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Abstract

This study explored how using computer simulations helped 7th grade students improve their understanding of chemistry. At my school, many students are below grade-level in reading and math, which can make science more challenging. During a 3-week chemistry unit, I used simulations from Amplify and other online tools. These simulations allowed students to interact with virtual experiments like combining substances and observing what happens directly on the computer. Students in two classes took a test before and after the unit. After using the simulations, their scores increased, and they were able to explain scientific ideas more clearly in writing, including using and developing and using models. Instead of just naming atoms, students began to show how atoms rearrange and stay balanced during chemical reactions by creating models. This study shows that computer simulations make learning science more engaging and accessible, especially for schools that don’t have full lab equipment. It also helps support Next Generation Science Standards (NGSS) by giving students opportunities to build and test their own models. This kind of learning which is called model-based reasoning helps students better understand abstract science concepts in a meaningful way.

Introduction

Many middle school students are excited to learn about chemistry, but they often find it difficult to understand. At my school, a lot of students are still catching up in reading, writing, and math. This makes it harder for them to do well in science, especially in chemistry, where students need to read complex texts and do calculations to understand how atoms combine and react. From my experience, chemistry is one of the most challenging units for my students. One big reason is that they struggle with the math behind chemical reactions, like balancing equations or interpreting particle diagrams. We usually do hands-on labs in class, but there are limits. Some experiments are too dangerous or require materials that we do not have. Instead, we often use videos or drawings to show how reactions work. But these do not always help students truly understand the science. That is why I wanted to try something new in implementing computer simulations.

My students come to my classroom with strengths that I used in this research. They have a growth mindset, creative skills for different and unusual perspectives, and technology skills. The students have a mindset where they have a willingness to improve capabilities but also engage in science concepts. They are eager to learn chemistry because they want to mix chemicals and know how life depends daily on the chemical processes on the planet and their own bodies. They bring creativity into the classroom by always trying to find different ways to solve problems and, although they are not all visually creative, they have demonstrated novel ways of solving problems. Lastly, the students come to the class with technology skills since they have grown up using technology at the elementary level. Technology highlights skills like analytical thinking, research, and the willingness to learn. Therefore, it is a powerful tool for engagement and cultural relevance, all while motivating me to find ways of integrating technology in the science classroom.

My students come to me at two grade-levels below in reading, writing, and math performance. This in turn has translated into a decline in their success in the science classroom, especially when we cover chemistry. From my experience, students struggle with the chemistry unit the most because of their poor mathematical skills in making calculations and mostly have the inability to balance chemical equations and/or reactions. This has led to me reflecting on my teaching practice and looking at ways to improve learning. When teaching chemistry, I use hands-on activities and experiments, but not many lessons can be taught in the classroom for safety reasons. I rely on videos or models to demonstrate certain chemical reactions and concepts. This study will incorporate the use of computer simulations to aid in bridging the gap between hands-on and modeling in the classroom. This will be done through the use of textbook-aligned computer simulations and those from other textbooks and online. The technology will enhance hands-on experiential learning rather than replace it. Next Generation Science Standards (NGSS) call on students to be able to develop and use models in the classroom. The study will test the effects of using computer simulations in the Amplify textbook on the students' ability to use models.

Computer simulations are interactive models that students can use on a computer. These simulations let students test things out, change variables, and watch what happens. They are not just like watching a video. According to Sneider et al. (2014), simulations are "dynamic computer models" that help students understand science by letting them explore how changing one thing affects another. They give students a chance to do experiments in a safe, virtual way. Simulations are also supported by the NGSS, which asks students to develop and use models as part of learning science. In fact, models are one of the eight science practices in the standards and the learning targets we use in my district. As Krajcik (2012) says, "It is important for students to construct models that explain phenomena, show how their models are consistent with their evidence, and explain the limitations of those models." Simulations can help students do just that in building and testing science ideas in a way that is meaningful.

Research Questions

1. Is there a difference between student achievement scores on a pre-test and post-test after students are taught with computer simulations?
2. Is there a difference between the students' use of models after students are taught with computer

simulations?

Significance

This study matters because it explores a new way to teach chemistry to students who may not learn best through traditional lessons. In schools where students often perform below grade level, teachers need tools that support different learning styles and give all students a chance to succeed. Computer simulations offer one possible solution. Several researchers support using simulations in science classrooms. Develaki (2019) found that simulations help students build stronger reasoning skills and make better decisions. Gouvea and Passmore (2017) also explain that simulations help students connect scientific ideas to what they experience in the classroom by giving them more time to explore and test those ideas. These tools can also make learning fairer. Not all schools can afford expensive lab materials, but simulations can bring those experiences to every student through a computer screen. This study is also important because there is still not enough research about how simulations work for middle school students, especially in diverse and under-resourced schools. If the results show that students learn more through simulations, then teachers, schools, and curriculum designers might start using them more often. It could lead to science classes that are more engaging, safer, and better at helping all students understand challenging topics like chemistry.

Operational Definitions

In this study, computer simulations refer to interactive, digital tools that allow students to explore science concepts by manipulating variables and seeing real-time results, rather than just reading or watching videos. Student achievement scores are the results students receive on a pre-test and post-test designed to measure their understanding of chemistry concepts taught during the unit. When referring to models, this means the ways students represent scientific ideas like particle diagrams or explanations that show how substances interact and change during chemical reactions.

Theoretical Framework and Literature Review

This study is grounded in constructivist learning theory, which suggests that students build understanding through active engagement with content. Vygotsky's theory of the Zone of Proximal Development (ZPD) supports the idea that learners benefit from scaffolded experiences like simulations. Computer simulations also align with model-based reasoning emphasized in the NGSS science practices, particularly the development and use of models to explain phenomena (Krajcik, 2012).

Next Generation Science Standards (NGSS) are a three-dimensional approach to teaching and creating learning experiences for students in middle school. More specifically, developing and using models in the classroom provides opportunities for learning. Computer simulations are technological models that "give learners the opportunity to solve problems without the authoritative persuasion of the teacher by providing a learner-centered context" (Freirmuth, 2002). Some advantages of computer simulations include easier accessibility to real-life problems and aids the process of learning.

NGSS Allows Flexibility in Classroom Design

The state of California has adopted the Next Generation Science Standards (NGSS) as a three-dimensional approach for K–12 instruction. The three distinct, but equal, dimensions to learning science are crosscutting concepts, disciplinary core ideas, and science and engineering practices. Crosscutting concepts aid students in exploring connections across the domains of physical science, life science, earth and space science, and the engineering design. The disciplinary core ideas are key concepts across the four domains that build on each other. Lastly, the science and engineering practices explain how engineers design and build systems, while scientists investigate the natural world. NGSS standards "give local educators the flexibility to design classroom learning experience that stimulate students' interests in science and prepares them for college, careers, and citizenship" (NGSS, 2000).

Developing and Using Models Provides Opportunities for Learning

One of the eight core science and engineering practices is developing and using models. Students use models from kindergarten to twelfth grade and beyond. The use of two-dimensional or three-dimensional models in the science classroom provide students with opportunities to learn conceptual matter because they "represent both concrete and abstract ideas [and] students will ultimately be able to create simple models that may reflect data, show relationships, or represent their own designs" (Watkins, 2021). In middle school, students access prior knowledge and use models to build upon it to understand phenomena, predict outcomes in systems, and modify models to change variables and explore possible new outcomes. Krajcik (2012) "It is important for students to construct models that explain phenomena, show how their models are consistent with their evidence, and explain the limitations of those models" (Krajcik, 2012). Cartier et al.'s (2001) research found that providing students opportunities to work with models can support their understanding of scientific models and inquiry.

Computer Simulations in the Science Classroom

Students can use drawings or build structures to create models, but the Next Generation Science Standards call on students to develop three-dimensional representations of new information gathered by either hand or a computer (Schwarz, et al., 2009). The computer representations are called computer simulations. By using computer simulations, students are engaging in the scientific process of developing models and using them to make sense of new information. "Simulations that allow students to use computational thinking are not simply animations, they are dynamic computer models that involve students in changing conditions and observing new outcomes" (Sneider, 2014). For example, in an energy computer simulation, students can learn about the conversion of kinetic energy to potential energy by choosing how much friction a skateboarder has going down a ramp and/or whether the skater is on the moon or on Earth, thus altering the amount of gravity.

Advantages of Computer Simulations

The advantages of computer simulations include fostering reasoning, increasing understanding, and accessibility. Develaki (2019) found that computer simulations can foster sound reasoning and decision-taking abilities. A study by Gouvea (2017) found that students can better develop an understanding of phenomena by using computer simulations because it allowed them to have more time to interact with phenomena. The study showed that you can learn as much by using computer simulations as you can with notetaking and lectures. Chemical experiments and/or labs are sometimes difficult to do in the classroom because certain chemicals might be unsafe or too expensive. Mohondro (2018) found that middle school students developing and using models as computer simulations is a powerful tool, especially when it comes to phenomena that are difficult to observe in the typical classroom setting due to scale, time, safety, or budget limitations.

Disadvantages of Computer Simulations

Mohondro (2018) concludes that if used incorrectly, computer simulations will be treated in the old definition of models, being less effective in the students' learning process because they will treat the computer simulations as representations of what they know as opposed to using it as a tool to generate new knowledge. Another disadvantage of computer simulations includes the amount of training necessary to build models "it is an art learned over time and through experience" (Banks, 1999) and requires specialized training where skill levels of users vary widely" (Shannon, 1992). All the training for students is time consuming and will take time away for instruction (Carson, 2005). In conclusion, the goal of a teacher in the classroom is to facilitate learning and instill 21st Century skills. In doing so, computer simulations are an option for stimulating learning and growth in all academic classes. The computer simulations will allow students to manipulate variables for certain phenomena and study the outcomes of such changes. Its benefits seem to outweigh the disadvantages, so it might be worth trying in any classroom to help students solve real-world problems. It concerns all teachers at all levels because any phenomenon can be simulated on a computer screen, while some other limitations might include inadequate research done in middle schools and not enough simulation sites for students to access.

Method

The class consisted of males and females aged 12 and 13, made up of mostly minority students. Each class consisted of approximately 25- 26 students in a 55-minute class period. The class was a seventh-grade integrated science class focusing on a chemistry unit. The students were taken from each class, as an opportunity sample, with the class population including students from the Gifted and Talented Education (GATE) program, English Language Learners (ELL), and Reclassified Fluent English Program (RFEP) students.

Measures

Students will take a pre-assessment and post-assessment based on the Next Generation Science Standards for middle school. The questions used were a collection of chemistry-related questions focused on the practice of using models.

Instrumentation

The primary instrument used in this study was a teacher-created assessment aligned to the Next Generation Science Standards (NGSS) for middle school physical science, specifically focusing on the disciplinary core idea PS1: Structure and Properties of Matter and the science practice of Developing and Using Models. The assessment included 18 questions, combining multiple-choice items to assess factual knowledge and an open-ended prompt to evaluate students' ability to create, interpret, and revise particle models of chemical reactions.
Open-ended responses were scored using a 3-point rubric:

3 – Proficient: Accurate model, clear explanation, strong alignment with evidence.
2 – Basic: Partially accurate model or explanation, minor errors.
1 – Limited: Minimal understanding or incomplete response.
0 – No response or off-topic.

The assessment was reviewed by two science educators for content validity and alignment to NGSS practices. A sample copy of the pre-/post-test and rubric will be included in Appendix A.

Data Collection

The pre-test and post-test had students answer multiple-choice and open-ended questions on a packet with 16 multiple choice questions and 2 open-ended questions. Each student packet was labeled with an identifying number. The data sheet listed all participants by number and each column had each test question. Each participant's question answer was recorded by score. Each column was computed by the number of correct answers for each question and test total. A colleague was able to identify those who participated in the study and those who did not with a number. This helped differentiate between sample students and the others.

Data Analysis

The anticipated Analysis of Variance (ANOVA) method was used to analyze data. A one-way ANOVA was used, more specifically, since I had a single independent variable (computer simulations). I was able to understand how the classes within the independent variable are different, allowing me to understand which of them have a connection to my dependent variable (academic achievement).

Human Subjects Protections

The names, school name, assessments and assignments collected were not shared. Students were identified by a number in any data collection sheet (i.e., Google Sheets, Microsoft Excel) and they were password protected. A colleague was able to identify those who were participating in the study and those that were not by assigning a random number to each test/student.

Implementation of the Intervention

The intervention occurred during a 3-week chemistry unit. Students in the experimental group received instruction supplemented by computer simulations from the Amplify Science curriculum, including embedded digital modeling tools and interactive scenarios. Additional simulations were used from PhET Interactive Simulations and Gizmos by Explore Learning, selected to match the concepts of chemical reactions, particle collisions, and balancing equations.

Each simulation-based lesson followed this structure:

- Introduction of the phenomenon (e.g., mixing two substances)
- Prediction and setup within the simulation
- Manipulation of variables (e.g., temperature, particle types)
- Observation and recording outcomes
- Model construction or revision, often through drawing particle diagrams or answering guiding questions

The control group received the same content using traditional instruction (teacher modeling, video demonstrations, static diagrams), without access to computer simulations. Both groups completed the same pre- and post-assessments.

Results

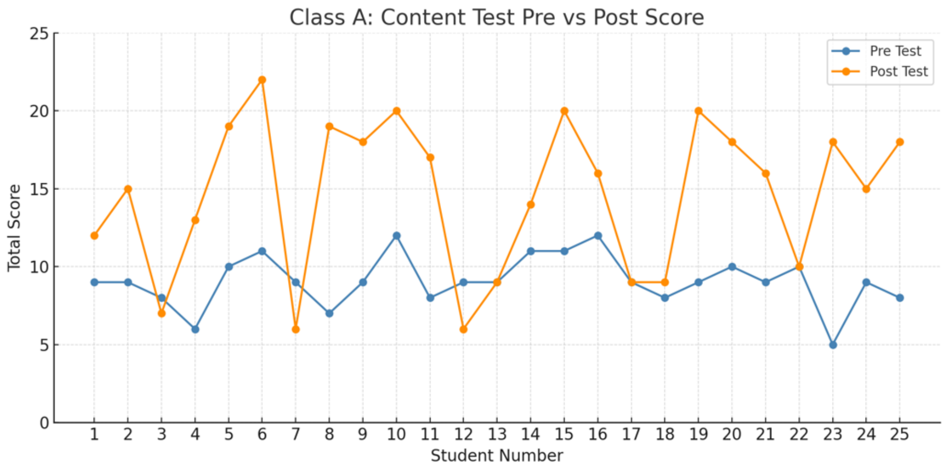
This study involved 51 seventh-grade students who were learning chemistry in two different science classes: Class A (25 students) and Class B (26 students). The goal was to find out if using computer simulations could help students understand chemistry better, especially hard topics like particle behavior and chemical reactions. The data gathered was from students that took a pre-test before starting the unit and a post-test after completing the lessons. The test was from their Amplify unit on Chemical Reactions and was made up of 16 multiple choice questions (1 question) and 2 open-ended questions (3 points). The highest possible score was 22 points. All students took the same test before and after the unit to keep things fair and reliable.

The first question: Is there a difference between student achievement scores on a pre-test and post-test after students are taught with computer simulations?
Test Scores Improved

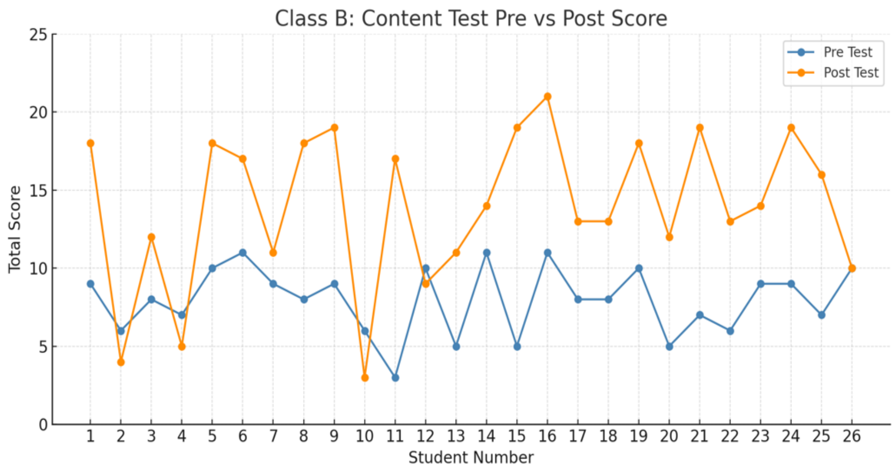
To evaluate the impact of computer simulations on student academic achievement, a one-way ANOVA was conducted. The independent variable was the instructional method (use of computer simulations), and the dependent variable was academic achievement, measured through combined multiple-choice and open-ended pre- and post-test scores.

Table 1. Descriptive Statistics on Student Achievement Scores

Class	Pre-Test Mean	Pre-Test Standard Deviation	Post-Test Mean	Post-Test Standard Deviation
A	9.08	1.66	14.64	4.86
B	7.96	2.14	13.96	4.93



Graph 1. Class A - Student Achievement Scores



Graph 2. Class B - Student Achievement Scores

ANOVA Analysis

A one-way ANOVA was conducted to determine whether the difference between pre- and post-test means was statistically significant for each class.

- Class A: $F(1, 48) = 29.27$, $p < 0.001$
- Class B: $F(1, 50) = 32.41$, $p < 0.001$

Both results indicate that the increase in student scores from pre-test to post-test was statistically significant, meaning the observed differences are unlikely to have occurred by chance. The data show that the use of computer simulations had a positive and statistically significant impact on student learning outcomes in both Class A and

Class B. While Class A began with slightly higher baseline scores, both classes exhibited substantial gains. The wider spread in post-test scores (SD > 4 in both classes) suggests that many students benefited from the intervention, although some had higher gains than others. These results support the hypothesis that computer simulations are an effective instructional strategy in middle school science classrooms for improving academic achievement, with gains shown in both of my classes. In support of previous research, the results support the idea that computer simulations can bridge learning gaps, especially in abstract topics like chemical reactions and particle behavior (Develaki, 2019; Sneider et al., 2014).

The second question: Is there a difference between the students' use of models after students are taught with computer simulations?

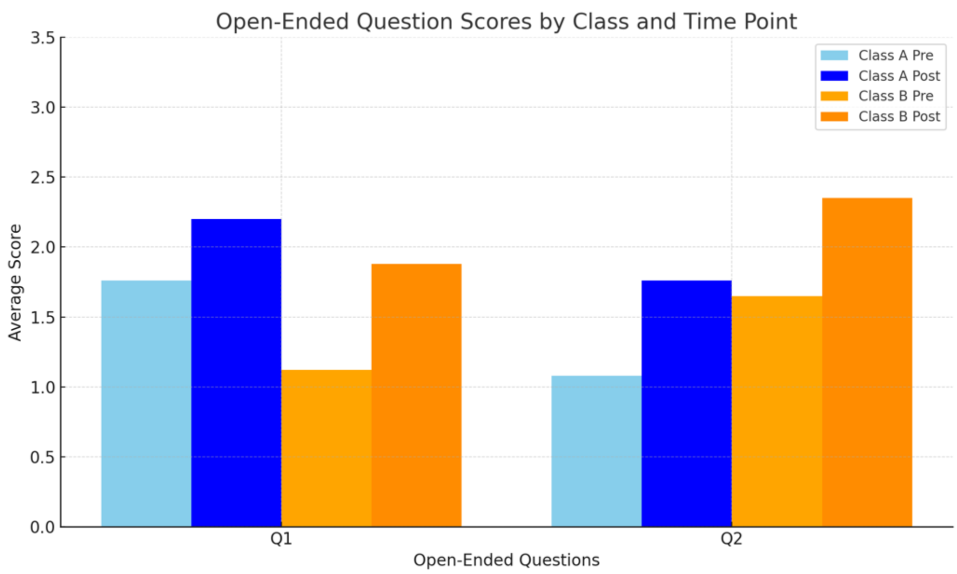
To assess students' understanding of chemical modeling, two open-ended questions were scored using a rubric based on Progress Build (PB) levels:

- **Level 1 (L1):** Identifying substances by different atoms and properties
- **Level 2 (L2):** Describing rearrangement of atoms during chemical reactions
- **Level 3 (L3):** Explaining conservation of atoms (no atoms lost or created)

Each question was scored on a scale from 1 to 3, corresponding to PB Levels 1–3.

Table 2. Model-Based Reasoning - Open Ended-Responses

Class	Question	Pre-Test Mean	Post-Test Mean	Average Gain
A	1	1.76	2.20	+0.44
A	2	1.08	1.76	+0.68
B	1	112	1.88	+0.76
B	2	1.65	2.35	+0.70



Graph 3. Open-Ended Responses - Class A/B

Discussion

The rubric-based analysis of open-ended questions revealed meaningful growth in students' ability to use models to explain chemical reactions, a key scientific practice aligned with NGSS (NGSS, 2013). Notably, the students moved from basic recognition (L1) to mechanistic reasoning (L2) and conservation-based explanations (L3). Additionally, the visual and interactive nature of computer simulations likely contributed to deeper conceptual understanding, especially among students who initially struggled. This analysis demonstrates that the integration of computer simulations in science instruction can lead to significant gains in both content knowledge and model-based reasoning. These findings suggest that simulations are an effective pedagogical tool for supporting students' understanding of abstract scientific concepts like atomic structure and chemical change (Develaki, 2019; Sneider et al., 2014).

Impact on Teaching Practice and Instructional Design

The results of this study will greatly influence my future teaching practices, especially in how I approach abstract science content. Simulations offered a safe, visual, and hands-on alternative to traditional labs, which are often restricted due to safety, cost, or equipment limitations. Students were able to manipulate variables, make predictions, and revise models, which are essential NGSS-aligned practices (Krajcik, 2012). I will continue integrating computer simulations during units that involve modeling, and pair them with open-ended assessment prompts to evaluate conceptual understanding more effectively. This approach addresses a variety of student needs, including English Learners and students with limited lab experience, by using visual and interactive tools to scaffold instruction (Watkins, 2021).

The use of diverse teaching strategies, including hands-on, digital, and written responses, ensures that every student has access to science learning in a way that works for them because I believe in equity. These findings have implications also for educators in low-income communities, where chemistry is many times taught without the tools that bring it to life. My findings support the belief that computer simulations give an opportunity into the abstract world of atoms and reactions that students struggle to comprehend or visualize. As Mohondro (2018) states, "computer simulations are a powerful tool, especially when it comes to phenomena that are difficult to observe in the typical classroom setting due to scale."

Reflection, Future Plans, and Theoretical Connection

Looking forward, I plan to share these findings and results with my school's science department, at district professional learning communities, and potentially through presentations at conferences such as National Science Teaching Association (NSTA). I also aim to contribute to broader conversations around equity in science education by publishing this work. Reflecting on the learning, the results support Vygotsky's Zone of Proximal Development (ZPD), which suggests students benefit from scaffolded tools like simulations that support independent problem solving (Freirmuth, 2002).

The findings prove the literature reviewed by offering evidence of simulation effectiveness in middle school classrooms serving under-resourced, high-needs populations. As I grow professionally, I intend to deepen my training in digital instructional design and explore student-created simulations to promote ownership and creativity. Most importantly, I will continue to focus on my students' learning needs, adapting content in ways that keep science rigorous, relevant, and accessible to all my students.

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