflective Journal, Entry #2, 4/3/23). This would have been previously impossible based on time and resource limitations in my classroom. Prior to using the simulator, students were provided with the definition and examples of chemical properties and chemical changes without any exploration or ability to determine characteristics through experience.

Students have always enjoyed the inquiry-based component of Activity 8: Is it a New Substance, but with the addition of the virtual simulation, students were able to look closer at the dissolution of NaCl in water. The addition of this simulation also led to immediate changes in understanding; as I mentioned, “It seemed that in all three classes, this is where the “lightbulb” moments happened as they saw the direct connection between the previous activity, the current demonstration, and the simulation” (Reflective Journal, Entry #3, 4/10/23). With this phenomenal visual example in mind, I noted that “it would be helpful if students could explore other types of physical or chemical changes in the same format so they could identify patterns at the molecular level” (Reflective Journal, Entry #3, 4/10/23).

The use of simulations in addition to the inquiry-based activities forced me to slow down my instruction. I wrote about this after Activity 9: What’s the Matter? (Physical and Chemical Changes), “instead of moving onto the next activity as I would in the past, I incorporated a simulation where students had to use examples from the simulation to explain one physical and one chemical change on a basic and molecular level" (Reflective Journal, Entry #4, 4/12/23). This was a significant impact of my teaching adjustments, as students were able to use the simulation to demonstrate their understanding, which had never been part of the curriculum previously.

The formative assessment in Activity 9: What's the Matter? (Physical and Chemical Changes) allowed students to share their knowledge as students had to come up with independent conclusions about physical and chemical changes using the camping simulation and the modeling activity. The simulation offered students a chance to represent the two types of changes at a molecular level, while the experiences in the classroom helped provide evidence for students to make conclusions about each type of change. This was evident in their models. During my reflection of this new formative assessment, I stated, "this was a great tool for student self-assessment, but also helped me identify glaring issues in student comprehension" (Reflective Journal, Entry #4, 4/12/23).

Challenges with the Intervention

Within each activity, challenges surfaced in different ways. Some challenges were due to flaws in the inquiry-based activity or resources, while others were difficulties with simulations or timing of lessons. In Activity 5: Solids, Liquids and Gasses, certain groups of students struggled more with the inquiry-based activity as they worked together to turn the ice cube into a liquid and then a gas. In the journal, I shared, "some groups were unable to compromise" and "other groups just copied their peers" (Reflective Journal, Entry #1, 3/15/23). These observations were very clear from the beginning of the activity and reflect students' abilities to collaborate with one another. This made it difficult to analyze how certain groups responded to the intervention as they had difficulty with group work, not necessarily the content. These are ideas that are important to consider when planning any activity in the classroom. However, when looking at the inquiry-based activity itself, there were a couple of challenges with materials to consider.

One of these challenges was shared, “students seemed to struggle more with strategies on how to change the ice cube from a liquid to a gas with limited resources” (Reflective Journal, Entry #1, 3/15/23). When writing this, I noticed how quickly students were able to change the solid ice cube into a liquid. More problem-solving was required to turn the liquid into a gas due to a need for higher temperatures. I considered changing my approach in the future by providing additional tools or lab materials for students to use, but I realized then that “I do not want to give suggestions” (Reflective Journal, Entry #1, 3/15/23) as it starts leaning towards a teacher-centered inquiry approach.

During the planning stages of my unit, I struggled with finding the best placement and timing to incorporate virtual simulations in my instruction. When thinking about prior studies, it seemed important to use virtual simulations at the right time to support inquiry-based activities, but sometimes it could be used for frontloading, and other times it might be used for additional experiences. Even after implementing the intervention, I was wavering on the timing of simulations in my teaching. An eduMedia simulation demonstration was used in Activity 8: Is it a New Substance? to show the dissolution of NaCl in water. This ties in well with the initial activity as students make predictions about a pot of boiling salt water and use their observations to explain why mixing salt and water is a physical change. The issue with this was that in Activity 7: Changing Matter, students mixed salt and water to determine the type of change. This type of change has always been challenging for students because they cannot see what is happening. In the journal I shared, “I am almost wondering if it would be helpful to incorporate the eduMedia Dissolution of NaCl in Water simulation/ demonstration in Activity 7: Changing Matter so students can see the change right away” (Reflective Journal, Entry #2, 4/3/23). This note from the reflective journal shows how I was struggling with the timing of different components in the intervention. I knew that this simulation would provide students with an important visual to eliminate any misconceptions, however, this would then give away answers for the following activity. This continues to bring up questions about the timing and planning of lessons in the overall unit.

Another significant challenge was the limitation of the simulations provided within this unit. In Activity 7: Changing Matter, “students were limited to 5 minutes of exploration with the website” (Reflective Journal, Entry #2, 4/3/23) because it was on a free trial. During this entry, I was able to reflect on student responses to the simulation. I saw the initial excitement, engagement, and learning occuring, however, when the time limit was up, students were immediately frustrated and wanted to continue using the program. This was bound to be a struggle when testing new simulations; however, it was surprising to me to see how much of an impact it had on student learning. The students were clearly disappointed that they could not have more time trying different types of chemical changes and different types of chemical changes, and they wanted more time to share observations with their group members. The simulation used in Activity 9: What's the Matter? (Physical and Chemical Changes) was another free version but allowed students to see physical and chemical changes at a molecular level. But, with limited options, the simulation might have been too advanced for some students. For example, "some students said that certain aspects were difficult to model because drawing parts from the camping simulation were challenging (specifically when chemical changes occurred)" (Reflective Journal, Entry #4, 4/12/23).

Ultimately, I was able to adjust future lessons based on some of the notes written in the reflective journal. I used the challenges as whole-class discussion points, to allow students to learn from one another. One example of this was when students were melting the ice cube in Activity 5, and some students ended up "melting the Ziplock bag because they put it too close to the direct heat source. This led to inaccurate results as the bag had holes in it" (Reflective Journal, Entry #1, 3/15/23). This was a beneficial conversation as students were able to determine what improvements could be made to the experiment and were able to identify the impact of human error.

Another example of this was at the end of Activity 9: What's the Matter? (Physical and Chemical Changes), when students were required to complete an assessment modeling physical and chemical changes at a basic and molecular level. I noted that, "one example from the simulation tripped up a significant amount of students in one class period. About 8-10 students thought that filtering water was a chemical change" (Reflective Journal, Entry #4, 4/12/23). This was an extremely important discussion in the class period that had the most difficulty, as we worked together in groups explaining how it is a physical change and then came together with the whole class to share ideas.

The conversation continued in the other two class periods, but students took it upon themselves to prove to me why it was not a chemical change based on everything they had learned.

Overall, the data provided from the reflective journal, student interviews, and STIR rubric show that the combination of inquiry-based activities and virtual simulations led to student learning. As with most interventions, there are still areas for improvement and different needs that should be addressed based on the groups of students and the resources available for instruction. With this evidence, I am confident that I can continue to refine my instruction to best fit the needs of my students and continue to enhance student learning.

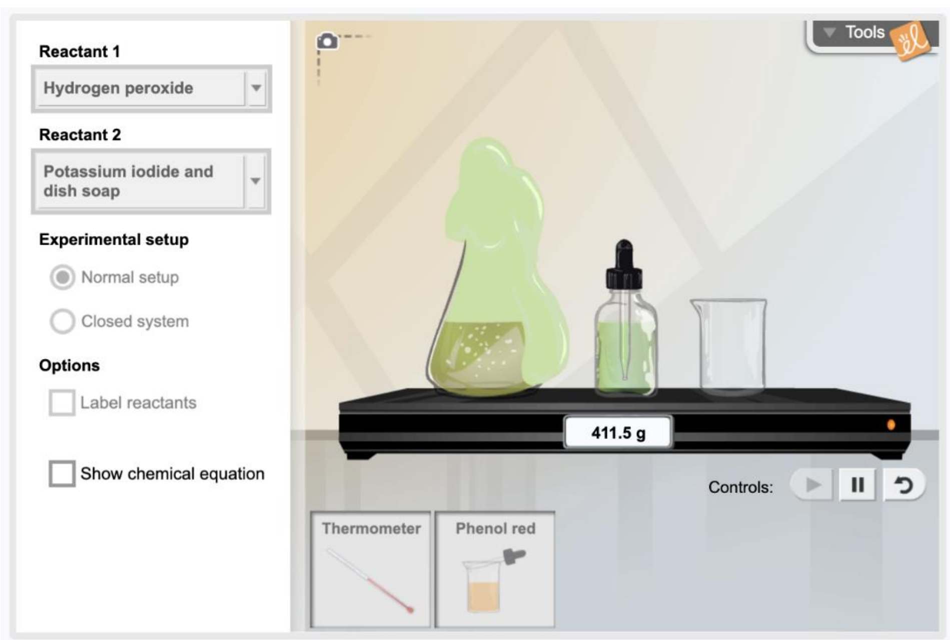
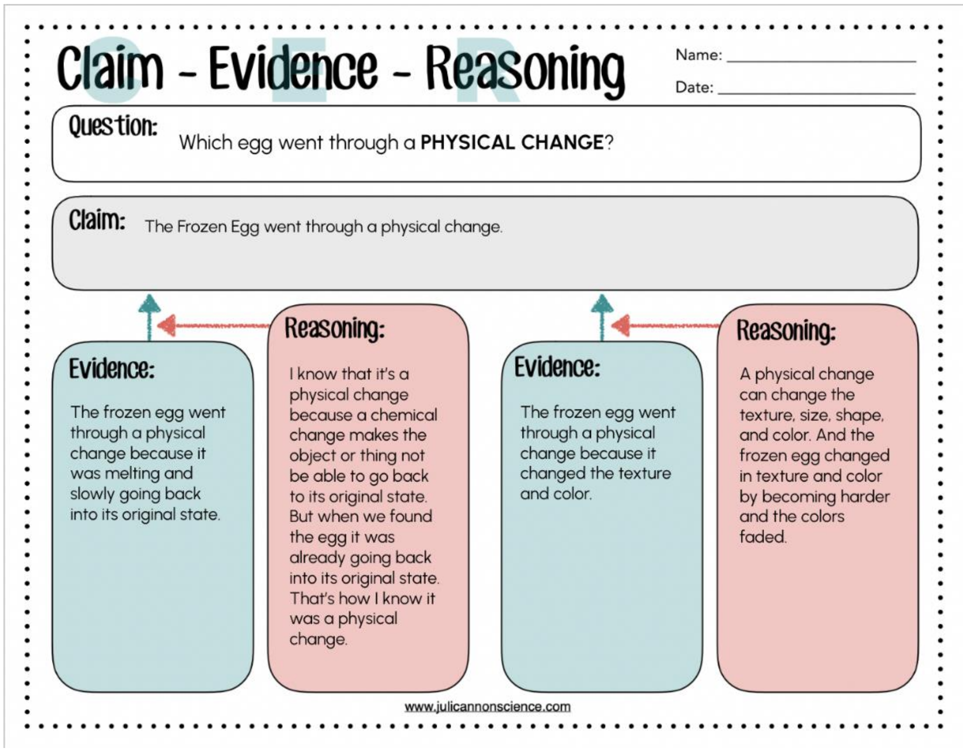


Figure 5-1. Screenshot of a chemical reaction observed by students while using the Gizmos simulator in Activity 8: Is it a New Substance? Photo courtesy of author.



Claim - Evidence - Reasoning

Name: ____________________

Date: ____________________

Question: Which egg went through a **PHYSICAL CHANGE**?

Claim: The Frozen Egg went through a physical change.

Evidence: The frozen egg went through a physical change because it was melting and slowly going back into its original state.

Reasoning: I know that it's a physical change because a chemical change makes the object or thing not be able to go back to its original state. But when we found the egg it was already going back into its original state. That's how I know it was a physical change.

Evidence: The frozen egg went through a physical change because it changed the texture and color.

Reasoning: A physical change can change the texture, size, shape, and color. And the frozen egg changed in texture and color by becoming harder and the colors faded.

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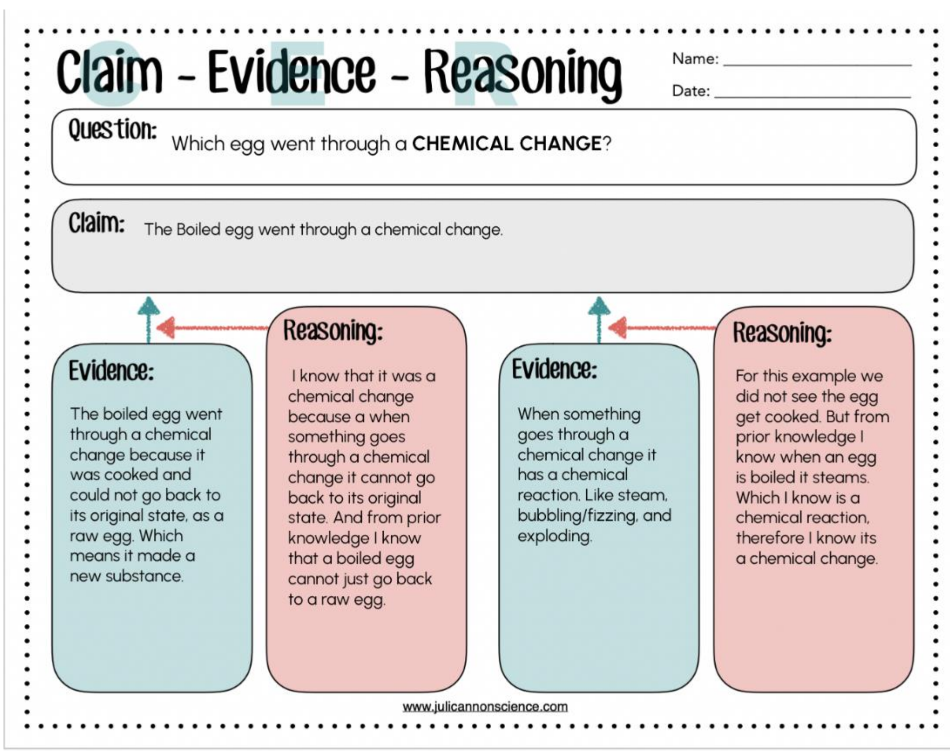

Claim - Evidence - Reasoning

Name: ____________________

Date: ____________________

Question: Which egg went through a **CHEMICAL CHANGE**?

Claim: The Boiled egg went through a chemical change.

Evidence: The boiled egg went through a chemical change because it was cooked and could not go back to its original state, as a raw egg. Which means it made a new substance.

Reasoning: I know that it was a chemical change because a when something goes through a chemical change it cannot go back to its original state. And from prior knowledge I know that a boiled egg cannot just go back to a raw egg.

Evidence: When something goes through a chemical change it has a chemical reaction. Like steam, bubbling/fizzing, and exploding.

Reasoning: For this example we did not see the egg get cooked. But from prior knowledge I know when an egg is boiled it steams. Which I know is a chemical reaction, therefore I know its a chemical change.

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Figure 5-2. Student documents of the CER response from Activity 8: Is it a New Substance determining which egg went through a physical or chemical change. Photo courtesy of author.

Theme 2: Lessons that incorporated student-centered instruction including choice and collaboration were preferred by students.

Students gravitated towards activities where they oversaw their learning. They preferred student-centered activities that incorporated options and collaboration. It is important to highlight the overall shift from teacher-centered instruction to student-centered instruction with the implementation of the intervention. There were large changes in scoring before and after the intervention. Table 5-2 reviews the scoring criteria on the STIR, and the following table includes data from before and after the implementation of the intervention.

Activity 5: Solids, Liquids and Gasses

Prior to the intervention, students had fewer opportunities to take charge of their learning. In Activity 5: Solids, Liquids and Gasses, students were provided with the three states of matter, examples, and observations for each. Meanwhile, after implementation, students were able to make predictions, test hypotheses, collect data and draw conclusions from the inquiry-based activity and states of matter virtual simulation. By providing these opportunities, students were able to develop their understanding through experience and creative problem-solving rather than using a teacher-centered approach. The reflective journal summarizes these thoughts, “it worked well to have all three classes come up with methods for melting and evaporating the liquid. Students came up with creative strategies based on what they saw in the simulation to change the state of matter of the ice cube” (Reflective Journal, Entry #1, 3/15/23). During student interviews, one student shared those experiments such as

Activity 5: Solids, Liquids and Gasses were helpful, “because then you get to actually do the things and experience it and if you are wrong you get to learn why” (Student Interview #4, 6/6/23). When students are provided with the opportunity to to learn through hands-on experiences, trial and error, and collaboration, they can make stronger connections and develop scientific models from these experiences.

Activity 7: Changing Matter

The following activity, Changing Matter, had a smaller amount of growth due to the lack of experimental practice students had prior to the activity. This unit was the first time students were able to use experiments to guide their instruction. Therefore, this activity was a bit more guided and required protocols and procedures, keeping it in a neutral category. In the beginning, I demonstrated how to complete the procedures for mixing salt and water and then mixing food coloring and water. However, following the first part, students completed the second two experiments with their group members. In the future, I would like to provide more opportunities throughout the school year to build student experience when it comes to experiments and handling lab equipment to prepare them for this unit. Even with the gradual release of guidance, multiple students shared that this was the activity that helped build their understanding the most, as they could see physical and chemical changes first-hand. During student interviews, one participant shared, “In Activity 7: Changing Matter, I really like reactions and explaining how it happens and actually seeing how it happens” (Student Interview #1, 6/6/23). Another student shared that the activity that was most helpful for their learning was Activity 7: Changing Matter because “then you can identify physical and chemical changes by actually seeing them in person instead of watching a video or looking at pictures” (Student Interview #5, 6/6/23).

When students began using the Gizmos simulation of chemical changes, I noticed right away that “there was a lot of excitement and sharing across group members to show what type of reaction they created, whether it was an explosion, fire, fizzing, etc.” (Reflective Journal, Entry #2, 4/3/23). This led students to have more collaborative conversations while they used the virtual simulation individually on their computers.

Activity 9: What’s the Matter?

Students seemed to genuinely enjoy the opportunity to learn from their peers. An example of this was in Activity 9: What’s the Matter? (Physical and Chemical Changes). The reflective journal states,

> ” Students enjoyed working with their groups and many benefited from sharing ideas and getting feedback from their peers when completing their group assignment. This helped them clarify any lingering confusion about physical and chemical changes and provided them with an alternative explanation from their peers for support” (Reflective Journal, Entry #4, 4/12/23).

Similarly, during the student interviews, one student shared why they learn best through group work, “because when we are working with a group you can see what other people's ideas are and if you don’t understand it then it can lead you in the right direction” (Student Interview #2, 6/6/23). Students truly enjoy having these conversations and learning from one another, and science naturally allows students to collaborate through interactive discussions and lab work.

Challenges

Other times students were too dependent on their classmates when completing an inquiry-based activity. In Activity 8: Is it a New Substance?, I shared, "some group members were overly reliant on their partners and did not understand what they were observing in the lab" (Reflective Journal, Entry #3, 4/10/23). This tends to happen if students are lacking some type of understanding and is important for me to consider as I move forward with instruction. These observations following the implementation of inquiry-based activities and virtual simulations encouraged me to adjust my teaching in the moment, or in future lessons.

After collecting and analyzing the information provided by the three data sources, I can see that I need to use a more guided-inquiry approach to begin the school year, but eventually allow students more opportunities to have a say in their learning. By combining student-centered instruction and time for collaboration, students will be more engaged and invested in their learning.

Final Student Perceptions

Some of the highlights of student preference comes from student responses to interview questions at the end of the unit. Of the 12 student interviews, 8 students shared that their favorite activities involved student choice and exploration with their groups. One student shared more about their favorite activity,

> "The final project because you get to actually make it and see how you did and what you have learned and it allowed you to choose your own because you have options, and I could think about examples - you could think of a recipe that had lots of examples" (Student Interview #8, 6/6/23)

Another had similar thoughts, “doing the cooking project because it is something you can do at home, and you can choose what you wanted to cook and observe the physical and chemical changes” (Student Interview #2, 6/6/23). A final student shared an emphasis on the collaborative component of the project, “the cooking experiment was my favorite because we got to share it with other people” (Student Interview #7, 6/6/23). This shows that students not only enjoyed this format of activity but preferred it to other types of instruction throughout the unit. Based on these results, the most popular activity was the final assessment, Activity 12: Cooking with Experimental Design, where students had to develop a cooking experiment to demonstrate physical and chemical changes using a recipe of their choice. When students have a voice in their learning, they are more engaged and excited to share their knowledge with others.

Theme #3: Students felt their learning was most impacted using inquiry-based activities when learning about physical and chemical changes.

After reviewing the student interviews and surveys, clear patterns arose regarding the impact of inquiry-based activities on conceptual understanding. When students reflected on their learning, they felt strongly that they learned the most from the inquiry-based activities and it was reflected in their responses and overall confidence in the subject matter as highlighted in the exit tickets at the end of each activity.

Inquiry-Based Learning was Helpful

When looking at Table 5-5, it shows that inquiry-based learning and experiments had 21 codes within that category. Most of the In Vivo codes included phrases about the importance of experiments in student learning. Some commonalities within this category include ideas about how the experiments allowed them to see and experience things. The data from student interviews shows that 10 out of 12 students (83.3%) shared that the experiments (inquiry-based activities) were most helpful in their learning. One student shared, “Inquiry-based activities were the most helpful because you could see the steps and how they work and then you can see what is left behind” (Student Interview #1, 6/6/23). Another student explained, “Chemical changes and physical changes on the table (were helpful because) we could see how it happens and then the discussions afterwards about why it happens. Because you could see the warm water mixing with borax which is a physical change and then adding the glue and turning into slime” (Student Interview #10, 6/6/23). Although the number of student interviews was small compared to the overall population of students, the idea resonated in student surveys following each activity.

The data from student surveys showed a similar pattern regarding the experiments included in the intervention, as shown in Table 5-5. In Activity 5: Solids, Liquids and Gasses, 80% of students strongly agreed or agreed that the ice-cube lab was helpful for their learning about solids, liquids, and gasses. Similarly in Activity 7: Changing Matter, 89.1% of students strongly agreed or agreed that the mixing substances experiment was helpful for their learning about physical and chemical changes. In Activity 8: Is it a New Substance, 63.7% of students strongly agreed or agreed that the demonstration was helpful for their learning about physical and chemical changes. I am curious if these numbers would’ve changed if students were evaluating the overall activity as they investigated the two types of eggs and determined which went through a physical or chemical change. Although student perceptions of learning do not equate to their actual understanding, student assignments, assessments, and the teacher reflective journal all align with the thoughts that the inquiry-based activities supported student learning. Students were able to use evidence from these activities in multiple ways to explain physical and chemical changes.

Inquiry-Based Learning Supports Demonstrating Understanding in Creative Ways

Additionally, the use of inquiry-based activities allowed students to demonstrate their understanding in a creative way. In the reflective journal from Activity 5: Solids, Liquids and Gasses, I shared, “This class was very creative even with limited resources. They were thoughtful in their ability to turn the liquid into a gas” (Reflective Journal, Entry #1, 3/15/23). This carried over into Activity 7: Changing Matter, as I stated, “Students seemed to enjoy this guided inquiry approach to learning about physical and chemical changes. They were able to easily follow procedures and collect observations before, during and after the mixture of substances” (Reflective Journal, Entry #2, 4/3/23). When students are excited about the activity or experiment, they are completing in class, they will have higher engagement and understanding than they would from other instructional formats. The true test of student understanding in Activity 7: Changing Matter came when students had to distinguish between physical and chemical changes. The reflective journal states, “This went well as students were able to work through their understanding with collaborative conversations” (Reflective Journal, Entry #2, 4/3/23).

Perceptions of Student Learning

At the end of the student survey for each activity, students answered a question regarding their overall learning from that activity. This was an excellent self-reflection for students, but also helped me determine whether to move forward with the curriculum or if I needed to go back and review different concepts from previous activities. In Activity 5: Solids, Liquids, and Gasses, 70% of students strongly agreed or agreed that they learned something new in the activity. In Activity 7: Changing Matter, 78.5% of students strongly agreed or agreed that they learned something new in the activity. Similarly, 84.9% of students strongly agreed or agreed that they learned something new in Activity 8: Is it a New Substance. Finally, in Activity 9: What's the Matter, 78.1% of students strongly agreed or agreed that they learned something new from the activity. It seems that students felt that the activities from the intervention all impacted their learning, with all activities holding scores of 70% or higher for new learning. In addition to data from exit tickets, student interviews helped solidify this theory. Out of the 12 interviews conducted, 10 students shared sentiments about how specific activities from the intervention impacted their learning. Some students mentioned specific activities, such as Act. 5: Solids, Liquids and Gasses when a student shared, "working on the device and seeing the different molecules (H_20) (was helpful) because then I knew how to model it throughout the simulation" (Student Interview #5, 6/6/23). Another student discussed how the simulations from the intervention were beneficial, "Simulations (helped) because they stimulated what we couldn't do on the table like watching water evaporate and seeing the water molecules traveling up because physically you cannot see things with your eyes" (Student Interview #10, 6/6/23).

Student Confidence

In addition to increased student learning, students also felt more confident in their overall understanding of the content following the activities from the intervention. This was reflected through student interviews. Students brought up the importance of inquiry-based activities for their learning as they shared that experiments have many advantages. For example, one student shared, “experiments are helpful to see it happening and how it works” (Student Interview #3, 6/6/23) and another student mentioned that “hands-on activities help me understand very clearly” (Student Interview #5, 6/6/23). Another example of this was when students discussed their increased confidence from inquiry-based activities because they “get to do things and experience it” (Student Interview #4, 6/6/23) but also “identify changes by seeing them in person” (Student Interview #4, 6/6/23).

Research Question 2 – Conceptual Understanding

Coding Cycles

When reviewing the data sources for the second research question, I continued my use of MAXQDA (2022) and descriptive coding for the student surveys, documents and reflective journal. Meanwhile, the interviews were coded using In Vivo Coding. Table 5-6 outlines the codebook for research question #2 and summarizes the code names, examples, and frequencies of the codes across the different data points.

Themes

For the second coding cycle of the summative cross-case analysis, I used pattern coding to identify major themes across the codes identified in the first coding cycle. This led to further discussion and analysis of the impact of virtual simulations and inquiry-based activities on students’ conceptual understanding. In Table 5-8, the themes are summarized alongside the aligning codes.

Theme #1: Students demonstrated new conceptual understanding of physical and chemical changes using inquiry-based activities and virtual simulations.

The final overarching theme from the data reviewed focuses on student learning of physical and chemical changes through combined methods of instruction. This theme was apparent across student exit tickets, the teacher reflective journal, and student documents.

In the beginning of the unit, students completed a pre-assessment where they were required to model or explain physical and chemical changes to the best of their ability. This pre-assessment was completed in the student lab notebooks so that the students could reflect on their learning throughout the unit. Student models and explanations of physical changes included ideas such as “something doing for fun like cooking,” “kneading dough,” “boiling water or mixing food,” and cooking rice, bacon or spaghetti. In terms of chemical changes, students identified them as “something that is important like an experiment,” adding flavor to food, producing bubbles or explosions, and “raw cold meat + fire = cooked meat.” This was the first component of the pre-assessment and it helped identify the varying backgrounds students had in terms of experience with physical and chemical changes. Following the student modeling, we completed an activity where students were given a statement and they had to determine whether it was a physical or chemical change. Overall, students were able to properly identify a few physical changes, like melting a popsicle or cutting a carrot, but beyond that they struggled to distinguish between the two types of changes. This was reflective of the overall student population. When looking at student scores on the assessment, the average was an 88%. This shows that, on average, students were able to identify both physical and chemical changes and explain the changes to the matter particles that are too small to be seen. These results show student understanding of multiple standards including PS1.A: Structure and Properties of Matter and PS1.B: Chemical Reactions. Table 5-9 shows the overall progression of learning for individual participants in the study based on each activity.

Activity 5: Solids, Liquids, and Gasses

Students started demonstrating shifts in their understanding after completing Activity 5: Solids, Liquids, and Gasses. The lesson started out by providing background knowledge for students as they used the PhET States of Matter simulation. When recording the Flipgrid™ videos, students used the simulation to explain the movement and shape of the molecules, the temperature, and the process of changing the state of matter for each phase change. Below is Student #11's explanation of the phase changes, which was similar to most student responses.

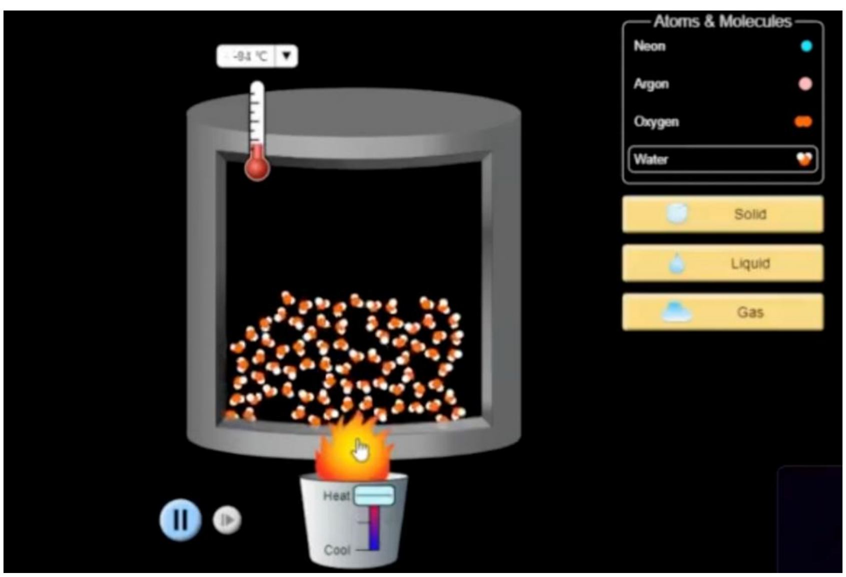


Figure 5-3. This is a screenshot of a student's Flipgrid™ video as they explained the phase changes below. Photo courtesy of author.

> "First you see the solid molecules here and they are all scrunched together vibrating a little bit and the temperature is -127 degrees Celsius. So, the thing that changes a solid to a liquid and a gas is changing temperature. So if I heat

> this up, it will slowly turn into a liquid. It is 13 degrees Celsius and they (the molecules) are all in the shape of the container, and they are vibrating and wiggling a lot more than when they were a solid. Heat this up and turn it into a gas, and they start separating and floating around in the air. The gas is 156 degrees Celsius which is when it turns into a gas and they are all floating around vibrating very fast. That is how you turn a solid into a liquid and then a gas."

By using the simulation to build background knowledge and encouraging students to explain their learning, they were able to use what they learned when their groups came together to change the ice cube into a liquid and then a gas.

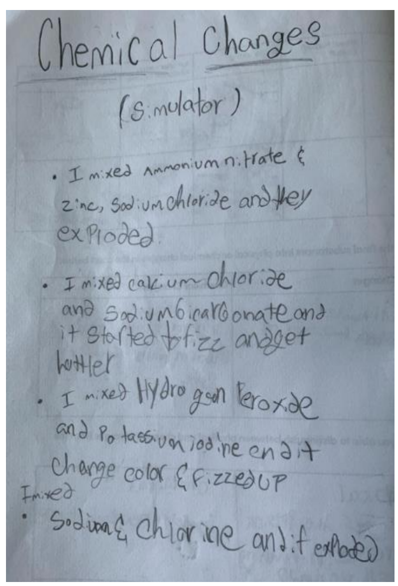
This understanding carried over to the inquiry-based activity following the simulation. During the inquiry-based activity, students realized through collaborative discussions that they needed to add different amounts of heat to change the state of matter of the ice cube. The methods of doing this looked different from class to class, but students were able to be resourceful and creative as they found ways to demonstrate physical changes. The reflective journal states, "it worked well to have all three classes come up with methods for melting and evaporating the liquid" (Reflective Journal, Entry #1, 3/15/23). At the end of the activity, students responded to the exit ticket question, "I learned something new in this activity." The responses showed that most of the students (71.7%) strongly agreed or agreed that they learned something new. Based on student models and reflective journal entriess from this activity, students demonstrated an initial understanding of physical changes through the combined instructional methods, as they explained and used their understanding of phase changes to complete the activity.

Activity 7: Changing Matter

The next lesson in this study, Activity 7: Changing Matter, used a similar lesson structure as students used a simulation first to build background knowledge, and then completed an inquiry-based activity. Up until this point in the unit, students had little to no experience with chemical changes. The Gizmos simulator was introduced to students in the beginning of the lesson, and students were able to test out a variety of chemical reactions and take notes to help build their understanding. The reflective journal states,

> "Students recorded some of the examples of chemical changes and their identifiers in their lab notebook. Most students were able to find 5-6 examples with the simulator. There was a lot of excitement and sharing across group members to show what type of reaction they created whether it was an explosion, fire, fizzing, etc." (Reflective Journal, Entry #2, 4/3/23).

The simulation allowed students to complete a diverse set of chemical changes in a short period of time, which would not have been possible to conduct safely in our classroom setting. Below is a Student #2's notes of the chemical change identifiers they observed when using the Gizmos simulation.



Chemical Changes

(simulator)

- I mixed Ammonium nitrate & zinc, Sodium chloride and they exploded
- I mixed calcium chloride and Sodium bicarbonate and it started to fizz and get hotter
- I mixed Hydrogen Peroxide and Potassium iodine and it change color & Fizzed UP
- I mixed Sodium & Chlorine and it exploded

Figure 5-4. This is a student document from Activity 7: Changing Matter, where a student used the Gizmos simulator and collected notes on identifiers and examples of chemical changes. Photo courtesy of author.

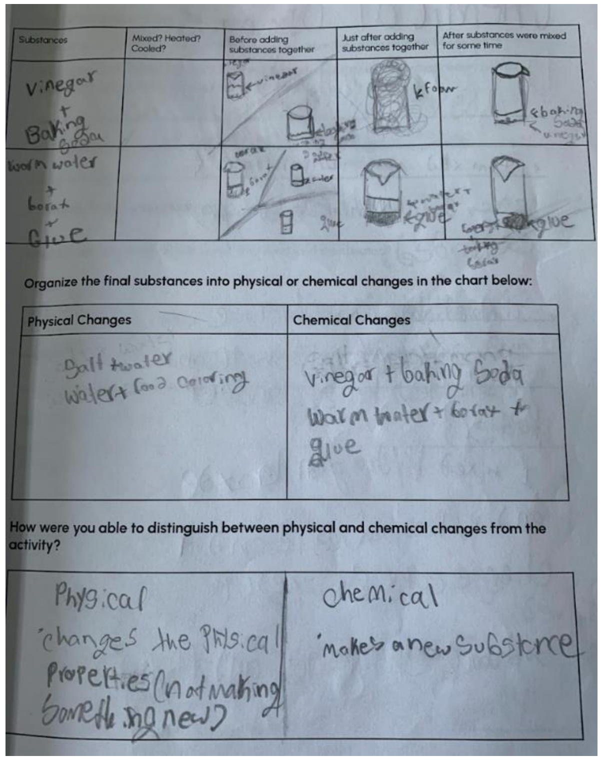
Using the simulation, students were able to test out real-world experiments and find patterns across different chemical changes such as fizzing, explosions, or color change.

Following the simulation, students completed the inquiry-based activity where they completed four different experiments, recorded observations before, during and after mixing, and determined whether the substances went through a physical or a chemical change. The reflective journal shares,

> "Students were able to identify some similarities between the simulation and what they observed during the activity. When mixing baking soda and vinegar, students found that it fizzed and bubbled up, and from the simulation, they were quickly able to identify that as a chemical change" (Reflective Journal, Entry #2, 4/3/23).According to the exit tickets, 78.5% of students strongly agreed or agreed that they learned something new in this activity. Both the inquiry-based activity and the virtual simulation were highly rated by students as being helpful for their learning with 89.3% of students strongly agreeing or agreeing that the experiment was helpful, and 76.9% strongly agreeing or agreeing that the simulation was helpful for their learning. Without the combined methods of instruction, each component would have had gaps and led to confusion or struggles with student learning.

Based on the reflective journal, it seemed that the virtual simulation was more impactful for student learning in this activity. Students were able to easily identify chemical changes using the distinguishing traits they identified through the use of the virtual simulation.

Overall, most of the students were able to easily identify the vinegar and baking soda solution and the borax, water and glue solution as chemical changes. Students explained that these were chemical changes because they created new substances, and they could not go back to their original form. Below is an example of the observations, and tables where students determined the different types of changes from the experiment.



Substances	Mixed? Heated? Cooled?	Before adding substances together	Just after adding substances together	After substances were mixed for some time
Vinegar + Baking Soda		vinegar	foam	baking soda
Warm water + borax + Glue		borax		water glue

Organize the final substances into physical or chemical changes in the chart below:

Physical Changes	Chemical Changes
Salt water water + food coloring	Vinegar + baking Soda Warm water + borax + glue

How were you able to distinguish between physical and chemical changes from the activity?

Physical ·changes the Physical Properties (not making Something new)	chemical ·makes a new Substance

Figure 5-5. This is a student document from Activity 7: Changing Matter where students collected notes from each experiment, and then determined which mixtures went through physical or chemical changes with provided reasoning. Photo courtesy of author.

As previously mentioned, some students struggled with the two physical changes in the activity as they could not yet understand how the salt and water or the food coloring and water could be separated, as they did not create a new substance. This was addressed in the following activities for further clarification.

Activity 8: Is it a New Substance

Students continued to demonstrate their understanding of physical and chemical changes as they completed Activity 8: Is it a New Substance. The simulation of the dissolution of water and NaCl was helpful for students to see the combination and separation of molecules as salt was mixed with water. Using the demonstration of boiling salt water in combination with the simulation, students were able to make connections between the two representations and could see how the substances stayed the same before and after mixing leading to a physical change. The reflective journal explains,

> “This showed students what was happening at a molecular level, to distinguish between a physical and chemical change. It seemed that in all three classes this is where the “lightbulb” moments happened as they saw the direct connection between the previous activity, the current demonstration, and the simulation” (Reflective Journal, Entry #3, 4/10/23).

This concept is particularly challenging for students because when boiling the salt water, it seems as though we cannot get the water back as it evaporates. We had to discuss ways in which the water could be collected after separating it from the salt before moving forward with the activity.

Following the whole class discussion of the simulation and demonstration, students began the inquiry-based activity as they wrote observations while they took apart the hard-boiled egg and the frozen egg. Students used their observations to determine which egg went through a physical or chemical change. The inquiry-based activity allowed students to have collaborative discussions about what they were noticing with each egg and share what they remembered from previous activities about the different types of changes. This led them to their assessment using the Claim Evidence Reasoning response format.

According to the assessment data, 84.8% of students correctly determined that the frozen egg went through a physical change. Similarly, 86.4% of students correctly determined that the hard-boiled egg went through a chemical change. Beyond the initial correct determinations, students had to provide evidence from their observations in the inquiry-based activity and reasoning from their understanding of physical and chemical changes to explain how they knew the egg went through that type of change. According to the reflective journal, “This pushed student thinking further than it has in the past as they had to analyze the observations they collected with their group” (Reflective Journal, Entry #3, 4/10/23). The data from student exit tickets shows that 84.9% of students strongly agreed or agreed that they learned something new in this activity. This lesson was multidimensional in the sense that students had to challenge misconceptions about salt and water mixtures, complete an inquiry-based activity, collect observations for future evidence, and conduct a written assessment that allowed students to demonstrate their understanding of each type of change with evidence and reasoning to support their claims.

Activity 9: What’s the Matter?

As students approached the end of the intervention, their requirements for demonstrating an overall understanding of physical and chemical changes were challenged in a new way. In Activity 9: What’s the Matter, students began by creating collaborative Venn Diagrams comparing the two types of changes and identifying examples through videos, pictures, or past experiences. Following this review, students completed an assessment that was shared in the reflective journal, “Instead of moving onto the next activity as I would in the past, I incorporated a simulation where students had to use examples from the simulation to explain one physical and one chemical change on a basic and molecular level” (Reflective Journal, Entry #4, 4/12/23). Even though this activity reviewed and assessed students, the exit ticket results showed that 78.1% of students “strongly agreed” or “agreed” that they learned something new in the activity. The camping simulation was highly ranked by students as 84.4% of students "strongly agreed" or "agreed" that the simulation was helpful for their learning.

Student perceptions of learning aligned with the results of the assessments for this activity. Students were assessed using the rubric shown in Figure 5-6. Using this rubric, students demonstrated proficiency in their understanding of physical and chemical changes by using explanations and scientific modeling to in each type of change properly. All three classes had high scores overall. The first class scored an average of 94%, the second averaged 84.6%, and the third class had an average score of 90.5% based on their models and the defined rubric. This assessment allowed me to identify some areas of reteaching in the second class, specifically the filtering water example, but also helped me to see how the students were able to use what they have learned throughout the unit in both the simulations and the inquiry-based activities, to demonstrate their growth in the understanding of physical and chemical changes.

Act. 9: Simulation Quiz

Physical Change

- ❑ Simulation example model (3 pts)
- ❑ Labels/ Color (1 pt)
- ❑ Explanation of change (2 pts)
- ❑ Representation of molecules (2 pts)

Chemical Change

- ❑ Simulation example model (3 pts)
- ❑ Labels/ Color (1 pt)
- ❑ Explanation of change (2 pts)
- ❑ Representation of molecules (2 pts)

Total: _____/ 16 or _______ %

Figure 5-6. This is a copy of the rubric used to grade student's scientific models of physical and chemical changes in Activity 9: What's the Matter. Photo courtesy of author.

Theme #2: Students struggled with confidence when explaining scientific models.

Throughout the unit, students had multiple opportunities to practice developing and explaining scientific models. As 5th graders, this was their first year using scientific modeling to explain a phenomenon. With that said, based on student exit tickets and the reflective journal, another theme that surfaced was the fact that students struggled with confidence when explaining their scientific models. This theme carried over throughout each activity in the study.

Early in the unit, students were expected to use a virtual simulation in Activity 5: Solids, Liquids and Gases to explain phase changes using water molecules. Students created Flipgrid™ videos where they screen shared and described what was happening to the water molecules as they changed from a solid, to a liquid and a gas along with the temperature changes that occurred during those phase changes. When students were making their Flipgrid™ videos, they seemed confident and were clear in their explanations using the simulations. At the end of the activity, students filled out an exit ticket. One of the questions stated, “I can explain these models on pg. 9 to someone else.” These models were student-created and included the molecular visuals from the simulation as well as examples from the inquiry-based activity when they changed the ice cube from a solid to a liquid and a gas. The results showed that 41.7% of students said they felt neutral that they could explain the models, 36.7% agreed, and 21.7% of students strongly agreed. This was pretty surprising to see because at this point students had already explained the simulation correctly in their Flipgrid™ videos. Because of this, it seems that they might not have felt as confident explaining the connections between their inquiry-based activity and the virtual simulation. This could have been because this was the first type of physical change we discussed in class, and they were not as confident in their understanding early in the unit.

Another example of this was identified in Activity 7: Changing Matter after students had completed the inquiry-based activity with two physical changes and two chemical changes. Students responded to the exit ticket question, “I can explain these my models of physical and chemical changes to someone else. (p. 11/12 drawings).” From this question, 21.5% of students strongly agreed, 36.9% agreed, 29.2% were neutral and 9.2% disagreed. When comparing these results to the reflective journal, I was not immediately surprised. The journal stated, ”Students seemed to struggle with the two physical changes of salt + water and water + food coloring. This seems to be a normal challenge for students because they cannot see how the two substances click or come together” (Reflective Journal, Entry #2, 4/3/23). This activity included an introduction to chemical changes with help from the Gizmos simulator. Previous activities focused on physical changes and students understood that a physical change is a change in texture, shape, temperature, or state of matter. They were also aware that the previous examples of physical changes did not create a new substance. The confusion with the two examples in this activity was likely due to the struggles students have with identifying how salt or food coloring combines with water. This was addressed in Activity 8: Is it a New Substance, as students investigated the combination of salt and water through a simulation and a demonstration of separating the two substances. In my reflective journal I noted,

> “This seems to be a normal challenge for students because they cannot see how the two substances click or come together or how they could ultimately be separated. This was brought up in all three class discussions when we tried sorting the four experiments into physical and chemical changes, If the students

> could not visualize how the substance could be separated, then they assumed it was a chemical change and made a new substance" (Reflective Journal Entry #2, 4/3/23).

In Activity 8: Is it a New Substance, students were required to use a CER response to explain both physical and chemical changes using evidence from the experiment and simulations. We started the activity with the difficult concept of separating salt and water, which was a challenge from the previous activity. Students were able to see a demonstration of water boiling, evaporating, and the salt being left behind. Following the demonstration, students viewed a simulation of the dissolution of salt water and created models demonstrating the physical change. The exit ticket asked students, "I can explain these models of the physical change - adding salt to water to someone else. (p. 13/13.5 drawings)" referring to the model of the dissolution of salt water and the salt water demonstration. The results showed that 18.2% strongly agreed, 33.3% agreed, and 39.4% were neutral that they could explain this physical change to someone else.

Conversely, the final component of Activity 8: Is it a New Substance was an assessment where students had to provide a claim determining which egg went through a physical change and a chemical change, provide multiple pieces of evidence from the activity and simulations, and reasoning to support their claim. Overall, students did really well with their CER responses and the majority of students were able to properly distinguish between the physical and chemical change, and provide meaningful evidence in support of their claims. The biggest challenge in this activity still seems to be the combination of salt and water as a physical change and the understanding of how the dissolution of water shows the separation of substances providing evidence of a physical change.

During Activity 9: What's the Matter, student confidence seemed to slightly increase in terms of their ability to explain their scientific models. The exit ticket from this activity asked, "I can explain my models of physical and chemical changes from the CAMPING simulation to someone else." The results of this showed that 26.6% of students strongly agreed, 42.2% of students agreed, and 28.1% were neutral. This was an increase in confidence compared to the other three activities reviewed in this study. This could be because students selected the physical or chemical changes they represented in their models, and they felt more confident in the explanation of their choices.

Summary

This chapter reviewed the data analysis process for each research question and the overall themes identified following each coding cycle. The first research question used the teacher's reflective journal, the Science Teacher Inquiry Rubric, and student interview responses through multi-stage coding using descriptive and pattern coding to identify themes. The second research question focused on the teacher's reflective journal, student interview responses, exit ticket results, and student documents that were analyzed using descriptive or In Vivo coding, and eventually themes were identified through pattern coding.

The first research question focused on the role of the teacher asking, "In what ways do I adjust my teaching with inquiry-based activities and simulations to facilitate student learning of physical and chemical changes?” After reviewing the data sources through multiple coding cycles, the major themes were identified. The first theme stated, “Integrating virtual simulations and inquiry-based learning led to student learning across activities, but there are components I need to adjust because students still struggle with certain concepts.” This was an important finding for this action-research study because it allowed me to see where there was overall growth for students using intervention, but also areas for improvement that need to be considered and adjusted for future instruction. The second theme looked at the student perspective of the adapted curriculum stating, “Students preferred activities that gave them a choice in their learning and enjoyed the ability to work with their group members and learn through discussion.” The student interview responses were a significant resource for this theme as they shared insights to how students felt they learned best and what kept them engaged in the activities from the intervention. The final theme found that “Students felt their learning was most impacted by the use of inquiry-based activities when learning about physical and chemical changes.” This was insightful as student confidence was reflected in their work and through the results of exit tickets and student interview responses.

The second research question focused more on student learning asking, “In what ways, if any, will using virtual simulations and inquiry-based activities in my instruction improve my students’ conceptual understanding?” There were two themes that were identified from the coding cycles of the teacher reflective journal, student interview responses, exit tickets, and student documents. The first theme identified was, “Students struggled with confidence when explaining scientific models.” This is very helpful information as I move forward with using scientific modeling in my classroom. Earlier in the school year I need to provide more teacher modeling on how students should develop scientific models, and proper methods for explaining them. By using these scaffolding techniques earlier in the year, students will grow more confident in their abilities as they learn new scientific concepts. The final theme for this research question was, “Students demonstrated new learning of physical and chemical changes through the use of inquiry-based activities and virtual simulations.” This theme truly encapsulated the goal of the second research question. There were many examples of new learning shown through student documents, exit tickets and the reflective journal. Students were able to progressively show growth in their understanding of physical and chemical changes as they moved throughout the unit, specifically using the lessons from the intervention.

As an educator, these findings are extremely valuable for my overall understanding of how students learn, their preferences in learning styles or instructional methods, and finding what works best for diverse groups of learners.

Table 5-1. Codebook established for research question 1.

Code Name	Description	Example	Number of times used in Reflective Journal	Number of times used in STIR	Number of times used in student interviews
Student comprehension	Evidence of student learning as demonstrated through discussions, group work, assessments, and models	"Gizmos simulator was an important experience for students to define a chemical property and a chemical change." (Reflective Journal - Activity 7, Pos. 2)	16	0	10
Inquiry-based	Components of lessons and activities that involved students developing questions or hypotheses, experimenting with hands-on activities, analyzing observations/ data, and developing conclusions	"The second part of the activity was set-up as an inquiry-based activity that I typically use in my classroom. Students explored the frozen egg and hard-boiled egg, collecting observations and determining the type of change based on what they saw." (Reflective Journal - Activity 8, Pos. 2)	11	4	16

Table 5-1. Continued

Code Name	Description	Example	Number of times used in Reflective Journal	Number of times used in STIR	Number of times used in student interviews
Student-led	Learning that is self-directed and involves students using curiosity and collaboration to solve problems	"The final project because you get to actually make it and see how you did and what you have learned, and it allowed you to choose your own because you have options, and I could think about examples - you could think of a recipe that had lots of examples." (Student Interviews (Q4+Q7), Pos. 24)	7	5	10
Challenges	Difficult components of the lessons or activities that need to be considered for future planning	"The Gizmos simulator was a great visual for students, however, since we did not have a subscription, students were limited to 5 minutes of exploration with the website. Students really enjoyed the visuals, but wished they would have more time to explore and collect observations." (Reflective Journal - Activity 7, Pos. 2)	12	0	0

Table 5-1. Continued

Code Name	Description	Example	Number of times used in Reflective Journal	Number of times used in STIR	Number of times used in student interviews
Collaboration	Students working together intentionally or unintentionally	"There was a lot of excitement and sharing across group members to show what type of reaction they created whether it was an explosion, fire, fizzing, etc." (Reflective Journal - Activity 7, Pos. 2)	8	5	3
Simulation	Virtual experiment or activity that students use to better understand concepts or scientific phenomenon	"Instead of moving onto the next activity as I would in the past, I incorporated a simulation where students had to use examples from the simulation to explain one physical and one chemical change on a basic and molecular level." (Reflective Journal - Activity 9, Pos. 2)	10	0	1

Table 5-2. Overview of identified themes following both coding cycles for research question 1.

Themes	Codes
Integrating virtual simulations and inquiry-based learning led to student learning across activities, but there are components I need to adjust because students still struggle with certain concepts.	• Student comprehension • Inquiry-based • Simulation • Challenges
Students preferred activities that gave them a choice and say in their learning and enjoyed working with their group members and learning through discussion.	• Student-led • Collaboration • Student comprehension
Students felt their learning was most impacted using inquiry-based activities when learning about physical and chemical changes.	• Inquiry-based activities/ Experiments • New learning • Student confidence

Table 5-3. Scoring levels for the Science Teacher Inquiry Rubric.

Scoring	
0-1	Teacher Centered
2	Neutral
3-4	Learner Centered

Table 5-4. STIR results before and after implementation of the intervention.

Activity	Before Intervention	After Intervention
Activity 5: Solids, Liquids, Gasses	0.5	3.0
Activity 7: Changing Matter	0.3	2.8
Activity 8: Is it a New Substance?	0.8	2.7
Activity 9: Comparing Physical and Chemical Changes	0.5	3.2

Table 5-5. Codebook developed from student interviews using In Vivo coding.

Group	In Vivo Codes	Number of codes in Category
Inquiry-Based/ Experiments	• "Cooking project- cooked makes more sense" • "Experiments with groups - see their opinion" • "Labs/ different experiments helped me the most" • "Chemical changes and physical changes on the table - see how it happens" • "Physical change stations - actually do different changes" • "Cooking project because I understood how things were changing" • "Introduces you to physical and chemical changes" • "Experiments help converge peoples' ideas" • "Liked stations around the room" • "Experiments helped to see things" • "Experiments hands-on activities understand very clear" • "Experiments can identify changes by seeing them in person" • "Experiments to do things and experience it" • "Learn about different substances by experimenting on them" • "Experiments helpful to see it happening and how it works" • "Identify substances by looking at how they react" "I like doing experiments" • "I like reactions and explaining how it happens" • "Inquiry-based activities were helpful" • "Experiments with reactions makes me more interested" • "Experiments let us look at things firsthand"	21

Table 5-5. Continued

Group	In Vivo Codes	Number of codes in Category
Simulations	• "Simulation helped me see molecules and how they are changing" • "Closer look with the tool on a smaller scale" • "See the molecules changing" • "Seeing the action of wood burning or water evaporating" • "Seeing molecules throughout the simulation" • "See the molecules" • "Add more detail understand why it is a chemical change" • "Seeing the molecules close up" • "Switched to simulation and flipped back was hard" • "Simulation helped give visual to see molecules" • "Simulation - seeing what you cannot see with your eyes" • "Simulation showed what would happen and particles flying" • "Visualize wood burning and particles being pushed" • "Simulation showing what is happening and why" • "See how the molecules looked and interact"	15
Group work	• "Group work - see what other people's ideas are" • "Discussions are helpful" • "Get in groups and check work with another person" • "Group work helped me understand" • "Share with other people" • "Group work to see if my answers are correct" • "Experiment with groups to see their opinion"	7

Table 5-6. Summary of student exit ticket responses following each activity.

Activity	Total Students	Percentage of students that strongly agreed that the inquiry-based lesson was helpful for their learning	Percentage of students that agreed that the inquiry-based lesson was helpful for their learning
Activity 5: Solids, Liquids, Gasses	60	33.3	46.7
Activity 7: Changing Matter	65	32.3	48.2
Activity 8: Is it a New Substance?	66	27.3	36.4

Table 5-7. Codebook established for research question 2.

Code Name	Description	Number of times used in student surveys	Number of times used in student documents	Number of times used in the Reflective Journal
New learning	Student or teacher identified learning from a particular activity from the intervention.	14	12	7
Inquiry-based activity	Discussion of inquiry-based activities from the intervention.	3	10	5
Virtual simulations	Discussion of virtual simulations from the intervention.	6	1	6
Combined methods	Discussion of both inquiry-based activities and virtual simulations.	3	0	0

Table 5-7. Continued

Code Name	Description	Number of times used in student surveys	Number of times used in student documents	Number of times used in the Reflective Journal
Cross-connections in learning	Identifying connections between different components in the activity, specifically between simulations and inquiry-based activities.	5	0	0
Student explanation	Discussion of students explaining or justifying their answers	4	9	9
Student confidence	Discussion of student confidence in learning and overall conceptual understanding	15	4	4
Scientific modeling	Use and explanation of scientific models	6	11	11

Table 5-8. Overview of identified themes following both coding cycles for research question 2.

Themes	Codes/ Categories
Students demonstrated new learning of physical and chemical changes using inquiry-based activities and virtual simulations.	• New learning • Virtual simulations • Inquiry-based activities
Students struggled with confidence when explaining scientific models.	• Student confidence • Scientific modeling

Table 5-9. Overview of student learning throughout the unit broken down by participant and activity.

Student	Activity 5	Activity 7	Activity 8	Activity 9
1	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully identified the physical and chemical change, but struggled with providing proper evidence to support the claim from the experiment	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.
2	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.
3	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.

Table 5-9. Continued

Student	Activity 5	Activity 7	Activity 8	Activity 9
4	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated a proficiency of understanding of physical changes through their model, however they incorrectly identified filtering water as a chemical change.
5	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated a proficiency of understanding of physical changes through their model, however they incorrectly identified filtering water as a chemical change.
6	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated a proficiency of understanding of physical changes through their model, however they incorrectly identified filtering water as a chemical change.

Table 5-9. Continued

Student	Activity 5	Activity 7	Activity 8	Activity 9
7	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated a mastery of understanding of physical and chemical changes through their models but missed details of the changes to the molecules.
8	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.
9	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.

Table 5-9. Continued

Student	Activity 5	Activity 7	Activity 8	Activity 9
10	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.
11	Demonstrated initial understanding of phase changes during Flipgrid™ video demonstration	• Properly identified examples of chemical changes using the simulator • Correctly categorized physical and chemical changes and distinguishing factors in the activity	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated mastery in their models and explanations of both physical and chemical changes at the molecular level.
12	Did not complete the Flipgrid™ video demonstration – unable to assess understanding	Data not available for this student	Successfully used the CER format to identify physical and chemical changes with sufficient evidence from experiments and reasoning	This student demonstrated proficiency in their models and explanations of both physical and chemical changes at the molecular level.

CHAPTER 6
DISCUSSION

This chapter will review the overall study outlining the purpose and context, methodology, overall findings, and discussions of research questions. Additionally, it will cover the study in relation to prior research, implications on four different levels, potential limitations of the study, and opportunities for future research.

Summary

Purpose and Context

The purpose of this action-research study was to improve my practice by finding ways to incorporate both inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding. The study focused on my 5th grade science classes over the course of one unit covering scientific modeling of physical and chemical changes. This particular study incorporated an intervention that was implemented across four different activities that encouraged students to use both inquiry-based activities and virtual simulations to learn about both physical and chemical changes. The overall goal of the study was to answer the following research questions:

1. In what ways do I adjust my teaching with inquiry based activities and simulations to facilitate student learning of physical and chemical changes?

2. In what ways, if any, will using virtual simulations and inquiry-based activities improve students' conceptual understanding of physical and chemical changes?

Methodology

In this study, data was collected throughout the unit, and alongside the implementation of the intervention. Data was collected through a teacher reflective journal, the use of the Science Teacher Inquiry Rubric scores following each activity, student surveys, student interviews, and student documents. As this data was collected, it was reviewed throughout the unit so that I could reflect on student learning and adjust my instructional practices based on student needs. At the end of the school year, 12 students were interviewed about the unit and how they learn best.

Data in this study was analyzed through a multi-stage approach. In the first stage, the reflective journal, STIR results, and student documents were analyzed to determine the ways in which I could adjust my teaching to incorporate inquiry-based activities and virtual simulations to facilitate student understanding of physical and chemical changes. This data was analyzed first through descriptive coding, then through pattern coding.

The second stage of data analysis included a summative review of the reflective journal, exit tickets, student interviews, and student documents. Student interviews were coded through In Vivo coding, while the journal, exit tickets and documents were coded using descriptive coding. During the second round of coding, all data was reviewed using pattern coding. The goal of this process was to determine the impact of using virtual simulations and inquiry-based activities on student conceptual understanding.

Overall Findings

The purpose of this study was to determine ways in which I could adjust my teaching with inquiry-based activities and virtual simulations to facilitate student learning of physical and chemical changes, while also determining how these changes impact students' conceptual understanding of this phenomena. The data collected and analyzed in this study allowed me to reflect upon my teaching practices, and better understand how to continue to improve instruction for my students.

The first research question centered around my teaching adjustments and findings research-based practices to improve my instruction through the combined methods of inquiry-based activities and virtual simulations. Data analysis shows that these adjustments to the curriculum led to student learning across activities, but also highlighted some components that need to be adjusted to help students struggling with certain concepts. When evaluating my teaching before and after implementation of the intervention using the STIR, it was clear how the changes enhanced the lessons by providing more student-centered instruction. Additionally, students were challenged in new ways as they developed scientific models and wrote and justified scientific explanations.

Challenges in this unit presented themselves in a variety of ways. Some of the difficulties that arose during the unit involved flaws in different inquiry-based activities, available resources, or difficulties with simulations. At times, students struggled with more abstract concepts such as the dissolution of NaCl in water. The use of demonstrations and virtual simulations was helpful, however, when applied in a new context, some students still identified this type of mixture as a chemical change. These challenges provided me with helpful insights into areas of growth in the curriculum. Finally, students felt their learning was most impacted by using inquiry-based activities when learning about physical and chemical changes. Student interview responses and exit tickets clearly demonstrated that students felt more confident in their learning when they had experiences where they could see what was happening in physical and chemical changes and learn more about how they worked.

The second research question looked closely at the combined methods of instruction and what ways, if any, those changes improve students' conceptual understanding of physical and chemical changes. The themes identified during data analysis were broken down into different perspectives. Students struggled with confidence when explaining their scientific models. This was identified through exit tickets, student documents, and the teacher's reflective journal. Overall students had no problem creating scientific models independently or with groups, but did not feel confident in their ability to explain these models to someone else. These findings helped me to take note of bigger changes in the curriculum where students will be provided with more scaffolding and modeling earlier on with both developing scientific models and properly explaining them.

The final big idea from this research question was the finding that students demonstrated a conceptual understanding of physical and chemical changes using combined methods of instruction. This is extremely important for student growth, and my future instructional practices. Students demonstrated a gradual understanding of the concepts throughout the four activities highlighted in the intervention. Over time, their understanding progressed as they were introduced to new aspects of the phenomena. This growth was supported by both the inquiry-based activities and the virtual simulations, and was measured through Flipgrid™ recordings, CER responses, student models, and formative assessment throughout the unit.

Findings Related to the Literature

Inquiry-based Learning

One of the biggest themes across this study has been the influence of inquiry-based activities on student engagement and learning. Inquiry-based learning has been extensively researched and there are many connections between this study and similar research.

The first research question in this study focused on finding ways to adjust my teaching using inquiry-based activities and simulations to facilitate student learning. Forbes (2011) discussed the importance of adapting curriculum to fit the needs of students using inquiry-based instruction. Similarly, Soonjana & Kaewkhong (2022) shared the importance of self-reflection for strong teaching practices. This study guided my assessments of the activities as I used the Science Teacher Inquiry Rubric to identify areas for improvement before the intervention, and the impact of the changes following the intervention.

As I started this study, I had already identified a need in our curriculum, and used this study to improve my instructional approaches to help support students. With these changes, students were provided with opportunities for real-world application as shared by Qablan & DeBaz (2015) when they used different scenarios such as cooking and camping to model physical and chemical changes.

Inquiry-based learning emphasizes the importance of student reflection (Schellinger et al., 2019) through experience and collaboration. The intervention for this study incorporated multiple activities where students had to develop CER responses, share with others, and evaluate their explanations which was found to be important for student learning by Forbes (2011). Additionally, each lesson focused on a specific investigation question that students referred to, and worked to answer throughout the activity (Forbes, 2011).

Virtual Simulations

Throughout this study, I was able to identify many connections between my findings and prior research. Prior to implementing the virtual simulations in my lessons, I considered the study by Smetana & Bell (2012) and the timing and organization of the lesson. In their study, they explained the importance of finding the goal for the simulation. If the goal is to help build conceptual understanding, the simulation should be used after inquiry-based activities, but if it was to strengthen understanding in the scientific process, it needs to be incorporated before hands-on explorations. Throughout the intervention, I strategically placed the simulations depending on the need, and it truly helped with the flow of the lesson.

Before jumping into the simulations, I found it was very important to set aside time to model the simulations for the students. Studies by both Smetana & Bell (2012) and Gonczi et al. (2016) discussed the importance of teacher guidance and modeling simulations. By taking them time to do this, students were able to get more out of the simulation and it made the experience worth it.

The virtual simulations incorporated within the intervention had many similar benefits to those discussed in previous studies. The simulations provided real-world application (Schellinger et al., 2019; Smetana & Bell, 2012), increased student engagement (Gonczi et al., 2016), allowed students to identify patterns in their observations (Smetana & Bell, 2012), and enhanced student conceptual understanding (Paul, Podolefsky & Perkins, 2013). The use of simulations allowed for students to see some of the micro phenomena that are impossible to see otherwise as discussed by Gonczi et al. (2016). Students really emphasized the importance of seeing the molecules in the simulation and how it impacted their ability to model physical and chemical changes. This type of simulation was beneficial in another study by Chang & Linn (2013).

Combined Methods of Instruction

The goal of the second research question in this study was to determine the impact of using combined methods of inquiry-based activities and virtual simulations to teach physical and chemical changes. By combining methods, I found that students were able to understand challenging and abstract concepts, which was similar to the research conducted by Yuliati et al. (2018) and Zacharia (2007). Without the use of both methods of instruction, it would be very challenging for students to develop scientific models of physical and chemical changes, which was outlined in a study by Schwarz et al. (2007).

When learning about physical and chemical changes, it is important to allow students to visualize the molecules to determine the type of change. This would not be possible without the addition of virtual simulations in the lessons. By giving students the opportunity to have inquiry-based experiences alongside the use of simulations, students could see things beyond what we could do in a classroom setting (Crompton et al., 2016; Nicolaou et al., 2007; Zacharia, 2015), and they were able to close the gap between theory and reality similar to the studies by Jaakkola & Nurmi (2008) and Zacharia (2015). The balance between inquiry-based activities and virtual simulations allowed students to benefit from the advantages of both instructional methods. Like

Zacharia et al. (2015), I found that students enjoyed learning from inquiry-based activities and getting hands-on experience through exploration, but the simulations were able to help students dig deeper into the molecular changes and use that evidence better to understand the differences between physical and chemical changes.

Conceptual Framework

Looking back at the conceptual framework for this study, the foundation of the intervention is based on the Next Generation Science Standards curriculum. When developing the intervention, the goal was to keep the lessons aligned with the NGSS but incorporate new instructional strategies to support the overall growth for the students and my teaching practice.

The conceptual framework guided the development of the intervention, as I incorporated inquiry-based activities within each lesson. Students had many opportunities to collaborate as they worked to better understand the investigation question for each activity. According to the Science Teacher Inquiry Rubric results, prior to the intervention, all four lessons were teacher-centered. Once mindful changes were made to the lessons, the STIR scores ranged from 2.7-3.2, towards a more student-centered learning experience. This was a significant improvement with the intervention and one of the goals for incorporating the inquiry-based activities.

In addition to the inquiry-based activities, students benefited from the use of virtual simulations as included in the framework. In the past, students had not used simulations to look at a micro scale for physical and chemical changes, so the addition of the variety of simulations offered new opportunities for learners. Students were able to develop scientific models with help from virtual simulations. Additionally, they were able to conduct more complex chemical change experiments that would not have been possible in the classroom. The addition of virtual simulations truly enhanced the curriculum and allowed students to capture a new perspective on physical and chemical changes.

After combining these methods within the NGSS curriculum, I was able to determine overall growth for the students and myself as an educator. Students were able to use examples from the combined methods of instruction to demonstrate their understanding of physical and chemical changes. This was done through scientific modeling, CER responses, discussions, and student reflections. As a teacher, I was able to learn about my practice, and use research-based methodology to adapt my instruction. This happened as I worked through the development of the intervention, but also as I evaluated myself through the STIR and reflective journals. Student feedback was extremely insightful for me as we moved throughout the unit, and I could make adjustments to future lessons as needed to support my students. This study gave me the opportunity to learn through action-research, and find ways to continue to reshape the curriculum, and my instructional practices, to fit the needs of my students.

Implications

Implications for the Researcher

Throughout the course of my doctoral program, I have found many topics within my area of specialization that I would like to research in the future. When developing this study, I had additional questions I wanted to consider, but found it was important to narrow down my focus to ensure the quality of my research. One particular question I considered was regarding the impact of multimodal instruction on diverse groups of students. As an educator, it is important to consider the diversity in my classroom and meet the needs of all learners. In the researcher role, I can continue my research and learn more about how interventions such as the one developed for this study might impact students that are English language learners or students that are impacted by learning disabilities.

In the field of education, my context is always changing. Each year brings new groups of students with different needs, and over time the curriculum will change. Even with all these changes, this study has allowed me to learn a lot about myself as an educator, how I can continue to use action-research in my practice and has continued my desire to incorporate inquiry-based activities with virtual simulations in my classroom. This study has encouraged me to continue to try new instructional approaches, collect feedback from my students, and adjust my teaching to fit the needs of my students.

Throughout this study, I have had the opportunity to analyze my instructional practice through a reflective journal, student responses to exit tickets, and by interviewing students at the end of the unit. During this process, I have learned about the benefits and challenges of shifting my instruction. Additionally, I had firsthand experience with adjusting my instruction based on student perceptions of the lessons and their overall understanding. From these experiences, I was able to identify important findings regarding the changes to my overall practice.

First, I found that by changing my instruction, I was able to make significant changes in student comprehension, clarification, and overall learning. Through the use of inquiry-based activities and virtual simulations, I was able to slow down my instruction, pushing students to dig deeper, and elevate their learning. By using the intervention, I saw immediate changes in student growth and learning when compared to the previous curriculum. The addition of simulations provided enhanced experiences for students to identify patterns with the inquiry-based activities to better understand the scientific phenomenon.

Additionally, by using an action research approach, I could identify student strengths and areas for growth following each activity. With those findings, I could redirect my instruction to meet the needs of the students prior to progressing to the next lesson. From the data, I found that students had enhanced opportunities for higher-level thinking through collaboration, and that the majority of students felt their learning was most impacted by inquiry-based activities. Alternatively, students demonstrated an area for growth in terms of their confidence when explaining scientific models. Throughout the unit, students developed various models, and were comfortable creating these independently. However, when it came to explaining and justifying their model, students lacked confidence in their ability and overall understanding of the concept. This shows me that there is still room for improvement in this intervention and in my overall instruction.

Surprisingly, this study has already had an impact on my practice as I have completed a curriculum review for the district. When analyzing different programs, I was much more critical about the quality of lessons, tools, and the alignment to the Next Generation Science Standards than I would have been before this study. The combination of learning from prior literature and the results from my study allowed me to narrow down our choices for a curriculum based on the practices incorporated in this study’s intervention.

As my department moves forward with a new curriculum, I will continue using an action research approach to continue to improve my instruction to best fit the needs of my students. The curriculum has virtual simulations that go along with the lessons, and I am hopeful that this will help me to give my students more time and practice with these tools. I believe that this will be a significant improvement from the free simulations I used while completing this study, and could potentially eliminate some of the challenges that surfaced during my research. Using action research, I will be more cognizant of the strengths and weaknesses of the curriculum, and I can adapt my instruction based on results of formative assessments. At the end of each unit, I will collect feedback from students to better understand their preferences before moving forward, and properly adapt instruction. This feedback will also be beneficial for future years as I learn more about the curriculum and how to morph it to fit my students. This process has allowed me to be more aware of my teaching. After using certain instructional strategies for so long, it was refreshing to try something new. I truly enjoyed researching evidence-based instructional practices, and I know that I will continue to learn more about what will benefit my students.

Following this action-research study, my goal is to learn and grow as an educator. This study has allowed me to dig deeper into research-based practices and take risks to improve my instruction. One of my next steps is to share my findings with my professional learning community, and work with my colleagues to set goals to move our department forward and ensure we are continuously learning from our practice and from one another.

Implications for the Profession

This study has highlighted the importance of action-based research in the profession of education. The first research question focused on finding best practices to facilitate learning in the classroom. Educators should always strive to improve their practice and sometimes do not even realize they are doing action research in their roles every day. The findings of this study show how educators can become more aware of their iterative cycle of teaching and use feedback from reflections, students, and formative assessments to make positive changes to their instruction.

Additionally, this study focuses on science instruction within an elementary classroom. At this point in time, many elementary educators focus on reading and math, which eliminates instructional time for science. It can be very challenging to have students come to a 5^{th}-grade classroom with little to no science experience, as they need to learn skills such as scientific modeling and phenomena-based learning skills before they are able to dig deeper into the content. My hope is that some of the strategies incorporated in this study could be considered by elementary teachers to help save time, such as the use of virtual simulations, keep students engaged through inquiry-based activities, and ultimately increase science instruction in elementary classrooms.

Implications for my Context

My district was recently up for adoption of a new science curriculum over the course of this study. Following the study, we piloted a program that is highly ranked in our regional consortium. This program successfully incorporates a variety of research-based practices, including scientific modeling, inquiry-based activities, and virtual simulations. With this curriculum, I will be able to continue finding ways to incorporate both instructional methods within my classes and learn more about the impact it has on student learning.

Limitations

This action research study helped provide beneficial information on my personal instructional practices and the use of combining inquiry-based activities with virtual simulations to enhance student learning. However, there were limitations that need to be addressed and considered for future research. These limitations included lack of resources, timing of student interviews, and restricted opportunities for collaboration with other science teachers.

Immediately after incorporating virtual simulations into my lessons, I started to find that the lack of resources, specifically free simulations available to students, limited the lessons and opportunities for students to learn. In Activity 7: Changing Matter, students used the Chemical Changes Simulator from Gizmos, which provided beneficial evidence of chemical changes for students to consider prior to completing the inquiry-based activity. Unfortunately, students were only able to interact with the Chemical Changes simulator for five minutes before the free trial was up. Students were told this might be an issue ahead of time, but they expressed their frustration during the lessons as they wanted to continue using the simulation to learn more about chemical changes. At the time, our district had a teacher-developed science curriculum, and minimal resources for funding beyond what we used normally in a school year. Therefore, I did not have the ability to purchase student accounts for Gizmos or the other simulation programs, which led to limited results and student frustration for certain activities.

Another challenge in this study was the timing of student interviews. According to IRB protocol, interviews needed to be conducted following the end of the term to avoid any potential for coercion or concerns with the study impacting student grades. This study was conducted in March-April 2023, but students were not able to be interviewed until the last days of the school year in June 2023. When conducting interviews, students were given their lab notebooks to help them remember what they did during each activity, but some struggled to give clear answers as they had been so separated from the unit at that point in time. If it were possible to conduct interviews immediately after the unit, students might have more distinct responses which would help to properly analyze their interviews.

This study allowed me to learn a lot about my own teaching practices on a deeper level; however, a final limitation of this study was the impact it had on opportunities for collaborating with other science teachers. Our science department finds it extremely beneficial to be able to review activities or lessons together as a group and discuss strengths and challenges as a professional learning community. This truly helps us grow as educators and allows us to understand how to improve our teaching. Due to timing constraints, I was unable to have these conversations with my colleagues and learn from them. With the implementation of the intervention, my classes moved at a slower pace than the other science classes and were behind for most of the unit. Other teachers were limited in time due to a new curriculum pilot, so they would not have been able to incorporate all the new instructional strategies that I used. I will use this study to help enhance my own teaching, but in the upcoming years, I will share my findings with my colleagues to try to move our instruction forward to meet the needs of our diverse learners.

Future Research

This action-research study opens new possibilities for future research in elementary science education. Currently, there is a gap in the research surrounding elementary science instruction. Elementary education studies are heavily focused on reading and math, as both foundational skills are strongly emphasized in early education. In some cases, students who are in upper elementary school are experiencing scientific phenomena for the first time and have not built much background knowledge on the scientific process or inquiry-based learning. There are a few areas of research that could be beneficial following this study.

The first is learning more about elementary students and the best instructional practices for teaching scientific modeling. Students can start doing this from an early age, but it would be helpful to find out how to progressively build a curriculum to promote regular scientific modeling and allow students to explain these models to others. If we learn more about how to best develop this type of foundational skill, students will be set up for success as they move forward in their educational journey.

Another area of future research could be developing or refining evaluative systems for NGSS aligned curriculum that incorporate inquiry-based learning and virtual simulations to promote student conceptual understanding. This study focused on finding ways to implement the combined methods of instruction; however, the findings were based on self-assessment through the teacher reflective journal and student data. If there were some types of evaluative tools that considered both methods of instruction, along with the Next Generation Science Standards, it could be beneficial for teachers piloting curriculum or developing their own curriculum based on the standards.

A final area of research that aligns with this study in particular is looking at different groups of students and determining the impact of using both inquiry-based activities and virtual simulations to promote student understanding of scientific concepts. This study focused on average science students, but a future study could look at subgroups such as English Language Learners, students with Individualized Education Plans or 504's, or students of varying levels in overall comprehension. This could provide new insights to support a diverse set of learners in the classroom

APPENDIX A
UNIT OVERVIEW

Table A-1. Overview the unit broken into each individual activity, standards, objectives, activities, and resources.

Module # and Name	Module Overview (summary)	Module Standards (NGSS)	Module Objectives	Readings/ Videos/ Lectures	Activities/ Assignments	Simulations	Assessments
Activity 1- Introduction to Unit Guiding question: How does cooking change our food? ENGAGE	Students will demonstrate their background knowledge by making predictions about how cooking changes food. They will show their understanding by categorizing changes as physical changes or chemical changes	N/A (Prior Knowledge)	*I can use prior knowledge to model the differences between physical and chemical changes.*	Cooked (video intro) Changes in Cooking (examples)	Warm-up (brainstorm) Discuss guiding questions and brainstorm ideas about food changes. Physical vs Chemical Changes (in lab notebook)		Physical vs Chemical Changes (in lab notebook)
Activity 2- Determining Physical Properties Guiding question: What properties make things different? EXPLORE	The instructor will bring 3 objects for the class to observe and identify physical properties. The objects will each have unique properties and will be categorized by the following qualities; shape, color, texture, hard/soft, magnetism, other.	5-PS1-3. Make observations and measurements to identify materials based on their properties.	*I can describe physical properties (shape, color, texture, etc.) of different objects.*			Day 1 - Inquiry-based activity (no simulation)	
Activity 3- Classification of Properties Guiding question: Why do scientists sort materials based on their properties?	Students will take pictures of their 3 observed objects (4-5 students). On the provided Google Jamboard, groups will add group member names and screenshot/ picture of each object. They will decide on categories/properties for their group objects and turn in one slide per group.	5-PS1-3. Make observations and measurements to identify materials based on their properties.	*I can describe physical properties (shape, color, texture, etc.) of different objects.* *I can classify objects based on their properties.*		BrainPop Sorting Sheppard Software Quia – Animal Classification Student predictions	Day 2- Properties of Matter	Group Classification (Google Jamboard)

EXPLORE							
Activity 4 – The Science of Lunch Guiding question: Why do scientists sort materials based on their properties? (continued) EXPLAIN	Students will be bringing snacks for this module. Using their knowledge of identifying properties (learned in Module 2-3), students will be recording observations about their snack on a guided template. They will then share their observations with a partner to try to have them guess their snack based on the properties provided. This will lead to a whole class discussion about defining properties and categorizing items based on their properties. They will then watch the Crash Course episode and be assigned the Science of Lunch worksheet for at home practice	5-PS1-3. Make observations and measurements to identify materials based on their properties.	*I can classify objects based on their properties.*		The Science of Lunch (Crash Course)	Day 1- Science of Snacks (investigation) Day 2- Mystery Powder Analysis	The Science of Lunch – Examples from home
Activity 5- Solids, Liquids, Gases Guiding question: What happens to matter particles when it changes from solid, to liquid, to gas? EXPLORE	Students will complete a states of matter reading as a whole class and answer comprehension questions with partners. The instructor will model how to use a simulator with the States of Matter website. Students will then use PhET simulations to model and better understand phase changes. The teacher may use one of the forms of formative assessment to determine student understanding of states of matter and phase changes.	5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen**.**	*I can model the differences in states of matter.*	States of Matter Reading Teacher Demo – States of Matter simulation (with discussion)	Warm-up: State of Matter Sort	States of Matter (states and phase changes) Phase Changes Phases of Water CK-12 Phase Changes	Formative - Trivia game - Quizizz

Activity 6- Physical Changes in Cooking Guiding question: What qualifies something as a physical change? EXPLORE	Students will be moving from station to station around the room following directions and collecting observations. Each station will have a different physical change that one might find in the kitchen. Students will record what the substance looked like before, and after and will explain how they were physical changes based on their understanding.	5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.	*I can identify and explain examples of physical changes in the kitchen.*		Physical change (Frayer model definition) Physical Changes in Cooking Directions (stations) Physical Changes in Cooking Handout		Physical Changes – Flipgrid (example from home)
Activity 7- Changing Matter Guiding question: What happens to the properties of substances when mixed, heated or cooled? EXPLORE/ EXPLAIN	Students will work in groups/ pairs to investigate and record observations and answers to discussion questions about changing matters. They will use four examples; warm water and salt, water and food coloring, water + glue + borax, baking soda and vinegar. Students will determine what changes occur and whether it is physical, or chemical based on the properties before and after combining substances.	5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.	*I can determine the effects of two substances when they are mixed, heated or cooled.*	Physical vs Chemical Changes (PBS video) Change Brothers Story Teacher example slides	Chemical change (Frayer model definition) Act. 7: Changing Matter (p. 11) data collection chart	Day 1- Inquiry-based investigation Day 2- Chemical Changes (normal set-up)	Formative - Physical vs Chemical Changes - Venn Diagram
Activity 8- Is it a New Substance? Guiding Question: How do we know if a new substance has formed when two or more substances are mixed	To begin, students will make a prediction about what they think will happen when salt is added to water and then is heated (boiled). After writing their prediction, students will share their ideas with their lab partner. Students will draw a before/ after model of salt and water in their observation box and take notes. While they are waiting for the water to boil, students will	5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.	*I can explain the creation of new substances using evidence and reasoning from the experiment.*		Salt + Water (teacher demo) Egg Experiment (hard boiled + frozen)	Salt + Water (Simulation)	Is it a New Substance? - CER Response

together or heated? EXPLAIN	then begin collecting data about their 2 eggs. Students will spin the eggs on the table and discuss as a group why they move differently. Then, students will make a prediction about the eggs to identify if either one has gone through a chemical change. They will share their predictions about the eggs with their lab partner. After, students will crack both eggs and draw models of each showing similarities and differences between the two. At the end of the activity, students will complete a CER response about whether or not a new substance has been formed based on evidence and reasoning from the activity.						
Activity 9- What's the Matter? (Physical vs Chemical Changes) Guiding Question: What conditions determine whether something has gone through a physical change or a chemical change? EXPAND	At this point, students have had plenty of practice with identifying and explaining physical and chemical changes. During this elaborate/ expand activity, students will work in groups to find NEW examples of physical and chemical changes. Our focus for this unit has been on examples from cooking, but in this activity, students will work on finding videos of different examples (inside or outside of the kitchen). Groups will then add videos of each to the Venn Diagram while filling out similarities and differences between the examples they found.	5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances	*I can use definitions, experiments, and activities to create a Venn Diagram comparing/ contrasting physical and chemical changes.*			CK-12: Physical vs Chemical Changes	

Activity 10- Cooking up Reactions Guiding Question: How does cooking food change its properties? EXPAND	Students will use what they have learned about physical and chemical changes to identify AT LEAST two examples of each type of change while cooking. This will be completed on a Google Slides presentation and each slide should include: • Pictures or videos showing the before, during, after phases of the change • Explanation of HOW you know this is a physical or chemical change • Based on previous activities, how can you PROVE that this is correct?	5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances	*I can use definitions, experiments, and activities from class to demonstrate physical and chemical changes in cooking.*		Act. 10: Cooking Up Reactions		Similar to FINAL evaluation (scaffold prior to assessment)
Activity 11- Air- Is it Really There? Guiding question: How can we measure and observe matter that is too small to be seen? EVALUATE	Students will begin by brainstorming ideas of how to measure matter that is too small to be seen. Following a class discussion about predictions, students will learn about each station they will travel to throughout the room. Each station has different methods for showing "invisible air" and students have to create small models and explain how they know air is really there even when the particles are too small to be seen. After completing each station, the class will discuss results, and students will answer the follow-up questions in their lab notebook.	5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.	*I can develop a model that describes that matter is made of particles too small to be seen.*		Air is it Really There? Air is it Really There? (activity)	Gas in a Syringe	Analysis questions - end of activity in lab notebook
Activity 12- Law of Conservation	Students will learn about and define the law of conservation of matter by completing readings, watching videos, watching demonstrations, and	5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs	*I can use scientific modeling to understand the law of conservation.*	What's Matter? (review) Part(icles) of Your World	Law of Conservation (p. 18) - Observations (before/ after) teacher demo - Mass before and after	PhET Simulation	Summative - Law of Conservation explained in final Cooking Experiment

Guiding question: What happens to the mass of a matter when it is mixed, cooled or heated? EXPAND	participating in a whole class activity. After students have developed their background knowledge, they will use a PhET simulation to practice using the law of conservation and will follow up with a hands-on lab to test the law. This will be applied in their final Cooking Experiment (summative assessment).	when heating, cooling, or mixing substances, the total weight of matter is conserved. 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.		Vacation or Conservation (of mass) Teacher Demo The Law of Conservation Professor Dave	- Explanation of results Alka Seltzer Lab- Conservation of Mass	Day 2- Chemical Changes (with Gas collection)	CER Response (following Alka Seltzer Lab)
Activity 13- Cooking with Experimental Design	Students will write up the experiment in which they predict physical and chemical changes, including a paragraph abstract, they will observe and record physical and chemical properties, list materials (ingredients), and write a detailed, repeatable scientific procedure for the cooking project. While cooking, they will record quantitative and qualitative data, and pictures of physical or chemical changes. They will then answer data analysis questions, and a conclusion summarizing what they learned.	5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved. 5-PS1-3. Make observations and measurements to identify materials based on their properties. 5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances	*I can conduct an investigation to determine physical and chemical changes in cooking using observations, measurements, and evidence to support my analysis.*		Act. 13: Cooking with Experimental Design (template) Conclusion Slide		Peer Evaluation Rubric Analysis Rubric

APPENDIX B
SCIENCE TEACHER INQUIRY RUBRIC

Table B-1. The Science Teacher Inquiry Rubric (Beerer and Bodzin, 2003) used to evaluate lessons before and after implementation of the intervention.

Science Teacher Inquiry Rubric (STIR)

Directions: Reflect on the science lesson that you taught today. In your reflection, consider each of the following categories and the six statements on the left, written in bold. After looking at each bold statement, assess today's science instruction based on the categories delineated for statement. Place one "X' in the corresponding cell for each bold-faced statement. If there is no evidence of one of the statements in today's lesson, place a slash through the bold-faced statement. When you are finished, you should have 6 total responses.

Learner Centered ⟷ Teacher Centered

	Learner Centered			Teacher Centered	
Learners are engaged by scientifically oriented questions.					
Teacher provides an opportunity for learners to engage with a scientifically oriented question.	Learner is prompted to formulate own questions or hypothesis to be tested. ☐	Teacher suggests topic areas or provides samples to help learners formulate own questions or hypothesis. ☐	Teacher offers learners lists of questions or hypotheses from which to select. ☐	Teacher provides learners with specific stated (or implied) questions or hypotheses to be investigated. ☐	No evidence observed. ☐
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.					
Teacher engages learners in planning investigations to gather evidence in response to questions.	Learners develop procedures and protocols to independently plan and conduct a full investigation. ☐	Teacher encourages learners to plan and conduct a full investigation, providing support and scaffolding with making decisions. ☐	Teacher provides guidelines for learners to plan and conduct part of an investigation. Some choices are made by the learners. ☐	Teacher provides the procedures and protocols for the students to conduct the investigation. ☐	No evidence observed. ☐
Teacher helps learners give priority to evidence which allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.	Learners determine what constitutes evidence and develop procedures and protocols for gathering and analyzing relevant data (as appropriate). ☐	Teacher directs learners to collect certain data, or only provides portion of needed data. Often provides protocols for data collection. ☐	Teacher provides data and asks learners to analyze. ☐	Teacher provides data and gives specific direction on how data is to be analyzed. ☐	No evidence observed. ☐

Learners formulate explanations and conclusions from evidence to address scientifically oriented questions.					
Learners formulate conclusions and/or explanations from evidence to address scientifically oriented questions.	Learner is prompted to analyze evidence (often in the form of data) and formulate own conclusions/ explanations. ☐	Teacher prompts learners to think about how analyzed evidence leads to conclusions/explanations, but does not cite specific evidence. ☐	Teacher directs learners' attention (often through questions) to specific pieces of analyzed evidence (often in the form of data) to draw conclusions and/or formulate explanations. ☐	Teacher directs learners' attention (often through questions) to specific pieces of analyzed evidence (often in the form of data) to lead learners to predetermined correct conclusion/explanation (verification). ☐	No evidence observed. ☐
Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.					
Learners evaluate their conclusions and/or explanations in light of alternative conclusions/ explanations, particularly those reflecting scientific understanding.	Learner is prompted to examine other resources and make connections and/or explanations independently. ☐	Teacher provides resources to relevant scientific knowledge that may help identify alternative conclusions and/or explanations. Teacher may or may not direct learners to examine these resources, however. ☐	Teacher does not provide resources to relevant scientific knowledge to help learners formulate alternative conclusions and/or explanations. Instead, the teacher identifies related scientific knowledge that could lead to such alternatives, or suggests possible connections to such alternatives. ☐	Teacher explicitly states specific connections to alternative conclusions and/or explanations, but does not provide resources. ☐	No evidence observed. ☐
Learners communicate and justify their proposed explanations.					
Learners communicate and justify their proposed conclusions and/or explanations.	Learners specify content and layout to be used to communicate and justify their conclusions and explanations. ☐	Teacher talks about how to improve communication, but does not suggest content or layout. ☐	Teacher provides possible content to include and/or layout that might be used. ☐	Teacher specifies content and/or layout to be used. ☐	No evidence observed. ☐

APPENDIX C
STUDENT INTERVIEW ASSENT

Hi,

As you know, I am currently working towards my doctorate at the University of Florida. I am trying to learn how the virtual simulations we used in class impact how you learn. If you would be willing, I would like to ask you about 9 questions that would help me with my research.

There are no known risks for your participation. You do not need to be in the study if you don't want to and you can quit the study at any time. I will be the only person that will know your answers, then following our interview, your name will be removed as I move forward with my research. If you don't like a question, you don't have to answer it and if you decide you do not want to be in the study during the interview, your responses will be removed immediately.

This interview will not influence your experiences or grades in this program. Your parents/guardians will allow you to participate in this study if you give permission. Would you be willing to answer a few questions and help with my study?

APPENDIX D
IRB APPROVED DOCUMENTS

Study ID:IRB202300673 Date Approved: 5/22/2023

Combining Inquiry-Based Activities with Virtual Simulations in 5th Grade Science
An Action Research Study

Research Description

The purpose of this qualitative study is to find ways to incorporate both inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding. The current research includes discussions around the impacts of inquiry-based learning in elementary science education, the importance of authentic learning, and the combination of virtual simulations and physical experiments or activities in higher education. The research questions for this study are as follows:

1. In what ways do I adjust my teaching with inquiry based activities and simulations to facilitate student learning of physical and chemical changes?
2. In what ways, if any, will using virtual simulations and inquiry-based activities improve students' conceptual understanding of physical and chemical changes as evidenced by the models they create?

All students in Mrs. Tomczak's science classes will benefit from the tools offered in the intervention, whether or not they are part of the study. Data will be collected in the form of field notes, documents, interviews, observations, a reflective journal, and student surveys (exit tickets). The data will be analyzed using Descriptive, In Vivo, and Process coding. Credibility is established through methodological triangulation of data sources. The ethical considerations included in this study are reflexivity, procedural ethics, relational ethics, informed consent, and approval from the University of Florida's Instructional Review Board and Okemos Public Schools.

Thank you for your consideration!

Julie Tomczak

Figure D-1. This is a screenshot of the approved research description sent to students and families participating in the study.

Study ID:IRB202300673 Date Approved: 5/22/2023

Informed Consent Parent Email

Dear Science Families,

This email is to inform you that I am currently working on my doctorate at the University of Florida and writing my dissertation. Today, I sent home more information about my research and provided an informed consent form for you to complete. The goals of this study are highlighted in the shared documents. Even if you choose for your child not to participate in the study, they will have access to the same lessons, activities, and simulations we use as a class; I just will not be collecting data on your child for my study. Please let me know if you have any questions or concerns.

Thank you,

Julie Tomczak

Figure D-2. This is a screenshot of the approved informed consent email that was sent to families providing more information about the study.

UF | Institutional Review Board
UNIVERSITY *of* FLORIDA

RESEARCH PARTICIPANT INFORMED CONSENT FORM

Please read this document carefully before you decide to participate in this research study. **Your participation is voluntary, and you can decline to participate, or withdraw consent at any time, with no consequences**.

Study Title:

COMBINING INQUIRY-BASED ACTIVITIES WITH VIRTUAL SIMULATIONS IN FIFTH GRADE SCIENCE: AN ACTION RESEARCH STUDY

Person(s) conducting the research:

Julie Tomczak

Purpose of the research study:

The purpose of this qualitative study is to find ways to incorporate both inquiry-based activities and virtual simulations to enhance instruction and improve student conceptual understanding. The current research includes discussions around the impacts of inquiry-based learning in elementary science education, the importance of authentic learning, and the combination of virtual simulations and physical experiments or activities in higher education.

What you will be asked to do in the study:

All students in Mrs. Tomczak's science classes will benefit from the tools offered in the intervention, whether or not they are part of the study. All students will be completing the lessons/ activities as planned by the district but will be provided with additional resources in the form of virtual simulations to enhance their learning. Additionally, all students will complete pre/post-scientific models of physical and chemical changes, exit tickets following the studied activities on Google Forms. If you consent, students who assent to participate in the research projects will be interviewed in small groups to provide feedback about the unit. I will also make use of their class materials and products in my study.

Time required:

The entire unit takes about 9 weeks (about 2 months) to complete. Students will be working on the four activities studied in this research over the course of 2 weeks. Scientific models and exit tickets will be collected during the class period from all students. The interviews will take place during the last week of school for no longer than 5-10 minutes during my planning period (5th hour). Students that chose to participate will only be interviewed once for concluding data.

Risks and benefits:

No risks are associated with involving children in this research as it provides additional support tools to classroom instruction - available to all students.

(a) Students will be kept anonymous throughout the study.

(b) Results of the study or participation in the study do not impact student grades. Additionally, interviews will be conducted at the end of the term to ensure no impact on student grades.

Confidentiality:

During the study, the researcher will collect pre/post scientific models created by the participants. Names will be removed from these documents and students will be given pseudonyms. Additionally, the researcher will collect exit tickets from all students and the participants in the study will have any identifiable information removed and replaced with pseudonyms. Finally, during the interview process, the researcher will take notes on student responses, but will not record the interview. This will help to keep students anonymous during the research process. At the end of the study, participant names from interviews will be removed from the study.

Compensation:

No compensation provided

May the researcher(s) benefit from the research?

We may benefit professionally if the results of the study are presented at meetings or in scientific journals.

Withdrawal from the study:

You are free to withdraw your consent and to stop participating in this study at any time without consequence. You can decline to answer any question you don't wish to answer.

If you chose to withdraw, your information will be removed from the study and discarded.

The researcher can withdraw you from the study if any data is missing during the analysis process.

If you wish to discuss the information above or any discomforts you may experience, please ask questions now or contact one of the research team members listed at the top of this form.

If you have any questions regarding your rights as a research subject, please contact the Institutional Review Board (IRB02) office (University of Florida; PO Box 100173; Gainesville, FL 32610; (352) 392-0433 or irb2@ufl.edu.)

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

____

Participant Name

____ ______________

Participant Signature Date

____

Name of Person obtaining informed consent

____ ______________

Signature of Person obtaining informed consent Date

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BIOGRAPHICAL SKETCH

Julie Tomczak earned her bachelor's degree in elementary education, specializing in Integrated Sciences, from Michigan State University in 2011. She began teaching 7^{th} grade science in Grand Rapids Public Schools for three years. In 2014, she started her master's program at Michigan State University and completed it in 2016 with a Master of Education degree with a major in educational technology. During that time, she moved districts in Michigan and began teaching 5^{th} grade science, language arts, and technology. She received her Ed.D. from the University of Florida in December 2023.

Over time, Julie found opportunities to learn more about science education and found ways to take action in moving elementary science forward using the Next Generation Science Standards. She was on the curriculum development committee for the Mi-STAR curriculum program in 2016. She also worked with her colleagues to develop a curriculum for the 5^{th} grade that aligned with the Next Generation Science Standards. In 2022, she began working with the Data Recognition Corporation (DRC) in Michigan to develop, analyze, and revise science questions for the Michigan Student Test of Educational Progress (M-STEP). Julie currently resides in mid-Michigan with her husband, Mark.