THE IMPACT OF ANALOGIES AS A MEANS OF INSTRUCTION AND ASSESSMENT IN HIGH SCHOOL SCIENCE

by

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ABSTRACT

Chemistry lessons often overwhelm students with complex vocabulary and intricate scientific concepts, potentially leading to a loss of the central idea. The purpose of this study was to attempt to enhance engagement, confidence, and potential learning gains by integrating familiar analogies into chemistry instruction. Over a three-week period focusing on periodic trends, students were taught using analogies covering topics including Coulomb's law, atomic radius, and electronegativity. Following each lesson, students analyzed the analogy through chemistry-based worksheets, while semi-structured interviews probed their conceptual understanding and frustration levels. After completing the worksheets, students could opt to participate in a survey or questionnaire gauging engagement, confidence, and perceived comprehension. Quantitative analysis of the analogy-based worksheets, using normalized gains, indicated small growth over time. Additionally, descriptive statistics were applied to both survey responses and questionnaire data. Overall, the data allowed for the inference that there was a small increase in learning gains among students and there was a widespread agreement that the use of analogies in the classroom were engaging and increased student confidence.

INTRODUCTION & BACKGROUND

Introduction

Montoursville Area High School (MAHS) is a rural 9th-12th grade school located in Montoursville, Pennsylvania. Montoursville has a population of 4,673 people (US Census, 2023). Overall, the Montoursville area is neither ethnically nor financially diverse; 96% of our population is Caucasian and less than 4% of community members live below the poverty line (US Census, 2023). Out of the 600 students that call MAHS home, this school year 99 students attend my science classes; 68 students are in general chemistry and 31 students are in physical science. Montoursville Area High School focuses greatly on transition planning and preparing students for life outside the classroom walls. The district focuses on not only academia and college-preparedness, but also a wide variety of career pathways including healthcare, trade school, and military occupations. MAHS offers a medical careers program to 12th grade students interested in healthcare in which they job shadow at the local hospital once a week. MAHS also encourages students to attend the local college for a trade-school program and encourages all students to take the Armed Services Vocational Aptitude Battery (ASVAB) test for potential careers in military services. Overall, MAHS has many science electives for students pursuing college, trades, military, or other science-based careers.

This action research project was conducted amongst the three general chemistry classes at the high school level (N=68). These three general chemistry classes are predominantly composed of tenth grade students (n=60), but they also host four eleventh grade students and four twelfth grade students. Of these students, 9% of the population is of non-Caucasian ethnicity and 10.5% of the population have an individualized education program (IEP). In general, the distribution of students with regards to age, ethnicity, and learning support needs is standard relative to my chemistry classes of previous years.

Purpose of Study

This research project was selected because in my prior years of teaching, students were observed to struggle with grasping and explaining key ideas in the periodic trends unit including concepts such as Coulomb's law and ion formation, atomic radius, ionization energy, and electronegativity. As a result, I developed an instructional and assessment method that still delivers those key concepts without overwhelming the student. By developing multiple lessons in the unit using analogies, I attempted to engage my students with the key chemistry ideas while reducing the vocabulary and initial memorization of scientific laws. The goal was to make the learning process of the periodic trends unit more engaging and easier for the student to understand by introducing the complex abstract ideas initially as a concrete analogy.

Focus Question

My focus question was, How will the use of analogies impact a student's ability to engage with, analyze, and explain abstract science concepts?

My sub-questions include the following:

1. How engaging are analogies as a form of instruction?
2. Do students prefer using analogies as a means of demonstrating their learning?
3. Does the use of analogies in assessment impact potential student learning gains in science?

CONCEPTUAL FRAMEWORK

Introduction

The literature outlined in this conceptual framework is organized by defining the roots of education-based analogies and the benefits and drawbacks of those analogies. Science education articles from Kipnis (2005), Zubrowski (2009), and Davson-Galle (2004) discuss the nature of analogies and their connections with student metacognition. References such as Angelo and Cross' (1993) *Classroom Assessment Techniques*, Armstong's (2010) analysis of *Bloom's Taxonomy for Education*, and Thiele and Treagusts' (1994) *Analogies in Chemistry Education* highlight the academic benefits on student learning in the science classroom; and sources including Kuo (2015), Keri (2021), and Sezer (2022) discuss the impact of analogies presented in instruction on student engagement. Finally, works from Brown and Salter (2010) heed a warning to teachers regarding misconceptions to better define the conditions under which an instructional analogy can be optimized.

The Use of Analogies in Education

Classroom analogies act as a bridge between a student's prerequisite knowledge and new content. Sezer and Karatas (2022) note in their work that

> in science courses, it is often encountered that students do not have the level of knowledge to explain a scientific concept and/or phenomenon. At this point, analogies are one of the techniques frequently used in the teaching process related to science (p. 217).

For an analogy to be effective it must develop a connection from one domain of thinking to another. Specifically, the analogy is most deeply rooted when it is based in a concrete familiar idea. Kipnis (2005) notes that analogies follow a structure-mapping in which the knowledge of the base domain connects to a target domain via a common system of relations. Furthermore, within this mapping there must exist "pragmatic centrality" in which "mapping should give preference to elements that are deemed especially important to goal attainment and should try to maintain correspondences that can be presumed on the basis of prior knowledge." (Kipnis, 2005, p. 201). This idea is emphasized by Sezer and Karatas (2022) who highlight that analogies can be used as an instructional tool to bridge the gap between prior knowledge, concept, or phenomenon and the new one. Therefore, when an analogy is used in the classroom, it should focus on the main elements of both the prerequisite knowledge of the students and the content they are aiming to teach. Ultimately, an instructional analogy reaches more students when it connects the main ideas between what students are intended to learn and what they already know.

Benefits of Analogies in Science Education

When analogies are used in science education as a means of assessment, they help students develop the ability to make hypotheses based on scientific facts and prerequisite knowledge. In *The Role of Metaphor, Models, and Analogies in Science Education* Zubrowski (2009) cited a quote by Keil (1991) stating that

> as children learn more about a domain, however, their knowledge appears to become structured so that future learning in that domain changes from being governed mostly by domain-general principles to being heavily governed also by structural principles that are specific to that area of knowledge. Thus, the child's hypothesis space becomes narrowed more and more by local, knowledge-specific constraints as opposed to general ones (p. 319).

Zubrowski then goes on to reflect that as a child develops their metacognition skills and practice with analogies, the connections they begin to develop become narrower within the specific scientific field. As a result, from a pedagogical standpoint, education can reap the benefits of analogy use. If analogies are used more frequently in the classroom, students will tap into scientific knowledge they have gained in prior instruction to develop a connection to new science content. Eventually, analogies can be implemented in the classroom to the extent that students are consistently referencing and recalling scientific facts they have already learned.

Analogies and Student Engagement

A key component in determining if analogies are an effective means of instruction in science education lies in the level of engagement it brings to the student. In *The Power of Analogy-Based Learning in Science*, authors Keri and Elbatarny (2021) explain that when reasoning occurs through analogies, the student can be more engaged in their learning and a deeper understanding of complex concepts can be achieved. Likewise, Kuo and Wieman (2015) note that this method of introducing an analogy into instruction is a form of interactive engagement, which lead to student gains in the classroom. Overall, by introducing analogies into student instruction, educators can identify an increase in engagement which in turn leads to potential gains in student understanding of complex science concepts.

Analogies and Critical Thinking Skills

As tools for developing a student's critical thinking skills, analogies play a key role in science education. *In Philosophy of Science, Critical Thinking and Science Education*, Davson-Galle (2004) note that for a scientist to be able to attain critical thinking, they must first achieve analysis and deductive reasoning skills. In accordance with Bloom's Taxonomy (2001), this means that a student must be operating within the analysis tier of understanding. This analysis tier is defined as "decomposing materials into their component parts so they can be examined and understood" (Anderson, Krathwohl, & Bloom, 2001, para. 5). Likewise, Bloom's Taxonomy (2001) then goes on to observe and note that when students are posed an analogy in science, they analyze the similarities between their base domain of prerequisite knowledge and the target domain of scientific knowledge. As a result, one can infer that students can achieve critical thinking because they are analyzing two different domains of thought to deduce a connection hence completing and comprehending the analogy presented. Overall, the process of breaking down an analogy into its abstract and concrete components displays that students have achieved analysis levels in Bloom's Taxonomy and are effectively utilizing their critical thinking skills.

Analogies also benefit science education as they can be used to gauge a student's ability to learn science concepts and synthesize new ideas. Angelo and Cross (1993) highlight the use of approximate analogies as a formative classroom assessment technique. They emphasize that this technique allows students to strengthen their knowledge networks while also requiring them to synthesize and integrate information and ideas (Angelo & Cross, 1993, p. 193). By using analogies as a means of assessment, students are required to make connections and generate new ideas to display mastery of the newly introduced content. Furthermore, the use of an analogy as a means of assessment also allows a student to reach the peak of Bloom's Taxonomy. Armstrong (2010) highlights this peak, known as the *creating tier* in the revised taxonomy, by student's use of generating, planning, and producing new materials. By using an analogy as a way of assessing learning, a teacher can observe a student taking content they have been taught to generate their own independent connections. Overall, the development of a student's ability to think for oneself is a vital bridge between the classroom and adult world. As such, using analogies as a bridge between mindset connections is an excellent route to take from an educational standpoint to deepen their capacity to think and generate their own ideas.

Factors Impacting Analogy Usage

A key factor in a student's ability to form analogies depends on if the knowledge bases they are trying to connect are abstract, concrete, or both. A domain is concrete if it is capable of direct sensory observation or consistent with the life or the experiences of most students (Thiele & Treagust,1994). For a student to effectively develop an analogy, it is preferred they are pulling from a concrete base domain which they are heavily familiar with to better support the transition from concept to concept. To elaborate, the prerequisite knowledge of the student from which an analogy is built should be something in the real world that they already have a strong understanding of to establish a strong common ground from which the analogy will be built. This concept is echoed by Vosniadou and Ortony (1989) who state that

> when considering within-domain and between-domain analogies the defining characteristic of analogical reasoning is its underlying structure. The level and definition of this structure will depend to a large extent on what previous educational experiences the students had had with the phenomenon that is used as the base of the analogy (p. 873).

In essence, an analogy is dependent on the prerequisite knowledge a student holds in their base domain and the context of the scientific phenomena in which the analogy is going to be used. Generally, the purpose of an analogy is to serve as a bridge connecting easily recalled prior information to new abstract content. Overall, if the student has strong prerequisite knowledge in their base domain to build the analogy from, they can better connect the critical pieces between the prior knowledge and the scientific phenomena.

Challenges and Limitations

One of the vital components in implementing analogies in classroom instruction is the delivery of the intended message from teacher to student. As such, a challenge associated with the use of analogies in the classroom is the risk of developing misconceptions or having a misconstrued idea of the intended target concept. Haywood (2002) positions that a teacher's choice to deploy an analogy in science education assumes that all students are in complete agreement of the nature of the target concept. To further explain, when implementing an analogy, it is critical to make the end target of the analogy clear to students such that the key scientific aspects of the analogy do not get lost in translation. Furthermore, Brown and Salter (2010) stress that when using an analogy, the teacher should very clearly specify both its components and its limitations. Great care is required in developing an analogy to ensure that it is understood as intended so that misconceptions are minimized (Brown & Salter, 2010, para. 1). From a pedagogical perspective, this means the educator must consider both the connecting features between the ideas, but also clearly outline where the analogy breaks down. It is important to note that an analogy should not be a "be all end all" for a scientific argument. Although using an analogy may help students make connections and demonstrate understanding, they must also be able to explain where the scientific phenomena and the analogy are not identical and where the analogy is no longer applicable with scientific laws or theories. Ultimately, an analogy is a learning tool to establish a connection between ideas, and full student understanding of the phenomena occurs when they can define the clear boundary between the analogy and scientific principle. To fully understand the depths of an analogy, a student must be able to recognize its faults and drawbacks.

Best Practices for Using Analogies in Education

Analogies can be implemented in the science classroom as an initial learning tool during instruction and as a means of assessing student learning. Flick (1991) articulates that the application of analogies in science provides students with insight to better understand how scientific theories are extended. Over time, with the increased use of analogies in the science classroom, one can deduce that students can further develop their interpretation of analogies. As a result, students have the potential to constantly expand their scientific thinking by consistently building off of prior learned scientific knowledge in an analogy. In the science classroom specifically, the goal is to have students use critical thinking to analyze abstract science content via analogies. To use analogies as a means of assessing science-based argumentation, students must be able to demonstrate that they understand the line between an analogy and scientific laws and theories. Furthermore, they must use the analogy as a supportive idea rather than a conclusion to their argument. For this to occur, a student must be able to complete three distinct tasks: 1) generate an analogy to explain a scientific idea, 2) define the limits of that analogy where it is no longer applicable to the phenomena to dismantle any misconceptions, and 3) go on to further defend their argument with scientific facts and knowledge.

METHODOLOGY

Demographics

The purpose of this action research project is to determine if analogies impact student learning in science education. Specifically, the use of analogies will be analyzed with regards to the instruction and assessment of periodic trends and elemental patterns in chemistry. The primary goal is to determine if the use of analogies will help increase engagement, ease of understanding, and satisfaction with learning and explaining the content. This research project was developed because in prior years of teaching, students were observed to struggle with grasping and explaining key ideas in periodic trends. To support the students in my classroom, I wanted to use analogies as a scaffolding tool to better tap into their prior knowledge before attempting to teach them highly abstract ideas in chemistry. Ultimately, the use of analogies as a means of instruction and knowledge demonstration was analyzed by both qualitative and quantitative research design methods to determine the impact of analogies towards potential learning gains of these abstract science concepts.

This action research project was conducted amongst three general chemistry classes at the high school level (N=68). These general chemistry classes are diverse in age, race, and academic ability. One factor that was greatly appreciated with these classes was that we had a strong durability of rapport built between teacher and student. I frequently asked for feedback, and they frequently gave me their honest opinions. This was beneficial going into the action research project because these students were already accustomed to giving feedback and they had also practiced the skill of identifying their areas of confusion or weakness with me-asking them to do the same thing for a research project was nothing out of the ordinary. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

Research Design

Throughout the duration of the action research project, student feedback regarding the effectiveness of analogies as a means of instruction and knowledge demonstration was continuously analyzed as the frequency of analogies increased. Therefore, the constant comparative method of qualitative research design was implemented. When multiple data sources are used, the constant comparative method allows for ongoing analysis of the data to gauge changes over time (Mertler, 2020). This method of research design best supports sub-questions 1 & 2 as it allows for continuous analysis of student opinions about their ease of understanding, perspectives on engagement, and an overall feeling of satisfaction with the new analogy-based teaching method. Ultimately, the constant comparative method was best suited to determine if the use of analogies as a means of instruction and assessment has an impact on students over time.

Once analogies had been implemented in the classroom throughout the course of the unit, it was vital to determine if their use had an impact on the overall learning gains of the abstract chemistry concepts. To determine this, both a quantitative correlational study and normalized gains analysis was conducted to determine any correlation between the use of analogies in the classroom and the potential learning gains of the students. Mertler (2020) describes a correlational study as a study in which the action researcher examines whether and to what degree a statistical relationship exists between two or more variables. Mertler also notes that this relationship is measured by both the degree of magnitude and the numerical value of the correlation coefficient between those variables. It is important to note that the correlational study will not indicate any causation between the use of analogies and their outcomes on student learning. Instead, the data collected can be used to make future predictions between analogy use and potential learning gains. Because sub-question three addresses the impact for potential learning gains, a correlation between analogy frequency and potential impact can be inferred. Likewise, the use of normalized gains in this research analysis was also used to infer growth between analogy assignments. The normalized gain was calculated to determine differences in student knowledge. Normalized gains of less than 0.3 percent were considered low, gains 0.3 to 0.7 were considered a medium gain, and normalized gains greater than 0.7 were considered high (Hake, 1998). By implementing a normalized gains test between the first and final analogy assignment treatment, an inference could be made about the growth of student analogy analysis and critical thinking skills.

Treatment

The primary change in instruction between my previous years of teaching periodic trends and this year is the defined implementation of analogies. In years prior, students would receive a very technical lesson on a periodic trend with immediate formal chemistry vocabulary. After the lesson, students completed a worksheet which emphasized the vocabulary, patterns, and key points of the lesson. This typically involved many open-ended responses from the students. Although the vocabulary and key points are still present in the analogy method, they are being introduced in the form of an analogy during instruction prior to any technical definitions. The hope was that, in doing this, students will have an analogy that connects with their prior knowledge to better understand patterns in atomic trends before they are asked to learn the abstract science concepts. Furthermore, after instruction, students were then presented with the same analogy from the lesson in a class assignment to check for comprehension, ease of understanding, and overall satisfaction. The intention behind implementing the same analogies in the post-lesson worksheet was to attempt to reiterate the idea, improve retention of the lesson, and develop a common ground to reference for scaffolding further instruction.

The treatment plan for implementing analogies in instruction and assessment began with the first lesson taught in the periodic trends unit and continued throughout each lesson until the end of the unit. Table 1 outlines the implemented treatment plan. It is important to note that not all instructional tools used in the unit are listed, only those specifically outlined as designated instruments used to assess the impact of analogies in the classroom.

Table 1. Treatment plan for analogy instruments in the periodic trends unit.

Lesson	**Treatments Implemented**
Lesson 1: Coulomb's Law & Ion Formation	1. Direct instruction with analogy introduction 2.Student work: analogy assignment 1 (Appendix B) • Feedback from written work • Student Interviews 3. Post-analogy assignment feedback • Likert scale surveys & questionnaires
Lesson 2: Atomic Radius	1. Direct instruction with analogy introduction 2.Student work: analogy assignment 2 (Appendix C) • Feedback from written work • Student Interviews 3. Post-analogy assignment feedback • Likert scale surveys & questionnaires
Lesson 3: Valence Electrons & Electronegativity	1. Direct instruction with analogy introduction 2.Student work: analogy assignment 3 (Appendix D) • Feedback from written work • Student Interviews 3. Post-analogy assignment feedback • Likert scale surveys & questionnaires

The treatment plan outlined in Table 1 was categorized by lesson. The treatments were then implemented in stages throughout each lesson. On the first day of the lesson, students were introduced to the chemistry content using a visual and auditory analogy during the lesson. On the second day of the lesson, students were able to work independently or in small groups on the analogy assignment in class, during which time student interviews were also conducted. Upon immediate completion of the analogy assignment, students had the option of completing one of the feedback forms, either the Likert scale survey or the questionnaire.

Data Collection and Analysis Strategies

To collect sufficient data throughout the intervention plan, a series of both qualitative and quantitative instruments were designed to answer the focus questions of the action research project. Table 2 outlines the Data Triangulation Matrix which gives an overview of the instruments and the focus questions they address.

Table 2. Data Triangulation Matrix.

	Focus Questions		
Data Collection Instruments	How effective are analogies as a form of instruction?	Do students prefer using analogies as a means of demonstrating their learning?	Does the use of analogies in assessment generate increased learning gains in science?
Analogy Assignment 1: Coulomb's Law	X		X
Analogy Assignment 2: Atomic Radius	X		X
Analogy Assignment 3: Valence Electrons and Electronegativity	X		X
Student Interviews	X	X	
Analogy Assignment Likert Scale Survey	X	X	
Analogy Assignment Questionnaire	X	X	

Data Collection Methods and Analysis

Content Introduction Analogy Assignments & Answer Keys

Analogy Assignment 1: Coulomb's Law (Appendix B) was a sample assignment completed by participants to introduce the use of analogies as a means of instruction and knowledge demonstration. Throughout the course of the unit, two additional analogy assignment instruments, like that outlined in Appendix B, were provided to students. An analogy assignment was used as a treatment method after every lesson in our unit covering periodic law, totaling three treatments. The feedback provided by the students on those written analogy assignments was not anonymous, but students names were instead replaced by a key-code. The purpose of the key code in place of student's names allowed me to track the impact of the analogy assignments over time as treatment frequency increased. Specifically, I was better able to determine the student's growth and confidence in both chemistry content and analogy analysis.

The analogy assignments generated quantitative data as they acted as a summative assessment for the lesson. Summative assessments are those that are implemented after an instructional period to measure student achievement (Mertler, 2020). The results that students provided in the analogy assignments were cross-referenced against their respective answer keys. The fill-in-the-blank responses on the answer key were be valued a 1 point per correct response and the open-ended questions were valued at 2 points per correct response, but with a partial credit of 1 point allotted if students attempted to analyze the analogy and justify their response. The analogy assignment was designed to assess if students can generate responses to science content related questions based on their interpretation of an analogy. Numerical data was gathered for those students based on their responses and can therefore infer the assignment's correlation to the impact of analogies in science content instruction. With these results, two major data pools of descriptive statistics were generated: 1) a median score amongst the entirety of the research group for each analogy assignment treatment, and 2) the individual median scores for one student, tracked across all three treatments. To better interpret potential learning gains over time from this data, this data was visualized in a scatter plot via a Pearson correlation test (Figure 2) and key statistical values with regards to normalized gains were included in the data analysis section.

Student Interviews

Student Interviews (Appendix D) were conducted in conjunction with each analogy assignment to probe and gauge the impact of the assignment in the moment and were semi-structured in nature. The benefit of implementing semi-structured interviews is that the base questions can still be answered for the intended qualitative data collection, but follow-up questions can be applied depending on the circumstance (Mertler, 2020). Because I am using analogies as a form of instruction and knowledge demonstration in the classroom, I can use the base questions from the interviews to gauge student perceptions and the follow-up questions to scaffold skill-building where necessary. Using student interviews as a data collection method most closely aligns with sub-questions 1 & 2 because I can note both the potential engagement and frustration from students in real-time.

Analogy Assignment Likert Scale Survey

An optional Analogy Assignment Likert Scale Survey (Appendix E) was provided to participants in the research group immediately upon completion of every analogy-based assignment (*N*=82 responses). The results of the Likert scale survey were submitted anonymously by participants to remove any potential bias and allowed the students to provide me with honest feedback. The goal of this instrument was to gauge the effectiveness of analogies as both a means of instruction and knowledge demonstration. Specifically, using the same Likert scale survey over the course of the unit after each treatment allowed for continuous analysis of student opinions about their ease of understanding, perspectives on engagement, and overall feeling of satisfaction with the new style of instruction. The scaled survey allowed participants to rank the strength of their responses based on a pre-established set of questions, the results of which were turned into uniquely categorized quantitative data (Mertler, 2020). It is important to note that this Likert scale survey does not include a neutral option, because I am assessing to see if the participant group, on average, either agrees or disagrees with a statement based on their perceptions immediately after the treatment has occurred. Because everyone in the research group will have already been impacted by those items outlined in the Likert scale survey, it will not be possible to have a non-applicable opinion on the treatment they have already undergone. As noted by McIver and Carmines (1981), the Likert scale survey being used for this project does not treat *neutral* as the average opinion of the participants, rather the average score of the respondents is treated as the midpoint. That is to say that the average response among the whole research group after the treatment is the common standing, and any deviation from that average is either more or less favorable than the average opinion of the group (McIver & Carmines, 1981). It is important to note that the removal of the neutral option from the Likert scale survey had the potential to result in biased responses from participants who may not truly hold an opinion, but it is important to do so for the purposes of this study to determine the average student perspective and establish a midpoint. The data collected from the Likert scale surveys over the three treatments was analyzed to see the impact of analogies from student's perspectives over the course of the entire research project. This data was visualized using a clustered bar graph displayed in Figure 1 and justified using descriptive statistics. In Appendix F, those categories are sorted by engagement (outlined in red), ease of understanding (outlined in yellow), and overall satisfaction (outlined in green).

Analogy Assignment Questionnaire

An optional Analogy Assignment Questionnaire (Appendix F) was implemented anonymously among the research group after every treatment with an analogy-based assignment. (N=82 responses). The goal of the questionnaire was to detect correlations to engagement, self-confidence, and skill-building that would otherwise go unnoticed in a Likert scale survey. The key difference between a questionnaire and a rating scale is that questionnaires allow for open-ended responses whereas a ranking scale only allows for participants to rank their strength of a response to a pre-established question (Mertler, 2020). It is the open-ended aspect of the questionnaire that makes it a key instrument in analyzing the qualitative data presented by the students. As such, questionnaires are ideal for data collection regarding the impact of analogies as a means of instruction and knowledge demonstration. Because the use of questionnaires allowed for continuous data tracking of a large quantity of participants, I was able to better interpret how the continued use of analogy treatments impacted the participant group over time. Furthermore, Check and Schutt (2012) emphasize that "the context created by the questionnaire has a major impact on how individual questions are interpreted and answered" (p.2). By generating concise questionnaires for each treatment, data analysis will allow for the interpretation of impact on the participant group over time.

Upon collection of qualitative statements from student questionnaires, emergent thematic analysis was used to determine the impact of analogies on instruction of abstract chemistry concepts by looking for themes in student quotes. As outlined in *Applied Thematic Analysis*, the goal of the researcher is to compare the content of narratives and highlight similarities and differences amongst the data (Guest et al., 2012). This technique is echoed by Fugard and Potts (2019) who wrote

> Thematic analysis is constructing themes using the data plus the researcher's understanding, intuition, and theory. It is a process of making sense of the data and abstracting broader ideas than the explicit words on the paper (p. 29).

In essence, emergent thematic analysis allows the researcher to code the data such that a wide array of results can be categorized and interpreted. This method of data analysis is best suited for the clarification of questionnaires because it allows the qualitative data to be correlated to a more definite result regarding student perspectives on analogies in the classroom.

CHAPTER FOUR

DATA ANALYSIS

Purpose Statement and Methods of Data Analysis

The purpose of analyzing the data from the instruments used in the treatment plan served two key purposes: 1) To determine if student perception of analogy use in the classroom was impacted at the conclusion of the unit, and 2) to determine if the use of analogies in the classroom had an impact on potential learning gains of chemistry content. In order to determine this, descriptive statistics were used to summarize the results of the Likert scale surveys, emergent thematic analysis was used to identify themes in student questionnaires and interviews, and both a Pearson correlation analysis and normalized gains analysis was conducted on the written analogy assignments submitted by the students in the research project.

The Impact of Analogies on Student's Perceptions of Instruction and Assessment

Analogy-based assignments, Likert scale surveys, student interviews, and questionnaires were utilized in the classroom to assess students'' preferences for analogies as an instructional tool and initial assessment when introducing new chemistry content. The results of the surveys (*n*=82) indicated that the use of analogies increased student enjoyment and self-perception of potential for success in the classroom. By summing the number of students that selected *agree* and *strongly agree* on the Likert scale data, 63% of students found analogies captivating for instruction, 72% reported increased confidence in completing classwork accurately, and 69% felt they better grasped the chemistry content when introduced through analogy-based assignments (Figure 1).

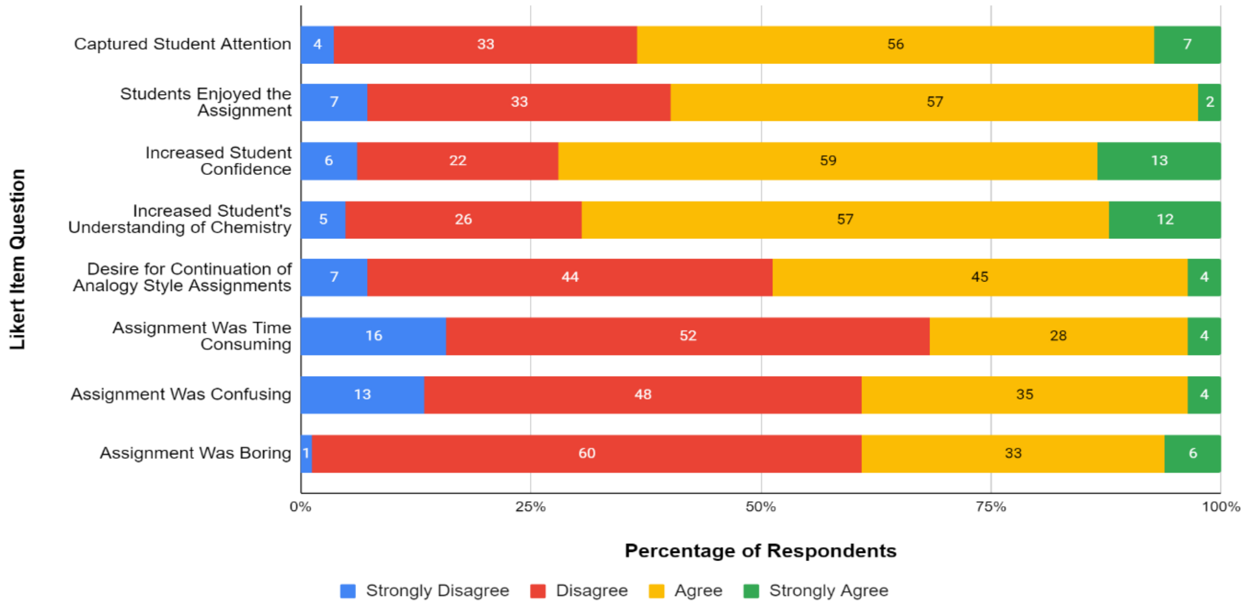

Figure 1: Analogy Assignment Likert Scale Survey Data

Furthermore, qualitative data from questionnaires completed by students (*n*=23) gave insight to specific opinions about the analogy-based assignments. Emergent thematic analysis of these responses elaborated on the student perceptions. When asked "Write three words that best describe your opinion in the analogy assignment you just completed," the most frequent words used by students included "helpful," "fun" and "easy." The questionnaire also asked students to provide any additional feedback, comments, or questions to the teacher. One student wrote "I liked the analogy stories; I just wish I could listen to them instead of reading them on paper." Ultimately, the questionnaires provided vital qualitative data to help support the claim that the use of analogies were found to be engaging and a strong confidence booster for many participants.

The Impact of Analogies on Potential Learning Gains

To determine if the use of analogies had the potential for increased learning gains, A Pearson correlation analysis, and normalized gains analysis was conducted on the results of the three analogy-assignment assignments (*n*=68). It is important to note that because the questions were not identical over the three treatments, the analysis has partial bias and cannot infer results as accurately compared to true pre- and post-test data analysis. The Pearson correlation was conducted comparing the results of the last analogy assignment treatment and the first analogy assignment treatment. This test resulted in a t-value of 0.865 and a p-value of 0.39, indicating that there was an insignificant correlation between the first and final treatment. However, the scatter plot shown below generated from the Pearson correlation (Figure 2) indicates a linear relationship between the treatment scores with an R^2 value of 0.748. Based on this linear relationship, it can be inferred that most of the student population grew in analogy interpretation as the frequency of treatments increased.

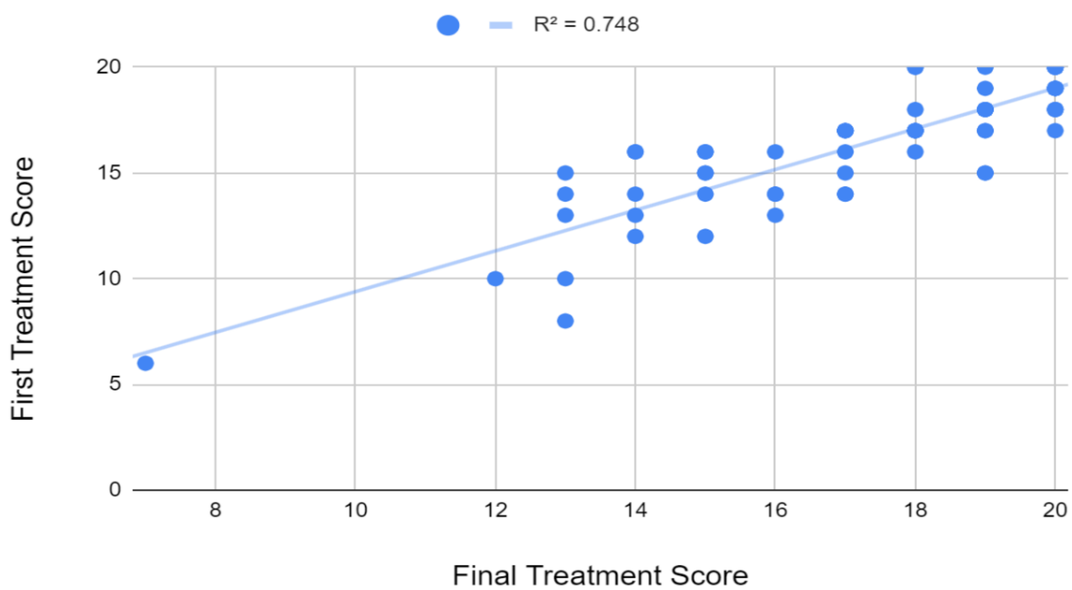

Figure 2. Pearson Correlation Between First and Final Analogy Assignment Treatment

To gain insight into the changes in analogy assignment scores, normalized gains were calculated. The average normalized gain was 27%, indicating a collective improvement of 27% between the initial and final analogy-assignment treatments, which aligns with small percentage learning gains according to Hake (1998). These gains were supported by student interviews conducted throughout the treatment plan. Initially, students expressed frustration and asked questions frequently. However, by the final analogy assignment, students recognized their own knowledge development from prior assignments. They asked fewer questions, showed more confidence, completed assignments more efficiently, and provided more detailed responses. Notably, common student responses included "I think I'm finally getting this" and "I remember this idea from our first story." These quotes help demonstrate that as the frequency of analogy assignments increased, the student's ability to analyze and discuss these analogies also compounded over time.

CHAPTER FIVE

CLAIM, EVIDENCE, AND REASONING

Claims From the Study

The three main claims that can be made regarding the findings from this study include: 1) The use of analogies as a means of instruction increased student engagement, 2) the use of analogies as a means of assessment increased student self-perceptions of confidence and understanding, and 3) the implementation of analogies in the classroom can serve as an effective tool for increasing understanding of abstract chemistry content.

Value of the Study and Consideration for Future Research

The first claim presented in this research project was that the use of analogies as a means of instruction increased student engagement. Likert scale surveys, questionnaires, and student interviews collectively reflect a favorable student perspective on the incorporation of analogies in the chemistry classroom. Likewise, Likert scale surveys also supported the second claim that the use of analogies as a means of assessment increased student self-perceptions of confidence and understanding. Numerous students expressed enjoyment with this instructional approach and noted heightened confidence and improved understanding of the content. When I first took on this idea as a basis for my research project, I intended to try something new in hopes of improving engagement and aiding ease of understanding on a notoriously tough chemistry unit. The number of "lightbulb moments" and positive feedback from the students made the endeavor worthwhile. Keri and Elbartarny (2021) noted in their work that through engagement and piecing together analogies a student can achieve a much deeper understanding of the idea. Likewise, Wieman (2015) notes that this method of introducing an analogy into instruction is a form of interactive engagement. I found that the more I told these analogy stories during lessons or had students read them in assignments, the more often they would try to make sense of the idea, rather than just attempt rote memorization. In the long run, the students and I were able to reap the fruits of this labor when the sense-making of the analogy led deeper into the sense-making of the scientific content. It was not only a beneficial instructional process, but also a process that the students reported enjoyment being involved in. Consequently, the use of analogies in the classroom enhanced student satisfaction with the learning experience throughout the unit.

With regards to the first and second claims and considerations for future study, I reflected on some of the quotes provided to me by students on questionnaires and in interviews. The most impactful constructive criticism I received from students throughout this project was that, although many students enjoyed the analogy-based stories, some struggled with reading. Reflecting on this, if I were to undertake this project again, I would ensure that assignments are presented in multiple formats to cater to different learning styles. While reading aids visual learners, I would also create audio versions of the analogies for auditory learners and incorporate hands-on experiences for kinesthetic learners. Additionally, recognizing that not all students excel in written expression, I would diversify assessment methods to accommodate various ways of demonstrating understanding. Just as I would vary instructional approaches, I would prioritize accepting multiple forms of knowledge demonstration during assessments. Knowing now that the use of analogies was an enjoyable experience, in the future I could try my best to incorporate that experience in multiple ways to make it more accessible for everyone.

The third claim presented in this research project was that the implementation of analogies in the classroom can serve as an effective tool for increasing understanding of abstract chemistry content. The data generated from the student work on the analogy assignments showed that students improved in their ability to interpret analogies as well as a small impact in understanding chemistry content. When analyzing the results of the normalized gains, there was a small improvement between the first and final analogy-based assignment. When analyzing the results of the Pearson correlation, it was interesting to note a significant linear relationship between the first and final analogy assignment treatment. This linear relationship correlated the frequency of analogy use to student analogy interpretation, which makes sense as they increased their amount of practice with this skill. As both a teacher and observer in this research project, one of the most impactful things I was able to witness was the connection back to the analogy assignments. Instead of a student being lost in the translation of the abstract terminology, they were able to engage in discussion and reasoning through the analogies I had introduced. When probing students to provide justification for their ideas during student interviews, I often found them speaking first in an analogy-sense, then tying these ideas back to chemistry. I could see that the analogy had laid a foundation for which the rest of the chemistry knowledge had been built. This echoes prior research from Sezer and Karatas (2022) who highlight the ability of an analogy to act as a bridge between bodies of knowledge. As the treatment plan continued over time in the classroom, I was able to watch the previously frustrated students flourish with understanding; the main factor being that all these students shared was the ability to build off one idea onto the next. Eventually, nearly all my students were able to speak in scientific terms without the need for analogies, indicating that the analogies had served their purpose as a steppingstone. Work from

Bloom's Taxonomy (2001) and Davson-Galle (2004) noted that the use of analogies could improve student's critical thinking and deductive skills, and it was worthwhile to see that skill improvement within my own classroom with my students.

In addressing the third claim and considering future research, it is crucial to identify potential biases in the data. While the analogy assignments facilitated students' progress and development of ideas throughout the unit, they didn't provide as authentic data as a true pre-test and post-test, given the non-identical questions. The expectation for students to grow throughout the analogy assignments may have inadvertently led to lower treatment scores than expected. In future iterations of this research project, incorporating identical pre- and post-tests at the start and end of the periodic trends unit would offer a clearer indication of discernible growth, rather than relying on inferred growth between the analogy assignments. Overall, I feel that the use of analogies in the science classroom was a beneficial tool that has the potential to be implemented across multiple units.

Impact of Action Research on the Researcher

Implementing an action research project in my classroom served as a reminder of the importance of gathering feedback from students. While teachers often receive feedback in passing each day, we often only take this feedback on a day-to-day basis. Compiling, analyzing, and translating this feedback was a profound and new experience. It felt as though my students were collaboratively designing a blueprint for the next year's class, and it was my responsibility to fulfill my end of the bargain-addressing what needed improvement and highlighting successful aspects. This served as a strong reminder that the weight of my profession does not rest solely on my shoulders. I sensed that my students understood that they were contributing to my growth, not just for their own benefit, but also for the benefit of future students and myself. While some may have viewed it as just another activity in chemistry class, others recognized that I was genuinely listening and it empowered them to reflect deeply on their learning. The research project proved to be a valuable tool in facilitating learning in a challenging unit, but it was an even more effective tool for fostering self-reflection among both myself and my students as we journeyed through learning together.

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APPENDIX A

MONTANA STATE UNIVERSITY INSTITUTION REVIEW BOARD COMPLIANCE

Hello Ostrander, Hannah,

Your protocol was reviewed by the IRB and has been approved.

PI: Ostrander, Hannah
Approval Date: 1/22/2024
Title: The Impact of Analogies as a Means of Instruction and Assessment in High School Science

Protocol #: 2024-1149-EXEMPT
Review Type: Exemption
Expiration Date: 1/16/2029

APPENDIX B

ANALOGY ASSIGNMENT 1: COULOMB'S LAW

Content Introduction Analogy Assignment
Coulomb's Law: The Professional Dog-Walking Service

Part A. Training to be a Dog Walker: The Neutral Atom
Imagine you are in training to be certified as a professional dog-walker. Before you can be expected to walk multiple dogs in the business, the training program needs to be sure you can walk one dog. Luckily for you, your training program has the following benefits: 1) Even the most negative or crazy dogs have been attracted to your positive energy 2) If a dog was not attracted to its walker, the leash would break, and 3) The training program always starts you on the lowest energy dog.

Part A. Comprehension Questions

1a. Why would negative dogs still be able to be walked by you?

1b. *Fill in the blanks*: protons have a _________ charge and electrons have a _______ charge

1c. If you are the controller/leash puller (much like the nucleus of an atom), what does the dog represent in this story?

2. In this story, you always start the training program with ONE dog at its lowest energy. If the trainer & dog are replaced by protons and electrons, what element on the periodic table do you represent?

3. *Fill in the blanks using Coulomb's Law*: If the trainer represents the ___________ of the atom, and the dog represents the ____________ of the atom, then the leash shows the _________________ force.

Part B. Certified Dog-Walker: One Less Dog

You have been hired as a professional dog-walker and today has been an POSITIVE day! You have worked up the strength level to comfortably walk 11 dogs at a time. While you were walking your usual route, one of the customers met you on your path to pick-up their dog early. Your job felt so much easier after that-you have the strength to walk 11 dogs, but only had to walk 10. You were able hold those 10 remaining leashes in closer with much more control and finish your day at work.

Part B. Comprehension Questions

1. In this story you had a dog removed from your walking service. For an atom, this is the same as losing WHAT?:___________________________

2. Imagine instead of being a dog-walker in this story, you are an atom in the process of forming an ion. Fill in the chart below that best describes the analogy of the story.

At the START of the story:	
Number of protons	
Number of electrons	
Atom you represent on the periodic table	
At the END of the story:	
Number of protons	
Number of electrons	
Ion you represent on the periodic table (with charge)	

3. In this story did the attraction between the nucleus & electrons INCREASE or DECREASE? **Explain how you know.**

____

____

Part C. Certified Dog-Walker: One Extra Dog

You have been hired as a professional dog-walker and today has been a NEGATIVE day! You have worked up the strength level to comfortably walk 17 dogs at a time. While you were walking your usual route, you crossed paths with another person walking their dog. They saw you walking your dogs and said "Wow! Are you a professional dog-walker?" you replied "Yes" and they said "That's great! Walk mine too!" They handed you their dog's leash and sprinted off in the opposite direction. Your job felt so much more difficult after that-you have the strength to walk 17 dogs, but now had to walk 18. You struggled to hold onto those 18 leashes and as a result had to extend the distance the dogs were able to travel on the leash.

1. In this story you had a dog added to your walking service. For an atom, this is the same

as gaining WHAT?:___________________________

2. Imagine instead of being a dog-walker in this story, you are an atom in the process of forming an ion. Fill in the chart below that best describes the analogy of the story.

At the START of the story:	
Number of protons	
Number of electrons	
Atom you represent on the periodic table	
At the END of the story:	
Number of protons	
Number of electrons	
Ion you represent on the periodic table (with charge)	

3. In this story did the attraction between the nucleus & electrons INCREASE or DECREASE? **Explain how you know.**

____

____

Name: ANSWER KEY Date:____________ Period:_______

Content Introduction Analogy Assignment
Coulomb's Law: The Professional Dog-Walking Service

Part A. Training to be a Dog Walker: The Neutral Atom

Imagine you are in training to be certified as a professional dog-walker. Before you can be expected to walk multiple dogs in the business, the training program needs to be sure you can walk one dog. Luckily for you, your training program has the following benefits: 1) Even the most negative or crazy dogs have been attracted to your positive energy 2) If a dog was not attracted to its walker, the leash would break, and 3) The training program always starts you on the lowest energy dog.

Part A. Comprehension Questions

1a. Why would negative dogs still be able to be walked by you?

The dogs are attracted to the positive energy & the leash would break otherwise

1b. *Fill in the blanks*: protons have a positive charge and electrons have a negative charge

1c. If you are the controller/leash puller (much like the nucleus of an atom), what does the dog represent in this story?

The electron

2. In this story, you always start the training program with ONE dog at its lowest energy. If the trainer & dog are replaced by protons and electrons, what element on the periodic table do you represent?

Hydrogen (1 proton & 1 electron)

3. *Fill in the blanks using Coulomb's Law*: If the trainer represents the nucleus of the atom, and the dog represents the electron of the atom, then the leash shows the attractive force.

Part B. Certified Dog-Walker: One Less Dog

You have been hired as a professional dog-walker and today has been a POSITIVE day! You have worked up the strength level to comfortably walk 11 dogs at a time. While you were walking your usual route, one of the customers met you on your path to pick-up their dog early. Your job felt so much easier after that-you have the strength to walk 11 dogs, but only had to walk 10. You were able hold those 10 remaining leashes in closer with much more control and finish your day at work.

Part B. Comprehension Questions

1. In this story you had a dog removed from your walking service. For an atom, this is the same

as losing WHAT?: an electron

2. Imagine instead of being a dog-walker in this story, you are an atom in the process of forming an ion. Fill in the chart below that best describes the analogy of the story.

At the START of the story:	
Number of protons	11
Number of electrons	11
Atom you represent on the periodic table	Sodium atom (Na)
At the END of the story:	
Number of protons	11
Number of electrons	10
Ion you represent on the periodic table (with charge)	Sodium ion (Na^{+})

3. In this story did the attraction between the nucleus & electrons INCREASE or DECREASE? **Explain how you know.**

The attraction increased. Because there was one less dog (electron), you were able to pull the other dogs (electrons) in closer

Part C. Certified Dog-Walker: One Extra Dog

You have been hired as a professional dog-walker and today has been a NEGATIVE day! You have worked up the strength level to comfortably walk 17 dogs at a time. While you were walking your usual route, you crossed paths with another person walking their dog. They saw you walking your dogs and said "Wow! Are you a professional dog-walker?" you replied "Yes" and they said "That's great! Walk mine too!" They handed you their dog's leash and sprinted off in the opposite direction. Your job felt so much more difficult after that-you have the strength to walk 17 dogs, but now had to walk 18. You struggled to hold onto those 18 leashes and as a result had to extend the distance the dogs were able to travel on the leash.

1. In this story you had a dog added to your walking service. For an atom, this is the same

as gaining WHAT?: an electron

2. Imagine instead of being a dog-walker in this story, you are an atom in the process of forming an ion. Fill in the chart below that best describes the analogy of the story.

At the START of the story:	
Number of protons	17
Number of electrons	17
Atom you represent on the periodic table	Chlorine atom (Cl)
At the END of the story:	
Number of protons	17
Number of electrons	18
Ion you represent on the periodic table (with charge)	Chloride ion (Cl^-)

3. In this story did the attraction between the nucleus & electrons INCREASE or DECREASE? **Explain how you know.**

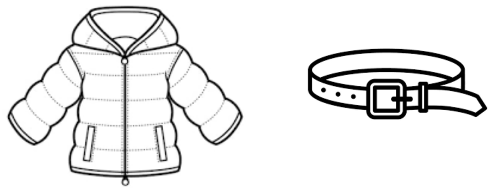
The attraction decreased. Because there was one extra dog (electron), the other electrons were able to get further away from the nucleus.

APPENDIX C

ANALOGY ASSIGNMENT 2: ATOMIC RADIUS

Name:____ Date:__________ Period:_______

Content Introduction Analogy Assignment 3
Atomic Radius: Coats & Belts



Part A. Atomic Radius Down a Column-Layering Coats

An atom's *atomic radius* is the distance from its nucleus to its outermost valence electron layer, and it can be manipulated when going **DOWN A COLUMN by increasing the electron layers**. To compare this to a person, it would be a lot like the distance from the center of our heart to our outer layer of clothing. When we look at the periodic table, we observe that each time we travel DOWN A COLUMN, a new layer of electrons is added for each new row. If this were a person, it would be like layering coats.

Part A: Comprehension Questions

1. Define **atomic radius**:____

2. In this analogy, an extra coat represents:____

3a. RANK the following atoms from LEAST to GREATEST atomic radius

Sodium (Na), Lithium (Li), Potassium (K)

__________________ < __________________ <__________________

3b. Explain your thinking for question 3a.

____

____

4. Locate magnesium (Mg) and barium (Ba) on your periodic table. How many MORE layers of electrons does barium have compared to magnesium?:_____________________

Part B. Atomic Radius Across a Row-Adjusting a Belt

An atom's *atomic radius* is the distance from its nucleus to its outermost valence electron layer and it can be manipulated when moving **ACROSS A ROW (LEFT TO RIGHT) by increasing the pull of protons in the nucleus**. To compare this to a person, it is like adjusting a belt on a very large pair of pants. When we look at the periodic table, we observe that each time we travel ACROSS A ROW (LEFT TO RIGHT), one extra proton is added in the nucleus which pulls the outer electron layer in closer. If this were a person, it would be like tightening the belt to hold a *single* pair of pants closer to our body.

Part B: Comprehension Questions

1. Define **atomic radius**:____

2. In this analogy, tightening the belt represents:____________________________________

3a. RANK the following atoms from LEAST to GREATEST atomic radius

Sodium (Na), Argon (Ar), Phosphorus (P)

________________ < ________________ <________________

3b. Explain your thinking for question 3a.

____

____

4. Locate lithium (Li) and neon (Ne) on your periodic table.

a. Which atom has more protons in its nucleus?:_______________

b. Which atom would pull its outer electron shell in closer?:_____________

c. Which atom has a SMALLER atomic radius?:_____________

APPENDIX D

ANALOGY ASSIGNMENT 3: VALENCE ELECTRONS & ELECTRONEGATIVITY

Name:____ Date:_________ Period:_______

Content Introduction Analogy Assignment
Valence Electrons & Electronegativity: An Atom's Form of Money

Part A. Hitting the Noble Lottery

Imagine you hit the lottery and won millions of dollars-you would be set for life! You would have enough money to keep you stable and you wouldn't need to work a day in your life to earn money any other way. Where people deal with money, atoms and ions work with their outer shell electrons, known as ***valence electrons***. If an atom (like those in column 18 of the periodic table, the noble gas family) has a full outer shell of valence electrons it is similar to hitting the lottery-the reach stability and no longer need to bond with other atoms to trade electrons. As a result, atoms in other families have a tendency to form ions to achieve this full outer shell. Recall from Unit 3 that **cations** have a **positive charge** and are formed by **losing electrons** whereas **anions** have a **negative charge** and are formed by **gaining electrons**.

Part A: Comprehension Questions

1. In this story, money is being compared to what?:_______________________

2. Define the term *valence electrons*

____

3. Why are noble gasses inert/non reactive? Justify your response using the information presented in Part A.

____

____

4. *Fill in the blank*: Cations have a _____________ charge and are formed by _____________ electrons whereas anions have a ___________ charge and are formed by ___________ electrons.

5. **Using the criteria for stability**, explain why atoms have a tendency to form ions:

____

____

Part B. All Alkali Metals Work for the Peace Corps

The alkali metals (column 1 of the periodic table) are known to be a highly reactive and energetic group of elements. In order to achieve stability and obtain a full outer shell of valence electrons, they always form **cations** with a **+1 charge**. Due to their generous nature of donating electrons, all alkali metals work for the peace corps-they hit the lottery once they have given back to the community through free charity.

Part B: Comprehension Questions

1. Fill in the missing boxes in the chart below using your periodic table

Atom or Ion	**Number of Protons**	**Total Number of Electrons**	**Number of VALENCE Electrons**
Potassium Atom (K)			
Potassium Ion (K^{+1})			
Argon Atom (Ar)			

2. How are the potassium ion & argon atom THE SAME?:________________________________

3. How are the potassium ion & argon atom DIFFERENT?:______________________________

Part C. All Halogens Work as Bank Robbers

The halogens (column 17 of the periodic table) are known to be a rough and tough highly reactive group of elements. In order to achieve stability and obtain a full outer shell of valence electrons, they always form **anions** with a **-1 charge**. Due to their thieving nature of stealing electrons, all halogens work as bank robbers-they hit the lottery once they have achieved the ultimate heist.

Part C: Comprehension Questions

1. Fill in the missing boxes in the chart below using your periodic table

Atom or Ion	**Number of Protons**	**Total Number of Electrons**	**Number of VALENCE Electrons**
Fluorine Atom (F)			
Fluoride Ion (F^{-1})			
Neon Atom (Ne)			

2. How are the fluoride ion & neon atom THE SAME?:________________________________
3. How are the fluoride ion & neon atom DIFFERENT?:_______________________________

Part D. Bank-Robbers & The Electronegative Chain of Command

It isn't only the halogens that work as bank robbers to steal money, in fact, all **anions** have a tendency to steal electrons from other atoms in an attempt to achieve stability. How then, does the elemental world create a "Most Wanted" list for these criminals? It is based on a property known as electronegativity. **Electronegativity** is defined as *a measure of an atom's ability to remove electrons from another atom*. Electronegativity is measured according to the Pauling Scale (See Figure 1). This scale was created based on two main characteristics: 1) The number of valence electrons away that atom is from stability and 2) The strength of the atom's attraction due to Coulomb's Law.

Pauling Electronegativity Values

H 2.1																	He
Li 1.0	Be 1.6											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.3											Al 1.5	Si 1.9	P 2.2	S 2.6	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.4	Ti 1.5	V 1.6	Cr 1.7	Mn 1.5	Fe 1.8	Co 1.9	Ni 1.9	Cu 1.9	Zn 1.6	Ga 1.8	Ge 2.0	As 2.2	Se 2.6	Br 2.8	Kr
Rb 0.8	Sr 0.9	Y 1.2	Zr 1.3	Nb 1.6	Mo 2.2	Tc 1.9	Ru 2.2	Rh 2.3	Pd 2.2	Ag 1.9	Cd 1.7	In 1.8	Sn 2.0	Sb 2.1	Te 2.1	I 2.5	Xe

Charles E. Sundin, University of Wisconsin-Platteville

Figure 1. The Pauling Scale of Electronegativity

Here are some key features to notice about the Pauling Scale of Electronegativity:

- Fluorine is the MOST electronegative-therefore it is the KING of bank robbers
- The Noble Gases do not have any electronegativity
- The anions in row 2 are MORE electronegative than row 3. They are smaller in size and therefore have stronger attraction between their nucleus and electrons (whether those electrons are their own OR belong to another atom)
- Anions that form a -1 charge have MORE electronegativity than those that form a -2 charge. This is because they only need to steal one electron to achieve stability instead of trying to steal two.
- Hydrogen is an anomaly of electronegativity compared to the other members of its family.

Part D. Comprehension Questions

1. Define electronegativity:____

2. According to the Pauling Scale, which element is the MOST electronegative?:___________

3. In your own words, explain WHY the Noble Gas family has ZERO electronegativity. For full credit you must:

- Include the criteria for stability
- Reference the money analogy from page 1-why don't they need to rob a bank?

____
____
____

4. **Using Coulomb's Law**, explain why atoms in row 3 are LESS electronegative than atoms in row 2. For full credit you must clearly state if attraction is STRONGER or WEAKER and WHY. (**Hint: think of the major factor that changes when you go DOWN a column*)

____
____

5.In your own words, make a prediction about WHY oxygen would be MORE electronegative than nitrogen. There are many acceptable responses.

____
____

6. In your own words, make a prediction about WHY hydrogen is much more electronegative compared to the rest of its family. There are many acceptable responses.

____
____

APPENDIX E

STUDENT INTERVIEWS

Student Interview Questions

**This question sheet is for instructor-use only. Participants will not have prior knowledge about the questions they are being asked.*

Base Interview Question	**Student Response**
1. **How do you feel like you are doing on this assignment**?	
2. What parts of this assignment, if any, are confusing?	
3. **Can you see the similarities between the analogy in the worksheet and the lesson we had today?** Follow-up if only given "YES": **What do you think those similarities are?** (*If students correctly provide information to the follow-up, note this as a correct response. If students do NOT give correct response information, note this as a negative response and move onto non-data collecting scaffolded questions) Follow-up if only given "NO": **That's okay-let's look at the characters in the story together** (*Note this as a negative response and move onto non-data collecting scaffolded questions)	
4. Do you like this style of worksheet better than worksheets we have had in pervious units?	
5. Do you feel like you had enough background knowledge to successfully complete this assignment? If given "YES"-note this as a positive response If given anything other than "YES": **That's okay-where do you need help?** (Note this as a negative response and move onto non-data collecting scaffolded questions)	
6. What things could I do as your teacher to make this assignment better?	

APPENDIX F

ANALOGY ASSIGNMENT LIKERT SCALE SUPERVEY

Directions: This form is to be submitted ***anonymously****. Do NOT include your name when submitting this survey. The purpose of this survey is to determine your perspectives as a student on the analogy assignment you just completed. Please circle the number, using the code below, that describes how much you agree with each statement. Please respond honestly and by only circling one number for each statement.*

1. The analogy assignment captured my attention.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

2. I thought the analogy assignment took too much time.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

3. I was confused about what the questions were asking for in the analogy assignment.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

4. The analogy assignment was enjoyable to read.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

5. After reading the analogy story, I felt confident I could complete the assignment.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

6. The analogy assignment was boring.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

7. The analogy assignment helped me better understand the lesson.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

8. I want to do more assignments like the analogy assignment I just did.

1	2	3	4
Strongly Disagree	Disagree	Agree	Strongly Agree

APPENDIX G

ANALOGY ASSIGNMENT QUESTIONNAIRE

*Directions: This form is to be submitted **anonymously**. Do NOT include your name when submitting this questionnaire. The purpose of this questionnaire is to determine your perspectives as a student on the analogy assignment you just completed. Please write out your honest responses to the open-ended questions below.*

1. In the space below, write THREE words that best describe your opinion on the analogy assignment you just completed.

I. ______________________________

II. ______________________________

III. ______________________________

2. Look back through the analogy assignment. List TWO chemistry facts that you learned from the lesson in class that you were able to identify in the story.

I. ______________________________

II. ______________________________

3. Imagine you are the teacher and are asking your students to complete the same analogy assignment that you just completed. List one possible BENEFIT that this assignment may have on your students.

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4. Imagine you are the teacher and are asking your students to complete the same analogy assignment that you just completed. List one possible DRAWBACK that this assignment may have on your students.

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5. OPTIONAL: Include any other feedback, comments, or questions for your teacher in the space below.

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