Differentiation in Chemistry for Students With Various Levels of Cognitive Efficiency

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Differentiation in Chemistry for Students With Various Levels of Cognitive Efficiency

by

Marilyn Anne Laistner

A thesis submitted to the Department of Education and Human Development of The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree of Master of Education

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Differentiation in Chemistry for Students With Various Levels of Cognitive Efficiency

By Marilyn Anne Laistner

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Table of Contents

Chapter One: Introduction........................................................................................................1

Chapter Two: Thesis

  Differentiation in Chemistry for Students With Various Levels of Cognitive Efficiency..4
    How Students are Learning Science.................................................................6
    Chemistry Teacher Preparedness.................................................................10
    Motivation in the Classroom.........................................................................11
    Application of Cognitive Load Theory to Student Achievement in Chemistry…13
    Students’ Learning Characteristics...............................................................15
    Strategies for Teaching.....................................................................................18
    Summary............................................................................................................20

Chapter Three: Project

  Lessons on Moles and Stoichiometry Differentiated for Students With Various Levels of Cognitive Efficiency……22
    Lesson Plan Template......................................................................................22
    Activity Plan Template.....................................................................................24
    Lesson 1
      Lesson Plan 1...............................................................................................25
      Identifying Molecules Practice and Commentary.........................................29
      Notes Packet..................................................................................................36
      Cognitive Efficiency Quiz and Commentary..................................................59
    Lesson 2
      Lesson Plan 2...............................................................................................64
      Percent Composition Activity.......................................................................67
      Recipes..........................................................................................................73
    Lesson 3
      Lesson Plan 3...............................................................................................74
Balancing Equations Activity .............................................. 77

Lesson 4

Lesson Plan 4 ................................................................. 83
Types of Reactions Poster .............................................. 85
Types of Reactions/Balancing Review ................................ 87

Lesson 5

Lesson Plan 5 ................................................................. 90
Stoichiometry Lab .......................................................... 93

Lesson 6

Lesson Plan 6 ................................................................. 97
Comparison Flashcards ................................................. 100
Race Activity ............................................................... 101

Chapter Four: Discussion .................................................. 104
Chapter Five: References .................................................. 106
Chapter I: Introduction

Problem

Populations of classrooms are growing both in size and diversity. Teachers can expect to see a variety of students with different ethnicities, languages, abilities, and motivations. Their students may be classified as having a disability, or may be classified as gifted. Still others may fall somewhere in between. With a large class size that includes such a diverse array of learners, one teacher alone is often hard-pressed to develop instruction that can effectively reach every student in the classroom (Kurtts et al., 2009; Dymond, Renzaglia, & Rosenstein, 2006). Effective instruction is meant to meet students at their current level and adapt itself to their needs (Sandlin, Harshman, & Yezierski, 2015). Yet, teachers often don’t effectively differentiate their instruction for inclusive science education (Kahn & Lewis, 2014; Kirch et al., 2007). They may lack the training, or already have curriculum in place that they are reluctant to change.

In addition, the new standards that New York State is developing are challenging students more than ever before (Eisenhart et al., 2015; “Bloom’s Taxonomy”, 2016; Houseal & Ellsworth, 2014; “Three Dimensional Learning”, 2016; Curriculum and Instruction, 2016; Shiland, 2004). Students who are unprepared and unable to motivate themselves to take control of their learning will face a great deal of difficulty (De Blasio & Jarvinen, 2014; De Castella et al., 2013; Parker & Engel, 1983). This makes it even more difficult for teachers to meet every student’s needs (Parish & Mahoney, 2006). If teachers are not prepared to differentiate for all student, both at this time and in the future, both they and their students will suffer for it.

Significance

Using Cognitive Load Theory as a tool to help teachers differentiate in a Chemistry classroom can benefit both teacher and student (Sweller, 1994; Schwonke, 2015). Using this theory, teachers can evaluate their lessons and activities and gauge how challenging they will be for their students, which invites teachers to adapt their methods based on their students’ skills.

Students’ capabilities can be measured using the idea of cognitive efficiency. If they complete a task quickly and with a low amount of effort, versus a peer who completes the same task over a long time, applying a great deal of effort with little result, the first student is said to have high cognitive efficiency (Mastropieri, Scruggs, & Graetz, 2005; Hoffman, 2012; . Teachers who are aware of the range of cognitive efficiencies in their classroom are better equipped to adapt their lessons and materials to the best benefit of the student (D’Mello and Graesser, 2012; Gog et al., 2009; Knaus et al., 2009). Students who are aware of their measurement using this scale are more intentional learners – they are aware of where they struggle and can work to improve it (Knaus et al., 2009).
Rationale

Cognitive load is an often-overlooked factor in education at the high school level. Current teaching methods do not always take advantage of the ways students learn, and both teachers and students suffer for it (Shiland, 2004). A large number of teachers are unprepared for teaching Chemistry in inclusive classrooms, and unmotivated students handicap themselves, making it more difficult for teachers to address their needs in a large classroom (Dymond, Renzaglia, & Rosenstein, 2006; Kurtts et al., 2009). Students who are not classified as having a disability that affects their learning may still struggle with the content and level of work required for a high school Chemistry course. If teachers have no methods of identifying why these students are struggling, they cannot take action (Kahn & Lewis, 2014; Kirch et al, 2007). It is likely that their students will continue to encounter the same barriers until they either lose motivation and quit, or complete the course with less understanding than if something had been done (De Blasio & Jarvinen, 2014; De Castella et al., 2013). In either case, students may leave with frustration and a poor opinion of the course and themselves (Parker & Engel, 1983; Parish & Mahoney, 2006).

With the application of cognitive load theory, students’ cognitive efficiency can be considered, which can result in both teachers and students being more informed about the student’s learning process and capabilities (Sweller, 1994; Schwonke, 2015; . Students’ learning characteristics can be made available to the teacher to inform their lessons and daily teaching (Mastropieri, Scruggs, & Graetz, 2005). Instead of differentiating lessons based on each individual student’s needs, teachers can consider the range of cognitive efficiencies in the classroom and create lessons that use this information to better serve students (Hoffman, 2012; D’Mello and Graesser, 2012).

To become more effective educators, teachers should consider the cognitive load of each task when creating standards-aligned activities and lessons (Gog et al., 2009; Knaus et al., 2009). If the cognitive load appears to be above the level some students are capable of handling, strategies such as the ones outlined in this paper may be employed to reduce the load and allow all students to succeed (Haslam & Hamilton, 2010; Kirschner et al., 2009; Luftenegger et al., 2012). Using groups or engaging in backwards design are two methods that research has proven successful at optimizing the cognitive load of assignments (Kirschner et al., 2009; Morgan & Brooks, 2012). Using cognitive efficiency as a benchmark allows students to avoid being classified into specialized groups, such as those with disabilities or gifted students, and instead places all students on the same scale.

Definition of Terms

Backwards design – A teaching strategy where students consider the results or goals they are trying to achieve, then develop and follow a method of achieving the results or achieving the goals.
Cognitive efficiency – The ratio of mental effort versus output produced. This can be used regarding students to determine their abilities in a classroom.

Cognitive load – The amount of strain placed on the working memory (see below). High cognitive load indicates large mental effort.

Cognitive Load Theory – A theory explored by John Sweller. He put forth the idea that learning occurs using two mechanisms: (1) schema (see below) acquisition, and (2) transfer of the acquired information to a place where it is able to be used automatically.

Schema – A blueprint or mental map detailing the steps needed to complete a task.

Working memory – The part of the mind that is used to store information that is readily available for use. High cognitive load places a large amount of information in the working memory.
Chapter II: Thesis

Abstract

Using Cognitive Load Theory as a tool to help teachers differentiate in a Chemistry classroom can benefit both teacher and student. Using this theory, teachers can evaluate their lessons and activities and gauge how challenging they will be for their students, which invites teachers to adapt their methods based on their students’ skills. Students’ capabilities can be measured using the idea of cognitive efficiency. If they complete a task quickly and with a low amount of effort, versus a peer who completes the same task over a long time, applying a great deal of effort with little result, the first student is said to have high cognitive efficiency. Teachers who are aware of the range of cognitive efficiencies in their classroom are better equipped to adapt their lessons and materials to the best benefit of the student. Students who are aware of their measurement using this scale are more intentional learners – they are aware of where they struggle and can work to improve it.

Keywords: backwards design, chemistry, chemistry education, cognitive efficiency, cognitive load, cognitive load theory, differentiation, education, Next Generation Science Standards (NGSS), working memory
Differentiation in Chemistry for Students With Various Levels of Cognitive Efficiency

It is evident that the populations of classrooms are growing both in size and diversity. A teacher can expect to see a variety of students with different ethnicities, languages, abilities, and motivations. Students may be classified as having a disability, or may be classified as gifted. Still others may fall somewhere in between. With a large class size that includes such a diverse array of learners, one teacher alone is often hard-pressed to develop instruction that can effectively reach every student in the classroom. Effective instruction is meant to meet students at their current level and adapt itself to their needs. Yet, teachers often lack the training to effectively differentiate their instruction for inclusive science education. While there are many possible methods of addressing such a problem, one of the most useful may be the application of cognitive load theory. Using this model as a tool to categorize each student’s learning abilities as well as evaluate the demands that specific learning tasks and activities place on students can help teachers tailor their instruction for the range of students they encounter. Additionally, if applied to students’ knowledge and learning, it can assist students in gaining both a better understanding of their learning process and awareness regarding how to improve it. Analyzing students’ cognitive efficiency, through the use of cognitive load theory, can be an invaluable tool to assist teachers in differentiating their inclusive science classrooms.

This work aims to explore the possible benefits and methods of enhancing Chemistry teaching in classrooms through the application of cognitive load theory. Many factors play a role in the development of an ideal learning environment; this paper outlines those factors and builds an argument for the inclusion of cognitive efficiency evaluations in inclusive science classrooms. Through close evaluation of the research relevant to this topic, it explores the following topics:
the methods in which students learn science, the degree to which Chemistry teachers are prepared to teach inclusively, student motivation in the classroom, the application of cognitive load theory to the Chemistry classroom, the characteristics of students with regard to cognitive efficiency, and several strategies for teaching using cognitive efficiency evaluations.

How Students are Learning Science

The current educational standards set in place by state governments influence teachers’ creation of lessons, which in turn influences student learning. At this time, New York State (NYS) employs the NYS Learning Standards for Mathematics, Science, and Technology (MST). These standards place emphasis students gaining understanding of the overarching concepts involved in each area of science. Memorizing terminology and technical details is downplayed in contrast to the focus on “concepts, relationships, processes, mechanisms, models, and applications” of science (Curriculum and Instruction, 2016). In addition, scientific literacy is considered an essential component that teachers are expected to include in their instruction. Students are expected to be capable of decoding texts that include language that is rich in scientific terms and ideas. They must then synthesize responses that both demonstrate understanding of the concept and apply the concept to a new situation or scenario. This is evidenced in the methods of assessment associated with these standards, known as the New York State Regents Exams (Shiland, 2004).

These assessments take the form of a summative, year-end assessment that is intended to gauge students’ learning of specific courses. This pen-and-paper test is comprised of multiple choice and constructed response questions (Shiland, 2004). In these constructed response questions, students may be asked to create diagrams, interpret given data, explain phenomena or
data, and make calculations (Shiland, 2004). However, there is also heavy emphasis on reading comprehension. While testing accommodations and alternative assessments are available, these are only accessible to students who are classified as having a disability or specific reason for needing them (Curriculum and Instruction, 2016). This does not take into account students who may struggle with reading yet have gained the requisite knowledge of the subject. Such assessments may inhibit their ability to demonstrate their knowledge, leading to biased results.

In the classroom, teachers use varied methods of assessment. Summative assessments are frequently used for post-unit tests, but formative assessment is a widely-used option that brings multiple benefits to both students and teachers. Students receive feedback regarding their understanding while teachers are able to see the effects of their teaching and use it to improve and adjust their methods (Sandlin, Harshman, & Yezierski, 2015). However, the formative assessment items must be clearly aligned with teacher goals in order to provide accurate information about instruction (Sandlin et al., 2014). The New York State standards for Chemistry aim to evaluate students’ ability to “explain, analyze, interpret chemical processes and phenomena, and use models and scientific inquiry”, which in turn motivates teachers to incorporate these practices in their classrooms and assessments in order to prepare students for these important state exams (Curriculum and Instruction, 2016).

Yet, there is a new set of standards under review in New York State. The Next Generation Science Standards (NGSS) are being used to inform the next round of NYS education reform. The NGSS is based on three areas: practices, crosscutting concepts, and disciplinary core ideas (“Three Dimensional Learning”, 2016). The practices and crosscutting concepts can be thought of as the essential skills and ideas students must understand in order to succeed in learning the central ideas of science, particularly pertaining to each science discipline.
Disciplinary core ideas are organized by field and cover the main content that should be taught (“Three Dimensional Learning”, 2016).

An innovative aspect of the NGSS is the emphasis on engineering design. The NGSS includes standards that focus on science-related engineering and technology with the intent to better prepare students for applying science to the world around them. There is specific emphasis on problem solving and real world application (“Three Dimensional Learning”, 2016). This can be viewed as a step up from the inquiry-based practices seen in the past; exploration has been enhanced with realistic problem-solving. Students are expected to go beyond simply “doing” and move into “applying”, using methods of scientific discourse and appropriate academic language to convey their ideas and conclusions. Students engaging in lessons that follow these guidelines have stated that they are able to learn more because they were able to delve into understanding why certain ideas are correct and were treated as independent researchers (Criswell & Rushton, 2014).

There are many potential benefits of the NGSS, but as student autonomy increases, the cognitive load placed on them does as well. Cognitive load, which will be addressed in more detail later in this paper, can be thought of as the “mental effort” students must use to complete a task. The NGSS include many complex tasks, such as engaging in argument or analyzing and interpreting data, which is a step above the MST standards of the past (Houseal & Ellsworth, 2014). This is clearly seen by examining how the NGSS relate to Bloom’s Taxonomy. The Taxonomy, developed by Benjamin Bloom and several collaborators in 1956, is a framework that organizes educational tasks into a series of tiers (“Bloom’s Taxonomy”, 2016). It was revised in 2001, but the central aspects remain. Tasks are described by action words, such as “memorize”, “classify”, “critique”, or “develop” and sorted where the highest tiers correspond to
the most difficult or complex tasks ("Bloom’s Taxonomy", 2016). Complex tasks require increased mental effort, or a higher cognitive load. This is a benefit in the long term, as students will become accustomed to the higher-level thinking and educational maturity needed to contribute to a highly scientific world; however, for the individual student, this increase could prove a challenge.

When considering the increased cognitive demands of NGSS, there is a demographic of students that need to be considered. Science classrooms are becoming more inclusive; students with disabilities are more often placed alongside their peers in a traditional classroom setting. These students have access to accommodations and learning aids as necessary, but otherwise participate in identical curriculum. This type of combined learning can present challenges for students with disabilities, as the adaptations that take place frequently are not best suited for them (Dymond, Renzaglia, & Rosenstein, 2006). A mainstream lesson is rarely reworked to address all students; instead, modified activities or classwork are tacked on to the original lesson, providing a patchwork effect that does not create a sense of community learning and may even be detrimental to a struggling student (Kurtts et al., 2009). Adapting in this way may prove a challenge to teachers, as will be addressed later in this paper.

One commonly used method of creating inclusive learning environments is the use of the Universal Design for Learning (UDL). This framework can be used as a guide by teachers to address the learning needs of a wide variety of students. UDL encourages using a variety of methods of representation, engagement, and expression to adapt instruction for all learners (CAST, 2016). Different methods of representation are intended to address students who are resourceful and benefit from exploring ideas from multiple angles. Multiple methods of engagement help motivated students who are interested in pursuing a deep understanding of the
topic (CAST, 2016). A variety of methods of expression assist students who are goal-oriented, giving them a clear path to understanding (CAST, 2016). UDL can provide many helpful tools for teachers preparing material for an inclusive classroom (Kurtts et al., 2009). However, Dymond et al. (2006) argue that students with severe cognitive disabilities are not being reached using this method. In that vein, UDL appears to need adaptation if they are to be used as a method to tailor instruction for all students.

Chemistry Teacher Preparedness

Research indicates that current teaching practices make few, if any, considerations for students who struggle with the coursework in higher level science courses. In particular, science teachers are unprepared to look at “average” students who struggle with the cognitive load of the course. While 99% of teachers surveyed from the National Science Teachers’ Association (NSTA) in a survey performed by Kahn and Lewis (2014) reported to have encountered students with disabilities in their teaching, 30% of those teachers indicated they did not remember receiving any training regarding teaching inclusively. Informal, “on-the-job” training was listed as the highest source among the 70% who reported being trained; yet only 42% indicated having received this training in college (Kahn & Lewis, 2014). In a study done by Kirch et al. (2007), all teachers surveyed reported having received little to no instruction on teaching science to students with disabilities in their professional coursework. This low level of training regarding teaching science to students classified as having specific disabilities is concerning. It stands to reason that teachers are even more unequipped to consider students who are unclassified, yet have a low cognitive efficiency that hinders their learning in a typical science classroom.
Science classrooms today contain more students from diverse backgrounds than they have in the past. As such, teachers should be aware of the options they have available in order to provide a learning environment that benefits all students. Ideally, a teacher should craft instruction that reaches all students - those with disabilities, those considered gifted, and those considered average. The differences in students’ academic abilities can provide challenges to teaching in an inclusive classroom, as many students will learn and complete work at a different pace. There is much that teachers can do to make their learning accessible, yet it cannot be done by a teacher alone; students must contribute to make the learning a success.

**Motivation in the Classroom**

It can be difficult to determine the reason a student is not progressing in their learning. Is it a result of poor teaching practices or a lack of personal motivation? Is the material too difficult or the assessments unfair? Teachers can only affect some of these factors; the rest falls on the student. For this reason, students also must play their part in creating a beneficial learning environment by bringing their own drive to succeed. In general, student motivation is comprised of a variety of factors such as age, health, and environment (De Blasio & Jarvinen, 2014). Some of these are uncontrollable; all students bring certain experiences and situations with them that a teacher is unable to influence. However, De Blasio and Jarvinen (2014) discuss the importance of what they term the “learner-context relation” - the interactions between the teacher and student. Motivation is tied to the environment around the learner, which includes the relationship between teacher and student. Since knowledge acquisition is a “function of the students’ background, experiences, and motivation”, students will benefit from experiences and interactions that engage them, encouraging growth and learning (De Blasio & Jarvinen, 2014).
Students who demonstrate a failure to self-motivate may do so for a variety of reasons. Some may be internal; for instance, students who fear failure may handicap themselves by trying to alter their perception of failure. Tactics such as defensive pessimism are used to avoid entering into a situation they think will result in failure. Material that is too challenging or places too high a cognitive load on the student can create a likely environment for this reaction. These students hold themselves to a lower standard and expect to do poorly, claiming this will prepare them for the worst and give them a pleasant surprise if they achieve higher (De Castella et al., 2013). Additional methods of self-handicapping include task-avoidance, denial, active procrastination, lack of practice, reporting illness, or using drugs. While this may seem logical to a student facing anxiety due to the possibility of failure, research has shown that students who engage in these practices are typically less successful in school and develop self-esteem problems and other issues later in life (De Castella et al., 2013).

There are actions teachers can take when faced with a student struggling with internal motivation problems. Parker and Engel (1983) analyzed the internal and external forces associated with the learning process. Most are internal, on the part of the student, but there are two roles a teacher or mentor plays, which can have a strong influence on the student (Parker & Engel, 1983). The external evaluator, the teacher, has the opportunity to influence the student’s internal process, which is guided by curiosity, the situation around them, how they think they will perform, and their readiness to perform the task (Parker & Engel, 1983). The external evaluator sets a value to the learner’s effort. Coupled with feedback, which is the second external role, teachers can ensure the influence they are having is as positive as they can make it. When the practice of positive feedback is present in a classroom, the students’ fear of failure can be
alleviated. This kind of collaboration between teacher and student is essential to creating an environment to support students’ learning (Parish & Mahoney, 2006).

### Application of Cognitive Load Theory to Student Achievement in Chemistry

Analysis of student learning indicates that cognitive load is a crucial component of comprehension. Cognitive load theory, or CLT, proposes a research-based reasoning for the variety of difficulties involved in learning diverse material. In short, it explains the relationship between how a learner’s mind processes new concepts and material, and how this affects their ability to comprehend and retain the information. John Sweller was the first to publish his findings on this topic. He believed that there were two mechanisms central to learning: schema acquisition and transfer of learned information from what he called “controlled to automatic processing” (Sweller, 1994). In simplified terms, the two mechanisms can be thought of as comprehension and retention.

Schema acquisition, or the method a student uses to learn new information, involves examining the way the information presented affects what and how much is learned. The brain then takes the information and sorts it based on what is already known about the topic. When faced with a problem, such as a math problem, the brain places it in a category with other problems it recalls that have been solved a certain way. This allows tasks or problems that are more complex to potentially be simplified down to a manageable level. The schema, or blueprints, in the mind allow for most of the mind’s daily capabilities (Sweller, 1994). The tasks and experiences encountered daily are similar enough that they each time they are encountered, they draw on several common schema. When faced with complex or new tasks, the brain’s
schema works akin to a shortcut, or a stepping stone, giving a place to begin rather than starting from scratch.

The second mechanism, transferring learned information, relies on the first. When a schema is first acquired, there is a low level of proficiency regarding the information or skill. Students will need to practice using the schema in order to completely master it. Thus, schema are developed and fine-tuned, eventually reaching a stage where competency, or even expertise, is reached. Sweller (1994) describes two methods of processing information: controlled, where information is consciously sought after and retained, such as learning about a previously unknown topic; and automatic, where information acquisition has become unconscious, such as reading words on a paper. A person who has acquired and practiced the schema for reading no longer needs to recognize every letter and sound out each syllable. They are capable of focusing on understanding the content, rather than deciphering the language. This automatic processing paves the way into controlled processing. The transition process between these mechanisms outlines the process of acquiring schema. New information and new schema are gained through concentrated application and accessible with the minimum of effort.

The processes in Sweller’s work have the benefit of lessening the cognitive load of a learner. Cognitive load refers to the amount of mental effort being used by the working memory. When mental information is accessible and being used, it is said to be in the working memory. Both schemas and automatic processing help alleviate the strain on the working memory when complex tasks are in process by allowing easy access to previously learned information. (Sweller, 1994). Any process not automated draws on the working memory; too much of this can result in difficulties understanding and using new information. Additional research by more recent academics makes the claim that successful learning includes student self-regulation and
metacognitive analysis, in addition to using the mechanisms from Sweller’s work (Schwonke, 2015). This would assist students in becoming aware of the process they use to retain information and enhance their ability to learn independently. This is particularly applicable in computer-based learning environments, which are becoming much more prevalent. High school Chemistry classrooms are situations in which students may be unprepared for the cognitive load they encounter. The complexity of the material and the increased work load can have a negative effect on their achievement.

**Students’ Learning Characteristics**

Students have unique ways of processing information and different learning abilities, especially regarding their working memory (Mastropieri, Scruggs, & Graetz, 2005). This implies that students will learn at different rates. Some may be called “gifted students” if they are quick to absorb new ideas, while others may struggle, taking more effort and a longer time to reach the same conclusion as the “gifted student”. This can be characterized using the idea of cognitive efficiency. Cognitive efficiency relates the amount of effort a student puts into a task to the resulting performance. High cognitive efficiency would be the case in which knowledge gain is high and the time or effort of using the working memory are low (Hoffman, 2012). This could be exemplified by a student who easily completes a complex acid-base titration lab and asks few, if any, questions yet understands the concepts. On the other hand, a student who demonstrates significant difficulty with the same lab, works slowly, and needs a large amount of support, would demonstrate low cognitive efficiency. Interruptions, confusing or unfamiliar ideas, and obstacles are only a few of the widespread factors that could inhibit that efficiency by derailing
the flow of engagement the learner experiences while immersed in a task (D’Mello and Graesser, 2012).

Explicitly quantifying cognitive efficiency is difficult due to the nature of the data. The dependence on interpretation, both from the learner and the tester, forces an element of uncertainty into the work. Yet, some methods have been used effectively, such as verbal reporting, either concurrent with the work or retrospective to it (Gog et al., 2009). Adding a brief survey of effort and time per task to the end of a laboratory activity or assignment could allow the teacher to gain an idea of students’ cognitive efficiency in a relatively effortless way. Concept mapping has been used to trace students’ schema and examine its development, while a more technical approach may make use of eye tracking equipment (Gog et al., 2009). Concept mapping is an activity easily applicable to the high school Chemistry classroom. Many concepts, such as energy or chemical reactions, have multiple connections to other aspects of chemistry that can be shown using a concept map. Students may show both the connections and provide a description of why they are linked. The NGSS in particular emphasize students explaining their answers and actions; these activities would reveal to both the teacher and the student the weaker aspects in their reasoning and provide areas for targeted improvement. Others have used a simple four-category sorting method, grouping students by scoring (high or low) and self-reported effort (high or low) (Knaus et al., 2009). While this method was researched using participants from an undergraduate Chemistry course, the idea can be applied to a high school level by using a pre-assessment to gain an initial understanding of the students’ cognitive efficiencies. Further information could be gained from systematic assessments throughout the year to track students’ changes and progress.
Teaching to students with a variety of cognitive efficiency levels is essential for any teacher, particularly in the field of science. As the state standards become more challenging, schools become more enthusiastic about the science, technology, math, and engineering (STEM) fields (Eisenhart et al., 2015). More students are encouraged to enter into higher level STEM classes in the hopes of graduating students with higher capability in these areas (Eisenhart et al., 2015). With the increasing numbers of inclusive classrooms, teachers need to be able to incorporate a variety of differentiation techniques in order to reach every student. Considering students’ levels of cognitive efficiency would be an effective method of gaining an idea of the abilities of a group of students and would allow for more effective differentiation. It provides an impartial skills assessment that includes every student, including those with disabilities and those considered gifted.

One drawback is the vagueness of the test. If the four-category test is used, students are categorized into three groups. The students who scored highly and reported they used low effort are classified as the “high cognitive efficiency” group (Knaus et al., 2009). This includes students who tend to be labeled as ‘gifted’, but also could include students who are very proficient with the schema needed for that task. The second grouping, at the middle level, includes a range of students from high scoring with high effort, to low scoring with low effort. Most students would fall in this range. The third category includes the students who put in high levels of effort but scored poorly (Knaus et al., 2009). These are the students with low cognitive efficiency, and the ones who might benefit most from a classroom differentiated with respect to cognitive efficiency.

At the high school level, teachers encounter a wide variety of students in their classes. Science classrooms, and Chemistry in particular, are where this type of differentiation could be
most useful. Prerequisites for Chemistry classes are not uniform throughout the United States, but it is commonly a class taken after students have completed both Earth Science and Living Environment. Based on the current New York State Standards, students are expected to have experience with science and math (Shiland, 2004). Yet, this is not always the case. Teachers can expect to encounter students of a variety of grade levels. Each will have their own level of experience and skills, but teachers have no way of knowing what those are until they reach the classroom. Often, a teacher isn’t fully able to understand a student’s abilities until weeks or even months have passed. Differentiation with a focus on cognitive efficiency could alleviate this problem by creating a built-in scaffold for students at different levels. Instead of creating lessons first and adapting them after a student begins to struggle - a practice that often results in less effective differentiation - lessons are already accessible to all students.

**Strategies for Teaching**

Students with low cognitive efficiency are likely to be the ones that need the most support. Haslam and Hamilton (2010) stated that complex tasks can overtax the working memory, resulting in cognitive overload. At this point, students are not learning at the best of their ability. A solution to this dilemma considers the ratio of each task’s cognitive load in relation to the student’s cognitive efficiency. Employing this analysis allows the teacher to make an informed decision about the amount of scaffolding needed for the student to complete that task. Haslam and Hamilton’s (2010) proposed solution incorporated graphics and visuals into reading questions, allowing students to find information from both the images and the text. This placed less emphasis on information stored in the student’s working memory and instead allowed students to access multiple methods of displaying the information (Haslam & Hamilton, 2010).
In a Chemistry classroom, this could easily be adapted in a lesson using the concepts of gases and the Ideal Gas Law. A word problem describing a system, such as a sealed box with a gas inside, could be adapted to include a diagram of that system as an aid to comprehension. If the question asked about a change in the system, a series of “before and after” images could also be included. This strategy lessens the load on the student, who originally would have had to read and comprehend the question, create an image of the system in their head, and then recall the details of the system as they began the work to complete the problem. With a diagram, students are provided a reference that alleviates the stress on their working memory.

The cognitive stress of complex tasks can also be alleviated by the strategic use of student groups. When students work in a group, the cognitive stress is shared, allowing the group as a whole access to a larger working memory. Kirschner, Paas, and Kirschner (2009) examined the results of group work and individual work for several tasks of varying cognitive load and discovered that the method of using groups to lessen cognitive load only worked effectively in certain situations. Mutually shared cognition is directly related to team effectiveness; therefore, equal collaboration is essential. This was effective only when tasks were complex enough to warrant the effort involved (Kirschner et al., 2009). Individual work however proved to be most effective when retention of information was the goal. When students perceive themselves as more self-determined and autonomous in classroom activities, they demonstrate higher self-efficacy (Luftenegger et al., 2012). Students completing basic tasks that were within their range of cognitive efficiency retained more than when the same information was conveyed through group work (Kirschner et al., 2009). The optimal balance between student characteristics, group characteristics, and complexity of the proposed task needs to be achieved in order to determine which situation would be most appropriate.
Laboratory work and reports contain a large cognitive load, and often students are unprepared for the effort involved. Using methods like backwards design, in which students begin an activity by determining their end goal rather than following a prescribed set of instructions, can assist students in grasping the main idea of the concepts involved in the lab work. Morgan and Brooks (2012) researched the idea of backwards design in laboratory work, using reflective questions as a scaffold to enhance student awareness of their reasoning processes. Students designed the results section of the lab first and used that starting point to complete the rest of the lab work. It was found that the use of backwards designed labs with lower cognitive load resulted in significantly higher scores and student comprehension (Morgan & Brooks, 2012).

Summary

Cognitive load is an often-overlooked factor in education at the high school level. Current teaching methods do not always take advantage of the ways students learn, and both teachers and students suffer for it. A large number of teachers are unprepared for teaching Chemistry in inclusive classrooms, and unmotivated students handicap themselves, making it more difficult for teachers to address their needs in a large classroom. Students who are not classified as having a disability that affects their learning may still struggle with the content and level of work required for a high school Chemistry course. If teachers have no methods of identifying why these students are struggling, they cannot take action. It is likely that their students will continue to encounter the same barriers until they either lose motivation and quit, or complete the course with less understanding than if something had been done. In either case, students may leave with frustration and a poor opinion of the course and themselves.
With the application of cognitive load theory, students’ cognitive efficiency can be considered, which can result in both teachers and students being more informed about the student’s learning process and capabilities. Students’ learning characteristics can be made available to the teacher to inform their lessons and daily teaching. Instead of differentiating lessons based on each individual student’s needs, teachers can consider the range of cognitive efficiencies in the classroom and create lessons that use this information to better serve students.

To become more effective educators, teachers should consider the cognitive load of each task when creating standards-aligned activities and lessons. If the cognitive load appears to be above the level some students are capable of handling, strategies such as the ones outlined in this paper may be employed to reduce the load and allow all students to succeed. Using groups or engaging in backwards design are two methods that research has proven successful at optimizing the cognitive load of assignments. Using cognitive efficiency as a benchmark allows students to avoid being classified into specialized groups, such as those with disabilities or gifted students, and instead places all students on the same scale.

Further research is needed into additional strategies that can be used in the high school classroom, and into the efficacy of students’ awareness of their learning as a tool for educational improvement. While the strategies presented above are theoretically beneficial, they include the particular limitation of student action. For example, if students working in groups choose not to collaborate and share the work equally, the cognitive load is not distributed effectively and students who are struggling will not gain the benefits. Yet, with further research and implementation, cognitive efficiency can provide a useful tool for Chemistry teachers aiming to differentiate instruction.
Lesson Plan Template

Lesson Name:

<table>
<thead>
<tr>
<th>Unit:</th>
<th>Intended grade level:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson number: <em>within the unit</em></td>
<td>CE rating*: High Medium Low *Ideal level for cognitive efficiency students must have to succeed</td>
</tr>
</tbody>
</table>

**PLAN:**

Main Question/Concept:

*What idea are you exploring with your students in this lesson? There should only be one main question.*

Supporting ideas to LEARN:

*These are the additional ideas or skills students will learn in order to understand the main question/concept. As students learn these skills and use them in the lesson to understand the main concept, they are likely to increase the load on their working memory (i.e. adding more things they need to keep “on the top of their head”) – this is in addition to the load from the next section, PRIOR SKILLS.*

Prior Skills/Knowledge to KNOW:

*These are the skills students should have mastered in previous lessons or other classes. Students who are less comfortable with these skills will struggle more, as these skills are necessary for them to learn the content from the current lesson. Scaffolding may be needed if students are unprepared in this area.*

**SPECIFY:**

Learning Objectives:

Standards covered:

Assessments:
## IMPLEMENT:
Lesson outline (step by step)

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>What responsibilities does the teacher have at this time?</strong></td>
<td><strong>How should students be acting/engaging in the lesson?</strong></td>
<td><strong>High/Medium/Low</strong></td>
<td><strong>What facts from above (prior skills and/or learned skills) are necessary for this step? For example, reference PS1, or LS1.</strong></td>
<td><strong>What facts from above (prior skills and/or learned skills) are necessary for this step? For example, reference PS1, or LS1.</strong></td>
</tr>
</tbody>
</table>

Resources/Materials needed:

## REFLECTION:

What went well?

What did not go well (why)?

What would you improve for next time?
Laistner 24

Activity Plan Template

Activity Name:

Objective: The goal of this activity; what students should accomplish.

Activity outline (step by step)

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Commentary: Rationale regarding this activity and cognitive efficiency (CE) levels.

Strategies used: What teaching strategies were used to help students succeed?

Differentiation: How will the activity be differentiated so that all students will learn?

Assessment: How is the student being assessed? What criteria will be used to create a grade, or determine if the student has reached the objective?

Materials: All papers or worksheets/materials for the activity should be attached to this plan.

Reflection:

What went well?

What did not go well (why)?

Did students achieve the objective?

Were additional modifications needed?

Were students motivated and interested?
Lesson Name: Molecules and Matter

<table>
<thead>
<tr>
<th>Unit: Chemical Reactions and Stoichiometry</th>
<th>Intended grade level: 10-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson number: 1</td>
<td>CE rating*: High Medium Low</td>
</tr>
</tbody>
</table>

**PLAN:**

*Main Question/Concept:*

What are molecules and how can we identify them?

**Supporting ideas to LEARN:**

1. Atoms combine to make molecules and compounds (not all molecules are compounds though). Compounds must include at least two different elements.
2. Atoms can be the same (diatomic molecules) or different.
3. Molecules are the smallest fundamental unit of a chemical compound that can react.
4. Compounds are written as a *molecular formula*. This tells the relative amount of each element in a molecule.
5. The *formula mass* is the mass of all the atoms in the molecular formula (units = grams)
6. The *gram formula mass* is the mass of the atoms in one mole of the compound (units = grams/mole)

**Prior Skills/Knowledge to KNOW:**

1. What are atoms?
2. What are elements?

**SPECIFY:**

*Learning Objectives:*

- Students will be able to identify the relative amount of each element in given molecular formulas.
- Students will be able to determine the formula mass and gram formula mass of two individual compounds.
- Students will determine their cognitive efficiency level through the quiz at the end of the lesson.

*Standards covered:*

NYS Science Learning Standards for Chemistry:
Performance Indicator 3.1 - Explain the properties of materials in terms of the arrangement and properties of the atoms that compose them.

- **3.1cc** A compound is a substance composed of two or more different elements that are chemically combined in a fixed proportion. A chemical compound can be broken down by chemical means. A chemical compound can be represented by a specific chemical formula and assigned a name based on the IUPAC system.

- **3.1dd** Compounds can be differentiated by their physical and chemical properties.

- **3.1ee** Types of chemical formulas include empirical, molecular, and structural.

**Key Idea 3.3** Apply the principle of conservation of mass to chemical reactions.

- **viii** calculate the formula mass and gram-formula mass

**Assessments:**

**Informal:**
- Observation of students and their conversations while working on the introduction activity and while working on practice questions.
- Practice questions

**Formal:**
- Quiz at the end of the lesson. Both content knowledge and cognitive efficiency will be assessed.

**IMPLEMENT:**

**Lesson outline (step by step)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>Provide students with 5 notecard packets of 3 cards each. Guide students through activity. Explain how the chemists have multiple ways of representing things.</td>
<td>Working in table groups, determine the common aspect between each set of cards. Complete each set as prompted by the teacher. Propose hypotheses for the final set (meant to invoke thought – not all students should understand it immediately).</td>
<td>Medium</td>
<td>Finding common aspects of different ideas</td>
<td>AP#1</td>
</tr>
</tbody>
</table>
Ask how, if we only have 112 elements (and many radioactive), how can we have such diverse things? Discuss how atoms combine to form molecules. Address diatomic molecules (7UP or HOBrINCl).

Take 5 minutes to complete the practice questions independently. Use the remaining 2 minutes to collaborate with a partner to compare answers/ask questions.

Explain what cognitive efficiency is, and how taking the quiz will help us become better students and aware of how we learn. Administer and monitor quiz.

Complete quiz, answering questions for both content and CE.

Resources/Materials needed:
Notecards for introduction activity
Notes packet for students to follow
Practice questions
Quiz
REFLECTION:

What went well?

What did not go well (and why)?

What would you improve for next time?

Were further modifications needed?

Were students motivated?
Activity Name:

Identifying Molecules Practice

Objective:

Students will be able to describe the number of units of each element in the molecule.

Students will be able to classify the molecule as a compound, element, or diatomic molecule.

Activity outline (step by step):

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill in the tree chart with the words “element”, “molecule”, “diatomic molecule”, and “compound”</td>
<td>Understanding of the difference between the given words. Recalls information from previous lesson (definition of element)</td>
<td>For students with low CE, provide a word bank. For students with medium CE, provide the tree outline excluding the word bank. For students with high CE, allow them to create their own tree relating the given words.</td>
</tr>
<tr>
<td>Answer questions about the amount of each element present in a molecule, finding formula mass and gram formula mass (gfm)</td>
<td>Understanding of element names and subscripts, formula mass and gram formula mass</td>
<td>Questions increase in difficulty down the page. Students of high CE are expected to begin further down the page than those with lower CE</td>
</tr>
<tr>
<td>Find a partner and check their work. Compare answers if the same questions were completed.</td>
<td>Ability to explain/teach another student how the problem was solved.</td>
<td>Students share their work with each other, so all students may see different levels of problems and how to complete them.</td>
</tr>
</tbody>
</table>

Commentary:

The first task, the tree chart, was chosen to help students form connections between important concepts (Haslan & Hamilton, 2010). In this case, students needed to determine the relationship between the four words given. This activity rates as a challenging problem, requiring a higher level of thinking. Students with high cognitive efficiency (CE) would have an easier time completing this task (Schwonke, 2015). Therefore, there are modifications that can be used in order to adapt this lesson for students with lower CE. The word bank and tree chart with blanks provides students with a lower CE a good starting place. They are able to see what is expected are only need to recall the definitions of the words in order to complete the activity. They are still making the connections, but required more direction. Students with a middle level of CE are given the tree chart with blanks, but are not provided the word bank. Students are
expected to infer which words are placed in the blanks using the context of the chart. This requires more effort on the part of the students, though they are still accessing some scaffolds (the tree chart/context). Students with higher CE are expected to create their own tree using the words given. This requires students to know the definition and come up with a way to relate them. This level gives students more freedom and access to create their own plan, using higher levels of Bloom’s Taxonomy, which leads to better learning. Teachers may choose to label each CE level with a color to avoid stigma associated with “low CE”, which students may interpret negatively. This example uses green for low CE, orange for medium CE, and purple for high CE.

The second task is less challenging conceptually, but does require students to have a strong knowledge of the concepts taught in this lesson – specifically, understanding how to find out the number of units of each element are present in a molecule. This understanding can be applied to a wide array of problems with different difficulties. Simple molecules would be appropriate for students with a lower CE, and more complex ones would provide practice for students with higher CE. In this activity, students are given a list of ten problems, with the molecules involved ranging from simple to complex. Students with lower CE may start at one of the earlier problems, while students with higher CE may start further down. The starting place is gauged by students’ self-reported confidence in the topic, by a scale of 10%. Students who feel 90% confident should begin at question 9, a more difficult problem. If a student struggles, they should work on the problem prior. If they find it too easy, they should skip ahead. The goal is to have students complete at least 5 problems. Student awareness and independence enhances their cognitive efficiency (Schwonke, 2015; Luftenegger et al, 2012).

**Strategies used:**
Concept mapping

**Differentiation:**
Directions read aloud, written instructions, large size font available

**Assessment:**
Teacher observation of student work and student discussions during the activity. Classwork grade. Correctness check occurs when students collaborate to check answers.

**Materials:**
Worksheets, pencils

**REFLECTION:**
What went well and what did not?
Did students achieve the objective?
Were additional modifications needed?
Were students motivated and interested?
Molecular Formula Worksheet

Part 1: Tree Diagram

Complete the concept map below. You must include the following words: **element**, **molecule**, **diatomic molecule**, **compound**.

![Concept Map]

Part 2: Practice

How confident do you feel with the information you learned today (on a scale of 1 to 10)?

________

This worksheet has ten questions. Begin at the question number you wrote above. If you struggle a lot, move down a question. If you find the problem you started with too easy, move up a question. YOU MUST COMPLETE AT LEAST 5 QUESTIONS! Repeat this process until you finish the worksheet. If you get to the end, start back at question 1.

1. What is the ratio of hydrogen to oxygen in the compound H₂O?
2. How many parts of calcium (Ca) are there in CaCl₂?
3. What is the formula mass of HCl?
4. Calculate the formula mass of the compound NaNO₃?
5. Find the gram formula mass of sodium chloride.
6. What is the gram formula mass of Fe₂O₃?
7. How many oxygens are in the compound Fe(NO₂)₂?
8. What is the formula mass of NH₄SCN?
9. What is the ratio of each element in C₁₁H₁₇N₃O₈?
10. Calculate the gfm of Ni₂(S₂O₃)₃.
Molecular Formula Worksheet

Part 1: Tree Diagram
Fill in the tree diagram in the space below. You should be able to fill in the blanks with key words you learned in class today!

Part 2: Practice
How confident do you feel with the information you learned today (on a scale of 1 to 10)?

This worksheet has ten questions. Begin at the question number you wrote above. If you struggle a lot, move down a question. If you find the problem you started with too easy, move up a question. YOU MUST COMPLETE AT LEAST 5 QUESTIONS! Repeat this process until you finish the worksheet. If you get to the end, start back at question 1.

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9. What is the ratio of each element in C₁₁H₁₇N₃O₈?
10. Calculate the gfm of Ni₂(S₂O₃)₃.
Molecular Formula Worksheet

Part 1: Tree Diagram

Create a tree diagram of your own design in the space below. You must include the following words: element, molecule, diatomic molecule, compound. Make sure to explain why each are related!

Part 2: Practice

How confident do you feel with the information you learned today (on a scale of 1 to 10)?
________

This worksheet has ten questions. Begin at the question number you wrote above. If you struggle a lot, move down a question. If you find the problem you started with too easy, move up a question. YOU MUST COMPLETE AT LEAST 5 QUESTIONS! Repeat this process until you finish the worksheet. If you get to the end, start back at question 1.

11. What is the ratio of hydrogen to oxygen in the compound H₂O?
12. How many parts of calcium (Ca) are there in CaCl₂?
13. What is the formula mass of HCl?
14. Calculate the formula mass of the compound NaNO₃?
15. Find the gram formula mass of sodium chloride.
16. What is the gram formula mass of Fe₂O₃?
17. How many oxygens are in the compound Fe(NO₂)₂?
18. What is the formula mass of NH₄SCN?
19. What is the ratio of each element in C₁₁H₁₇N₃O₈?
20. Calculate the gfm of Ni₂(S₂O₃)₃.
Regents Chemistry
Notes and Practice Packet

Unit: Moles & Stoichiometry

1 Adapted from http://www2.skanschools.org/webpages/rallen/index.cfm
Vocabulary

This is your cheat sheet. Write a quick and simple definition or clue that will remind you of each word!

Mole –

Formula mass –

Gram formula mass –

Coefficient –

Subscript –

Law of Conservation of Mass –

Law of Conservation of Energy –

Balanced Equation –

Synthesis Reaction –

Decomposition Reaction –

Single-replacement Reaction –

Double-replacement Reaction –

Molecular Formula –

Empirical Formula –

Percent Mass –
Day 1: Introduction

Before we can even begin to understand what this unit is about, we need to be able to find the mass of different compounds. Open your Periodic Table and we’ll get started…

- First, what are the units we use for the mass atoms?
  ________________________________ (____)

- What is the mass of one atom of oxygen?
  ________________

- Why don’t we use grams as the units for massing atoms?
  Atoms are too small—the number would be HUGE
  Ex: If we used grams to mass atoms, the mass of oxygen would be
  \(0.00000000000000000000027 \text{ g} \) or \(2.7 \times 10^{-23} \text{ g}\)

  Find the mass of the following atoms:
  1) Mg = __________ 3) Cl = __________ 5) Ca = __________
  2) Li = __________ 4) Al = __________ 6) H = __________

- __________ ELEMENTS = one atom of an element that’s stable enough to stand on its own (VERY RARE)—not bonded to anything

- __________ ELEMENTS or DIATOMS = elements whose atoms always travel in pairs (\(\text{N}_2, \text{O}_2, \text{F}_2, \text{Cl}_2, \text{Br}_2, \text{I}_2, \text{H}_2\))—bonded to another atom of the same element
So, what would the mass be of one molecule of oxygen ($O_2$)?

This means that the mass of $O_2 = 2 \times \text{______ amu} = \text{______ amu}$

Calculating the Formula Mass & Gram Formula Mass of Compounds:

- ________________: the mass of an atom, molecule or compound in **ATOMIC MASS UNITS (amu)**
  
  Ex: formula mass of a hydrogen atom is __________

- ________________: the mass of one ______ of an atom, molecule or compound in **GRAMS (g)**
  
  Ex: GFM of hydrogen is __________ (this is the mass of 1 mol H)

- ___________: $6.02 \times 10^{23}$ units of a substance (like a really big dozen)
  
  Ex: 1 mol of C = ___________ atoms of C = ___________ g of C

**PRACTICE:**

1) What is the formula mass of $K_2CO_3$?

2) What is the gram formula mass of $CuSO_4 \cdot 5H_2O$?
Day 2: Math It Up!

There are lots of things we can find out from molecular formulas. See below…

**Calculating Percent Composition:**

**Step 1:** Calculate the GFM for the compound (or the FM).

Ex: CaCl₂

\[
\text{Ca} = 1 \times 40.08 = \text{(this is the “part” Ca)} \\
\text{Cl} = 2 \times 35.453 = \text{___________} \text{(this is the “part” Cl)}
\]

**Step 2:** Check the last page of your periodic table for the formula for percent composition. Write the formula below:

\[
\% \text{ composition by mass} = \frac{\text{mass of part}}{\text{mass of whole}} \times 100
\]

Now, use the formula to find the percent composition of each element or “part” in our compound (to the nearest tenth of a %).

**PRACTICE:**

1) What is the percentage by mass of carbon in CO₂?

2) What is the percent by mass of nitrogen in NH₄NO₃?

3) What is the percent by mass of oxygen in magnesium oxide?
Converting from moles to grams and back:

We will need to convert from grams to moles and vice versa for this class.

The diagram below summarizes these processes:

1. **Converting from Grams to Moles:**
   From Table T, you would use the Mole Calculations Formula:

   \[
   \text{# of moles} = \frac{\text{given mass (g)}}{\text{GFM (g/mol)}}
   \]

   **Problem:** How many moles are in 4.75 g of sodium hydroxide (NaOH)?

   **Step 1:** Calculate the GFM for the compound.

   \[
   \begin{align*}
   \text{Na} &= 1 \times = \\
   \text{O} &= 1 \times = \\
   \text{H} &= 1 \times =
   \end{align*}
   \]
**Step 2:** Plug the given value and the GFM into the “mole calculations” formula and solve for the number of moles.

\[
\text{# of moles} = \frac{\text{given mass (g)}}{\text{GFM} \left(\frac{\text{g}}{\text{mol}}\right)} = \text{__________} = \text{__________}
\]

**PRACTICE:**
1) How many moles are in 39.0 grams of LiF?
2) What is the number of moles of potassium chloride present in 148 g?
3) How many moles are in 168 g of KOH?

**2. Converting from Moles to Grams:**
From Table T, you would still use the Mole Calculations Formula, but you must rearrange it since you are solving for _________ now:

\[
\text{mass of sample (g)} = \# \text{ of moles (mol)} \times \text{GFM} \left(\frac{\text{g}}{\text{mol}}\right)
\]

**Problem:** You have a 2.50 mole sample of sulfuric acid (H₂SO₄). What is the mass of your sample in grams?

**Step 1:** Calculate the GFM for the compound.
**Step 2:** Plug the given value and the GFM into the “mole calculations” formula and solve for the mass of the sample.

\[
\text{mass of sample (g)} = \# \text{ of moles (mol)} \times \text{GFM} \left(\frac{g}{\text{mol}}\right)
\]

---

**PRACTICE:**

1) What is the mass of 4.5 moles of KOH?
2) What is the mass of 0.50 mol of CuSO\(_4\)?
3) What is the mass of 1.50 moles of nitrogen gas?

---

**CHALLENGE:** Convert from grams to atoms/molecules or vice versa!

4) How many molecules of SO\(_2\) are there in a 1.75 g sample?
5) What is the mass of 3.01 x 10\(^23\) atoms of carbon?
Day 3: Chemical Equations

Chemical Equations:

- A CHEMICAL EQUATION is a set of symbols that state the ________ and ____________ in a chemical reaction.
  - ____________ = the starting substances in a chemical reaction (found to the ______ of the arrow)
  - ____________ = a substance produced by a chemical reaction (found to the ______ of the arrow)

Example:

\[ 2Na + 2H_2O \rightarrow 2NaOH + H_2 \]

- Chemical equations must be ___________. Think of the arrow (→) as an equal sign.

- LAW of CONSERVATION of MASS: mass cannot be ________ or _______________ in a chemical reaction

Balancing Equations:

The number of ______ of each ________ on the ________ (left) side of the equation must be the same as the number of ______ of each ________ on the ________________ (right) side of the equation.

__________ and __________ tell us how many moles we have for each element.

Let’s look at the BALANCED equation below:

\[ C + O_2 \rightarrow CO_2 \]
*Note that there is 1 mole of carbon and 2 moles of oxygen on each side of the arrow. That’s what it means to be BALANCED.

Now, let’s examine the following UNBALANCED equation:

$$\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}$$

**Q:** How does this unbalanced equation violate the Law of Conservation of Mass?

**A:** In this equation, oxygen would have to be __________ (there’s one less on the products side)

- ___________ = the integer in front of an element or compound, which indicates the number of moles present
- ___________ = the integer to the lower right of an element which indicates the number of atoms present
- ___________ = the individual reactants and products in a chemical reaction.

**Q:** What do we use to balance equations?

**A:** __________________

**NOTE: WE NEVER CHANGE THE SUBSCRIPTS IN A FORMULA!**

**Example:**

$$2\text{Ag} + \text{S} \rightarrow \text{Ag}_2\text{S}$$

**COEFFICIENTS:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>___</td>
</tr>
<tr>
<td>S</td>
<td>___</td>
</tr>
<tr>
<td>Ag$_2$S</td>
<td>___</td>
</tr>
</tbody>
</table>

**SUBSCRIPTS:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Subscript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>___</td>
</tr>
<tr>
<td>S</td>
<td>___</td>
</tr>
<tr>
<td>Ag$_2$S</td>
<td>___</td>
</tr>
<tr>
<td>Ag</td>
<td>___</td>
</tr>
<tr>
<td>S</td>
<td>___</td>
</tr>
</tbody>
</table>
Method for Balancing Equations:

**Step 1:** Draw a line to separate products from reactants.

**Step 2:** List each of the different elements on each side of the line.

**Step 3:** Count up the number of atoms on each side & record it next to the corresponding element symbol.

**Step 4:** Find the most complex compound in the equation. Balance the elements found in that compound on the opposite side of the arrow by changing the coefficients for the different species. Every time you change a coefficient, you must update the number of each element.

**Step 5:** Now, continue balancing the elements by changing coefficients until you have the same number of each element on both sides of the equation.

Example: \( ____ \text{H}_2 + ____ \text{O}_2 \rightarrow ____ \text{H}_2\text{O} \)

Example: \( ____ \text{Na} + ____ \text{H}_2\text{O} \rightarrow ____ \text{NaOH} + ____ \text{H}_2 \)

Example: \( ____ \text{CO}_2 + ____ \text{H}_2\text{O} \rightarrow ____ \text{C}_6\text{H}_{12}\text{O}_6 + ____ \text{O}_2 \)

**ONE LAST NOTE:**

When balancing chemical equations, ______________________ may be balanced as a ________________ rather than as separate elements as long as they stay intact during the reaction.
**Example:** $\text{Al}_2(\text{SO}_4)_3 + \text{Ca(OH)}_2 \rightarrow \text{Al(OH)}_3 + \text{CaSO}_4$

In this equation, we have the polyatomic ions SULFATE & HYDROXIDE, and both remain intact during the reaction. Since $\text{SO}_4$ has the subscript of 3, we could think of it as $3 \times 1 = 3$ sulfur atoms and $3 \times 4 = 12$ oxygen atoms. OR, we can just look at the UNIT and say there are 3 (SO₄)’s on the reactant side and 1 (SO₄) on the product side.

Now let’s balance the equation:

$$___ \text{Al}_2(\text{SO}_4)_3 + ___ \text{Ca(OH)}_2 \rightarrow ___ \text{Al(OH)}_3 + ___ \text{CaSO}_4$$
Day 4: Reaction Action!

**TYPES OF CHEMICAL REACTIONS:**

<table>
<thead>
<tr>
<th>Type 1: SINGLE REPLACEMENT</th>
<th>Type 2: DOUBLE REPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition:</strong> Reaction where one species replaces another (one species alone on one side and combined on the other).</td>
<td><strong>Definition:</strong> Reaction where compounds react, switch partners and produce two new compounds.</td>
</tr>
<tr>
<td>Ex: 3Ag + AuCl₃ → 3AgCl + Au 2Cr + 3H₂SO₄ → Cr₂(SO₄)₃ + 3H₂ 2Cr + 3FeCO₃ → Cr₂(CO₃)₃ + 3Fe</td>
<td>Ex: Pb(NO₃)₂ + 2NaCl → PbCl₂ + 2NaNO₃ Na₃PO₄ + 3AgNO₃ → Ag₃PO₄ + 3NaNO₃ K₂CO₃ + 2AgNO₃ → Ag₂CO₃ + 2KNO₃</td>
</tr>
<tr>
<td>Will look like:</td>
<td>Will look like:</td>
</tr>
<tr>
<td>______________</td>
<td>______________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type 3: SYNTHESIS</th>
<th>Type 4: DECOMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition:</strong> Reaction where we take more than one reactant and create one product.</td>
<td><strong>Definition:</strong> Reaction where we take one reactant and create two products.</td>
</tr>
<tr>
<td>Ex: 4Al + 3O₂ → 2Al₂O₃ 2H₂ + O₂ → 2H₂O</td>
<td>Ex: BaCO₃ → BaO + CO₂ 2H₂O₂ → 2H₂O + O₂ 2Bi(OH)₃ → Bi₂O₃ + 3H₂O</td>
</tr>
<tr>
<td>Will look like:</td>
<td>Will look like:</td>
</tr>
<tr>
<td>______________</td>
<td>______________</td>
</tr>
</tbody>
</table>
Day 5: Stoichiometry

Mole-Mole Problems: An Introduction

A chemical equation is basically the “recipe” for a reaction. The ___________ in an equation tell us the amounts of ___________ and ___________ we need to make the recipe work. Reactants in an equation react in specific _________ to produce a specific amount of products.

Below is a recipe for sugar cookies:

3 eggs + 1 cup of flour + 2 cups sugar → 24 cookies

Let’s simplify this to: 3E + 1F + 2S → 24C

If we massed the eggs, flour and sugar, they should (in a perfect world) equal the mass of the cookies. This illustrates the LAW OF

CONSERVATION OF MASS!

So then…

3E + 1F + 2S = 24C

(200 g + 160 g + 240 g = 600 g)

Q: If you had to bake 48 cookies, how many eggs would you need?

A: ___ (double it)
Method for solving mole-mole problems:
Set up a proportion using your known and unknown values, then cross-multiply and solve for your unknown.

Example 1: Set up the proportion from the Q & A above and solve.

\[3E + 1F + 2S \rightarrow 24C\]

\[\frac{48}{24} = \frac{x}{3}\]

\[\underline{x} \times \underline{x} = \underline{x} \times \underline{x} \]

\[x = \underline{x} \times \underline{x}\]

Example 2: If you have 10 eggs and an infinite amount of sugar and flour, what is the greatest number of cookies you can make?

\[\frac{10}{3} = \frac{x}{24}\]

\[\underline{x} \times \underline{x} = \underline{x} \times \underline{x}\]

\[x = \underline{x} \times \underline{x}\]

We can use the process we used with the cookie recipe and apply it to chemical equations. The only difference is we ALWAYS check to make sure we are starting with a BALANCED CHEMICAL EQUATION!

Example 3: Consider the following formula:

\[\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3\]

How many moles of nitrogen gas (N\textsubscript{2}) would be needed to produce 10 moles of ammonia (NH\textsubscript{3})?
Mole-Mole Practice:

Use the following equation to answer questions 1-3:

\[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

1) If 12 moles of \( \text{C}_3\text{H}_8 \) react completely, how many moles of \( \text{H}_2\text{O} \) are formed?

2) If 20 moles of \( \text{CO}_2 \) are formed, how many moles of \( \text{O}_2 \) reacted?

3) If 8 moles of \( \text{O}_2 \) react completely, how many moles of \( \text{H}_2\text{O} \) are formed?

Use the following equation to answer questions 4-7:

\[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]

4) If 2.5 moles of \( \text{N}_2 \) react completely, how many moles of \( \text{NH}_3 \) are formed?

5) If 9 moles of \( \text{NH}_3 \) are formed, how many moles of \( \text{H}_2 \) reacted?
6) If 3.5 moles of NH\textsubscript{3} are formed, how many moles of N\textsubscript{2} reacted?

7) How many grams of N\textsubscript{2} are reacted when 3.5 moles of NH\textsubscript{3} are formed?

**Day 6: Stoichiometry Lab**

Day 7: Types of Chemical Equations

Determining EMPIRICAL Formulas:

**Empirical Formula** – the *reduced* formula; a formula whose subscripts cannot be reduced any further.

**Molecular Formula** – the *actual* formula for a compound; subscripts represent *actual quantity* of atoms present.

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Empirical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{2}O\textsubscript{4}</td>
<td></td>
</tr>
<tr>
<td>C\textsubscript{3}H\textsubscript{9}</td>
<td></td>
</tr>
<tr>
<td>C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}</td>
<td></td>
</tr>
<tr>
<td>B\textsubscript{4}H\textsubscript{10}</td>
<td></td>
</tr>
<tr>
<td>C\textsubscript{5}H\textsubscript{12}</td>
<td></td>
</tr>
</tbody>
</table>
PRACTICE:
Determining empirical formula from molecular formula.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a) H₂O</td>
<td>h) C₂H₆</td>
</tr>
<tr>
<td>b) N₂O₂</td>
<td>i) Na₂SO₄</td>
</tr>
<tr>
<td>c) C₃H₈</td>
<td>j) C₆H₅N</td>
</tr>
<tr>
<td>d) Fe(CO)₃</td>
<td>k) P₂O₅</td>
</tr>
<tr>
<td>e) C₃H₁₀</td>
<td>l) H₂O₂</td>
</tr>
<tr>
<td>f) NH₃</td>
<td>m) SeO₃</td>
</tr>
<tr>
<td>g) CaBr₂</td>
<td>n) LiCl</td>
</tr>
</tbody>
</table>

Calculating Empirical Formula from % Mass:

**Step 1:** Always assume you have a 100 g sample (The total % for the compound must = 100, so we can just change the units from % to g)

**Step 2:** Convert grams to moles.

**Step 3:** Divide all mole numbers by the smallest mole number.
Example: A compound is 46.2% mass carbon and 53.8% mass nitrogen. What is its empirical formula?

Step 1: Assume a 100 gram sample.

\[
\begin{align*}
46.2\% \text{ C} &= 46.2 \text{ g C} \\
53.8\% \text{ N} &= 53.8 \text{ g N}
\end{align*}
\]

Step 2: Convert grams to moles (we have grams; we need moles)

But we must have **WHOLE NUMBERS** for **SUBSCRIPTS**.

Step 3: Divide each mole number by the smallest mole number (We will round in this step to the nearest integer if it’s very close).

For C:

For N:

So, the empirical formula for our compound is _______
PRACTICE:
Determine the empirical formula from the percent composition for each of the following:

1) A compound contains 24.0 g C and 32.0 g O. Calculate its empirical formula. (Hint: start with step 2)

2) A compound contains 0.50 moles of carbon for each 1.0 mole of hydrogen. Calculate the empirical formula of this compound. (Hint: start with step 3)

3) A compound contains 14.6% C and 85.4% Cl by mass. Calculate the empirical formula of this compound.

4) Find the empirical formula of a compound that is 32.8% chromium and 67.2% chlorine.

5) What is the empirical formula of a compound if 67.1% is zinc and the rest is oxygen?
Determining MOLECULAR Formulas:

So far, we know how to:
1. Find an empirical formula from percent mass
2. Find an empirical formula from a molecular formula

But how do we find out the molecular formula from an empirical formula?

Example: A compound is 80.0 % C and 20.0 % H by mass. If its molecular mass is 75.0 g, what is its empirical formula? What is its molecular formula?

First, we must determine the empirical formula using the 3-step process.

Step 1: Assume a 100 g sample.

80.0 % C =

20.0 % H =

Step 2: Convert grams to moles (we have grams; we need moles)

Step 3: Divide each mole number by the smallest mole number and round to the nearest integer.

For C:
For H:

So, the empirical formula for our compound is ________.

Now we can determine the molecular formula:

- Empirical mass (the mass of 1 mole of CH3) = ______ g
- Molecular mass = ______ g
- Molecular mass is ___ times larger than empirical mass
- Molecular formula must be ___ times larger than empirical formula
- Multiply ALL the subscripts in our empirical formula by ___

Thus, our molecular formula is __________

PRACTICE:
Answer the questions below in the space provided. SHOW ALL WORK.

1) What is the molecular formula of a compound that has an empirical formula of NO2 and molecular mass of 92.0 g?

2) A compound is 50% sulfur and 50% oxygen by mass. Calculate the empirical formula. If its molecular mass is 128 g, determine its molecular formula.
3) A compound is 63.6% N and 36.4% O by mass. Calculate its empirical formula. List three possible molecular formulas for this compound.

4) A compound is 92.3% carbon and 7.7% hydrogen by mass. Calculate its empirical formula. If the molecular mass is 78.0 g, determine its molecular formula.

5) A compound is 74.0% C, 8.7% H, and 17.3% N. Calculate its empirical formula. Its molecular mass is 162 g. Determine its molecular formula.

**Day 8: Review**
Activity Name: Cognitive Efficiency (CE) Quiz

Objective: Students should complete the questions to the best of their ability and record the amount of time spent on each question as well as the amount of effort they spent on it.

Activity outline (step by step)

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete the questions, showing work on a separate paper if needed.</td>
<td>Knowledge from the day’s lesson: formula mass, gram formula mass, ratio, knowledge of elements, atomic mass, and the periodic table.</td>
<td>Variable</td>
<td>Quiz may be read aloud, printed on colored paper or with large font, or adapted for individual students’ needs.</td>
</tr>
<tr>
<td>Record the amount of time each question took as well as the effort spent on each question (on a scale of short/medium/long)</td>
<td>N/A</td>
<td>Low</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Commentary: In addition to showing students’ content knowledge, this activity is also intended as an assessment of students’ cognitive efficiency. Students will self-report on their time and effort spent on each problem. In order to determine students’ cognitive efficiency, the teacher should take this data and find the weighted average for each of the two factors, time and effort. 1s are low and 3s are high. Students will score between the maximum, 30, and the minimum, 3, for each factor. Each student will likely have a different score. To visually represent the data, graph time spent versus effort spent. In order to best represent this, the axes should cross at (15, 15). This separates the graph into four quadrants: high time and high effort (low CE), low time and low effort (high CE), and non-matching time and effort (medium CE). This graph is able to show the progress of the entire class. The goal is for students to improve their CE by working closer to the top right corner of the graph (Knaus et al, 2009). As students learn to self-assess their learning, they will be able to increase their cognitive efficiency (Luftenegger et al, 2012).

It is important to take into account the number of correct answers given as well. The CE analysis ideally works best when students achieve the correct answer. Teachers may need to take their impressions of the student into account as well, instead of solely basing their analysis on the quiz. In addition, the ten quiz questions may be divided into the following categories: Low CE required = #1, 2, 5, 10; Medium CE required = # 3, 4, 8, 9; High CE required = #6, 7. These
could be considered “easy/medium/hard” problems, so teachers may take this information into account as well when assessing students’ CEs.

**Strategies used:** This activity is intended as a benchmark to measure students’ progress as well as develop a cognitive efficiency rating that can be used to help inform teaching and help students understand how they learn.

**Differentiation:** N/A

**Assessment:** There are two forms of assessment for this activity. The first is a content-based grade out of 10 points. Students will earn points with every correct answer given. Second, the students will develop a cognitive efficiency rating based on the answers they circled regarding the time and effort spent on each problem. Questions are given different CE levels, which help inform students’ individual CE ratings.

**Materials:** Pencil, scrap paper, quiz

**Reflection:**

What went well?

What did not go well (why)?

Did students achieve the objective?

Were additional modifications needed?

Were students motivated and interested?
# CE Quiz

Circle your answer, then record the relative time and relative effort you spent on each problem. 1 indicated a short time/less effort and 3 indicates longer time/more effort. Remember to be honest – no one else will see your answers!

1. What is the difference between formula mass and gram formula mass?
   - Time: 1 2 3
   - Effort: 1 2 3

2. Find the gram formula mass of carbon dioxide, CO.
   - Time: 1 2 3
   - Effort: 1 2 3

3. What is the ratio of carbon to hydrogen in the molecule C₂H₂?
   - Time: 1 2 3
   - Effort: 1 2 3

4. What is the gfm of the molecule H₂CS?
   - Time: 1 2 3
   - Effort: 1 2 3
5. Which element is most prevalent in the molecule CH₂CNH?
   Time:  1  2  3
   Effort: 1  2  3

6. What is the formula mass of 2H₂SO₄?
   Time:  1  2  3
   Effort: 1  2  3

7. A molecule is made of only hydrogen and oxygen. Its gfm is 18 grams/mole. What is the molecular formula?
   Time:  1  2  3
   Effort: 1  2  3

8. Find the gfm for aluminum hydroxide, AlOH.
   Time:  1  2  3
   Effort: 1  2  3

9. What is the molecular formula of a molecule that contains nitrogen and oxygen in a 2:1 ratio?
   Time:  1  2  3
   Effort: 1  2  3
10. Which element is least prevalent in the compound H$_2$CCN?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effort:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lesson Name: The Mole

<table>
<thead>
<tr>
<th>Unit: Chemical Reactions and Stoichiometry</th>
<th>Intended grade level: 10-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson number: 2</td>
<td>CE rating*: High Medium Low</td>
</tr>
</tbody>
</table>

PLAN:

Main Question/Concept:

How does understanding what a mole is help us decode molecular formulas?

Supporting ideas to LEARN:

7. A mole represents a number. It means $6.02\times10^{23}$ of something. In particular, we can relate the atomic mass of an element to 1 mole of that element.
8. Molecular formulas are like a recipe, and tell us how many moles of each “ingredient” we need.
9. Percent composition is a measure of how much of something is in the molecule.
   Percent composition by mass requires finding the mass of the molecule first.

Prior Skills/Knowledge to KNOW:

3. Reading molecular formulas
4. Element names
5. Reading word problems
6. Math – percent

SPECIFY:

Learning Objectives:

By the end of class, students will be able to decode at least three molecular formulas and determine the percent composition of each element in the compound.

Standards covered:

3.3 Apply the principle of conservation of mass to chemical reactions.

   vi determine the mass of a given number of moles of a substance
   viii calculate the formula mass and gram-formula mass
   ix determine the number of moles of a substance, given its mass
Assessments:

- Visual observations of student progress, and student discussions (both during initial question and student practice)
- Percent composition activity
- Results of student practice questions. Graded (1 point for correctness and 1 point for challenge)

IMPLEMENT:

Lesson outline (step by step)

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Present a problem to the students, such several unlabeled recipes. Say, “I found a bunch of old recipes but I don’t know what they are.”</td>
<td>Look at the recipes and determine which are for bread, cookies, pasta</td>
<td>Medium</td>
<td>Baking or any experience in the kitchen</td>
<td>See Recipes sheet</td>
</tr>
<tr>
<td>3 min</td>
<td>Once students have made their choices, confirm correct ones and ask why they were chosen.</td>
<td>Explain reasoning. It is ideal if students make references to quantity (“too much sugar” or “3 cups flour”)</td>
<td>Low</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>5 min</td>
<td>Explain how this applies to molecular formulas and how we can determine the percent composition of our “recipe” or molecular formula.</td>
<td>Follow along with notes and ask questions as appropriate.</td>
<td>Low</td>
<td>Previous lessons on molecular formulas</td>
<td>See notes packet</td>
</tr>
<tr>
<td>Time</td>
<td>Activity Description</td>
<td>Knowledge Level</td>
<td>Previous Lesson</td>
<td>Notes/References</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-----------------</td>
<td>-----------------------------------</td>
<td></td>
</tr>
<tr>
<td>5 min</td>
<td>Notes and explanation with example problems: percent composition, moles to atomic mass.</td>
<td>Medium</td>
<td>Previous lessons on molecular formulas</td>
<td>See notes packet</td>
<td></td>
</tr>
<tr>
<td>30 min</td>
<td>Introduce and assist students throughout the Percent Composition Activity.</td>
<td>High/variable (see activity plan)</td>
<td>Knowledge learned about percent composition</td>
<td>See Percent Composition Activity</td>
<td></td>
</tr>
<tr>
<td>3 min</td>
<td>Collect activity papers and individual practice questions.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Resources/Materials needed:
- Recipes
- Percent Composition Activity
- Notes packet
**Activity Name:** Percent Composition Activity

**Objective:** After completing this worksheet, students should be comfortable with the process of calculating percent composition.

**Activity outline (step by step)**

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read page 1 and complete the sample problem.</td>
<td>Identifying the important information from the text; applying the equation for percent composition.</td>
<td>Medium</td>
<td>Based on the overall CE level of the class, the teacher may choose to go over the word problem with the class and identify the key information as a group, then allow students to complete the calculations on their own.</td>
</tr>
</tbody>
</table>
| Part 1, chart #1: With a partner, follow the instructions, brainstorm a procedure, and complete the chart. End result should be the percent composition for each color of M&M. | Separately:  
  - Working together to brainstorm a procedure for the activity.  
  - Tallying M&Ms and applying the formula for percent composition. | Low                               | Students of a higher CE may choose to work individually on this task (with permission of the teacher). Students who struggle may work in groups larger than two. Teacher may choose, for the sake of time or ability, to provide students with a sample set of data. |
| Part 1, chart #2: With a partner, follow the instructions, brainstorm a procedure, and complete the chart. End result should be the percent composition for each color of M&M. | Using the given process, find the mass of each color group of M&Ms and the entire group, then apply the equation for percent composition by mass. | Medium                           | Students with a higher CE may be asked to come up with their own procedure. Students with lower CE may be asked to combine into larger groups as necessary. |
| Practice Questions                                                   | Complete the three practice questions on a separate paper and hand them in.               | Medium                           | N/A                                                                                                              |
Commentary: This activity leads students through a variety of CE levels. It begins with a basic example and practice question to introduce students to the math involved with calculating percent composition. Providing the step-by-step example allows students to refer back to the example if they get stuck, reducing the load on their working memory. Once students complete the practice, they are asked to apply it to a physical situation (percent composition of a cup of M&Ms). Filling in the first chart requires simple math and repetition to help students feel adept at performing the calculations. Students may work with a partner, which allows the cognitive load to be shared, and also may put down on the time needed for the activity (Kirschner et al, 2009). This technique carries over to the second chart as well. The concept of percent composition by mass is introduced as an extension of the first concept, and students complete a similar chart in order to practice this skill. Finally, students are introduced to the idea of using the percent composition by mass equation on a molecular formula. After again being provided with a step by step example, students are expected to independently complete three questions practicing this skill (Luftenegger et al, 2012). There is one question of each high, medium, and low CE rating. Student results will give the teacher an understanding of the student’s progress with these skills.

Strategies used: Interactive activity, partner collaboration

Differentiation: Multiple groups may collaborate on the chart work. Students who struggle with math may use visual aids for counting and calculating percent composition. The activity can be easily adapted for a variety of levels of student achievement.

Assessment: Students will hand in both the activity worksheet and the practice questions (on a separate paper) at the end of class. Informal assessments will be teacher observation of student interactions and questions during the introduction activity and the percent composition activity. Formal assessments will be a participation grade for completion of the percent composition activity, and a correctness grade for the practice questions.

Materials: Worksheet and pencil, calculator, plastic cups, M&Ms, balance

Reflection:

What went well?
What did not go well (why)?
Did students achieve the objective?
Were additional modifications needed?
Were students motivated and interested?
Percent Composition of M&Ms Activity

What is percent composition? Well, we see and use this math skill every day. If you are baking Christmas cookies, you may need to decide how much (which percent) you want to give away and how much you want to keep for yourself! If you want to buy a new pair of shoes, you may need to budget and see what percent of your paycheck you want to spend. When debating whether or not to eat that slice of cake, you might wonder exactly how much sugar is in it.

Let’s practice doing the math. Your equation is found in Table T of your reference tables. Write it below:

Example 1:
Ramone has two brothers, a sister, and two dads. What percentage of his family is female?

Step 1: What is the “part” we are looking for?
Females – there is one female in Ramone’s family.

Step 2: What is the “whole”?
The whole family – 6 people.

Step 3: Plug it in. (Don’t forget to multiply by 100!)

\[
\text{percent composition} = \frac{\text{part}}{\text{whole}} \times 100
\]

\[
\text{percent composition} = \frac{1}{6} \times 100
\]

\[
\text{percent composition} = 0.17 \times 100 = 1.7\%
\]

So, 1.7% of Ramone’s family is female.
Sometimes the questions can be more complicated. Try this one on your own. You may want to highlight the important information!

**Example 2:**

Joe works at the sporting goods store and has been wanting to get a new pair of sneakers. He just got paid and thinks this is the perfect time to get those fancy shoes all the cool guys have. He goes to the store and finds that the shoes cost $50. They look awesome, but he isn’t sure he wants to pay that much. He decides that if the shoes cost less than a quarter of his paycheck, he will buy them. Last week, his paycheck totaled $180. Should Joe buy the shoes?

**Part 1:**

**M&Ms by Percent Composition**

**The Activity:**

With a partner, grab a cup of M&Ms from the front table. Your goal is to find the percentage of every color M&M (red, blue, green, etc.) that are in the cup. With your partner, come up with a method to use and write it below. Use the chart below to help.

**Process:**

<table>
<thead>
<tr>
<th>Color: # M&amp;Ms</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Brown</th>
</tr>
</thead>
<tbody>
<tr>
<td># M&amp;Ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total M&amp;Ms (all colors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent composition can be used for anything in this way – percent of white shirts in a room, percent of sugar in a cookie or beans in chili, or percent of people passing a class.
But you may have noticed that the equation from Table T is listed as “percent composition *by mass*”. This just means that instead of counting numbers of things (in this case, M&Ms), we measure their mass instead.

<table>
<thead>
<tr>
<th>Color:</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Brown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of ____ color M&amp;Ms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of all M&amp;Ms (all colors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Composition <em>by mass</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Process:**

1. Get a clean plastic cup and record the mass.
   
   *Mass of cup: ____________*

2. Pick a color M&Ms and pour them in the cup, then find the mass. Remember to subtract out the mass of the cup in order to find the mass of the M&Ms.

   *Mass of _____ M&Ms plus cup: ____________

   *Mass of _____ M&Ms: ____________*

3. In the same way, find the mass of the whole cup of M&Ms.

   *Mass of all M&Ms: ____________*

4. Find the percent composition *by mass* of the color M&Ms. Does it match the percent composition by number?

5. Repeat for the rest of the colors and fill in the chart.

**Analysis:**

Why do you think the two different types of percent composition differed?
Part 2:

**Molecules: Percent Composition by Mass**

When finding the percent composition of a molecular formula, we need to be specific. We can’t just calculate part over whole – it wouldn’t be clear if we were talking about moles, atoms, or any other subset. Most often, we calculate percent composition of molecules by mass. Try applying what you’ve learned about calculating percent composition by mass to the problems below!

**Example:** What is the percent composition by mass of hydrogen in H₂O?

**Step 1:**
Find the mass of the “part” – in this case, hydrogen.
There are 2 moles of hydrogen. The gram formula mass of hydrogen is 1 gram/mole.
2 moles x 1 gram/mole = 2 grams
Therefore, our “part” equals 2 grams.

**Step 2:**
Find the mass of the “whole” – in this case, the whole molecule. (AKA the gfm!)
GFM = (2 moles x 1 gram/mole) + (1 mole x 16 grams/mole) = 18 grams

**Step 3:**
Plug it in!

\[
\text{percent composition by mass} = \frac{\text{part}}{\text{whole}} \times 100
\]

\[
\text{percent composition} = \frac{2 \text{ grams}}{18 \text{ grams}} \times 100 = 0.111 \times 100 = 11.1\%
\]

**Practice:**

1. What is the percent composition by mass of oxygen in glucose (C₆H₁₂O₆)?
2. Calculate the percent by mass of oxygen in Al₂(SO₄)₃.
3. A 4 g sugar cube (Sucrose: C₁₂H₂₂O₁₁) is dissolved in a 350 ml teacup of 80 °C water. What is the percent composition by mass of the sugar solution?
   Given: Density of water at 80 °C = 0.975 g/ml
Recipe #1

Ingredients:
1 1/2 cups butter, softened
5 cups all-purpose flour
2 teaspoons baking powder
1 teaspoon salt
1 teaspoon vanilla extract
2 cups white sugar
4 eggs

Recipe #2

Ingredients:
1 package (1/4 ounce) active dry yeast
2-1/4 cups warm water (110° to 115°)
3 tablespoons sugar
1 tablespoon salt
2 tablespoons canola oil
6-1/4 to 6-3/4 cups all-purpose flour

Recipe #3

Ingredients:
1 egg, beaten
1/2 teaspoon salt
1 cup all-purpose flour
2 tablespoons water
Lesson Name: Expansion on Molecular Formula

<table>
<thead>
<tr>
<th>Unit:</th>
<th>Chemical Reactions and Stoichiometry</th>
<th>Intended grade level: 10-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson number:</td>
<td>3</td>
<td>CE rating*: High Medium Low</td>
</tr>
</tbody>
</table>

PLAN:

Main Question/Concept:
How do molecular formulas work together to create new compounds?

Supporting ideas to LEARN:

10. Molecular formulas tell us the ratio of elements within them.
11. Molecular formulas (representing different compounds) can combine/REACT to create new ones. This is shown in a chemical equation.
   Students will learn the method for balancing equations that are unbalanced.

Prior Skills/Knowledge to KNOW:

7. How to read and decode molecular formulas
8. Element names
9. Math – percent and ratios

SPECIFY:

Learning Objectives:
By the end of the lesson, students will be able to balance unbalanced chemical equations – one simple and one that challenges them.

Standards covered:

NYS Chemistry Standards - Standard 4

a. Apply the principle of conservation of mass to chemical reactions.
   i) balance equations, given the formulas for reactants and products
   ii) interpret balanced chemical equations in terms of conservation of matter and energy
   iii) create and use models of particles to demonstrate balanced equations
Assessments:
- Visual observations of student progress and student discussions (both “teachers” and “students”) during main activity and introduction
- Classwork grade based on effort

IMPLEMENT:
Lesson outline (step by step)

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Introduction</td>
<td>Attempt to solve the problem.</td>
<td>Medium</td>
<td>Logic skills/puzzle solving</td>
<td>Balancing Equations Activity page 1</td>
</tr>
<tr>
<td></td>
<td>Question: Goat, Wolf, Cabbage Logic Problem shown on board</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Go over solution to introduction question and transition into notes on chemical equations and balancing.</td>
<td>Ask questions and fill in notes.</td>
<td>Low</td>
<td>Knowledge of molecular formula from previous classes.</td>
<td>Notes packet</td>
</tr>
<tr>
<td>35 min</td>
<td>Introduce and guide students in the Balancing Equations Activity. Review first page if necessary.</td>
<td>Listen to directions and get materials. Work with partner to solve problems.</td>
<td>Medium-High (see activity commentary)</td>
<td>Knowledge of balancing equations from notes.</td>
<td>Balancing Equations Activity</td>
</tr>
<tr>
<td>5 min</td>
<td>Ask students to clean up and do a 1 minute write up about how comfortable they feel with the questions they dealt with that day.</td>
<td>Clean up and write for 1 minute sharing their confidence level with the material so far.</td>
<td>Low</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Resources/Materials needed:

Notes packet, Activity and materials (see commentary), scrap paper for ticket out the door, whiteboard or chalk board for introduction question.

REFLECTION:

What went well? / What did not go well?

What would you improve for next time?

Were further modifications needed

Were students motivated?
**Activity Name:** Balancing Equations Activity

**Objective:** Students will be able to work with a partner to balance the equations on the worksheet correctly the first time with 80% or higher accuracy.

**Activity outline (step by step)**

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read the introduction and example.</td>
<td>Reading comprehension skills</td>
<td>Medium</td>
<td>Introduction may be read aloud or gone over as a teacher-led activity as preferred by teacher.</td>
</tr>
<tr>
<td>Working with a partner, follow the instructions on the worksheet to create kinesthetic models of the six (balanced) equations.</td>
<td>Understanding of how to balance a chemical equation from the earlier lesson</td>
<td>Medium</td>
<td>Students are expected to work with a partner as a method of lessening the cognitive load on each student. However, students who feel comfortable may work individually. Teacher may require students of varying CE levels to answer fewer or more challenging problems, respectively.</td>
</tr>
<tr>
<td>Individually or with a partner, decipher the unbalanced equations from the symbols, then balance the equation.</td>
<td>Understanding of how to balance a chemical equation from the earlier lesson; matching symbols and formatting/writing chemical equations.</td>
<td>High</td>
<td>Students may work in groups to complete this activity. (See previous row).</td>
</tr>
</tbody>
</table>

**Commentary:** This activity was chosen to help students create a schema for the skill of balancing equations (Sweller, 1994). Since this concept can often be difficult for students of all levels to understand, this activity combines kinesthetic modeling, partner work, and multiple methods of practice to help students learn. The partner work lowers the cognitive load on each student involved, allowing each to work together and ensuring each will understand the concept, even if they have different CE levels (Kirschner et al, 2009). The kinesthetic modeling and extensive practice help students view the process of balancing equations in several different ways, enhancing their formation of a “schema” – a kind of blueprint they can refer to in order to complete future problems (Sweller, 1994).

**Strategies used:** Partner work, kinesthetic modeling
**Differentiation:** Teacher may adapt the problems to be simpler or more complex for students at different levels. Students may use a variety of manipulatives if the beads/pipe cleaner are not suitable.

**Assessment:** This activity involves students bringing their work up for the teacher to check throughout the activity. Therefore, the assignment should be used as a classwork grade. Teacher will initial correct answers, and could use two different colored pens to identify if the correct answer was found on the first attempt, to collect data for the objective.

**Materials:** Pencil, beads, pipe cleaner, copier paper, scrap paper

**Reflection:**

What went well?

What did not go well (why)?

Did students achieve the objective?

Were additional modifications needed?

Were students motivated and interested?
Have you seen (or solved) this before?

A farmer wants to cross a river and take with him a wolf, a goat, and a cabbage. There is a boat that can fit himself plus either the wolf, the goat, or the cabbage. If the wolf and the goat are alone on one shore, the wolf will eat the goat. If the goat and the cabbage are alone on the shore, the goat will eat the cabbage. How can the farmer bring the wolf, the goat, and the cabbage across the river?

The solution to this puzzle involves some back and forth. It’s not as straightforward as we might hope! But balancing equations is a very similar process. We need to manipulate both sides of the equation in order to find our solution. And we have certain rules we need to keep in mind, just like the limitations in the problem above.

Applying to Chemical Equations:

**GOAL:** A balanced equation = equal numbers of each element on BOTH sides of the equation.

**RULES:**

1. The finished equation must obey the **LAW OF CONSERVATION OF MASS**
2. We may only add **whole number coefficients** (NEVER subscripts!)
3. Remember to distribute the coefficient out to **all** elements in the compound
4. Don’t give up – persistence is key!

---

2 Adapted from: www.mathisfun.com; www.xkcd.com; www.cpalms.org
Example:

Balance this equation: \(H_2 + O_2 \rightarrow H_2O\)

1. Keep track of how many moles of each *element* you have on each side (products vs. reactants) with a chart.

\[
\begin{align*}
H_2 + O_2 & \rightarrow H_2O \\
\text{Hydrogen (H)} & = 2 & \text{Hydrogen (H)} & = 2 \\
\text{Oxygen (O)} & = 2 & \text{Oxygen (O)} & = 1
\end{align*}
\]

2. Decide which compound’s coefficient you need to change to make the chart’s numbers equal on both sides.

   In this case, adding a 2 in front of \(H_2O\) will get us there – sort of.

   *Don’t worry if it throws off your other side – we can fix that one too*

3. Now we have this:

\[
\begin{align*}
H_2 + O_2 & \rightarrow 2H_2O \\
\text{Hydrogen (H)} & = 2 & \text{Hydrogen (H)} & = 4 \\
\text{Oxygen (O)} & = 2 & \text{Oxygen (O)} & = 2
\end{align*}
\]

   Repeat step 2. This time, let’s change the coefficient in front of \(H_2\).

4. Giving us…

\[
\begin{align*}
2H_2 + O_2 & \rightarrow 2H_2O \\
\text{Hydrogen (H)} & = 4 & \text{Hydrogen (H)} & = 4 \\
\text{Oxygen (O)} & = 2 & \text{Oxygen (O)} & = 2
\end{align*}
\]

   This works if you count moles (see chart) AND if you find the mass of the compounds on each side. Check it yourself!
Balancing Equations with Beads

PROCEDURE:

I. Obtain a petri dish of colored beads (see table below for quantity of each). If your dish of beads does not have enough, get them from the reserve stockpile at the teacher’s desk. The numbers shown below are the minimum for you to be able to do the equation balancing.

II. For equations (1) - (5) below, complete the following steps:
   a. Try to balance the equation first. Then, try to model the equation using beads.
   b. A pipe cleaner should be used to string beads onto in order to represent formula units or molecules. Pure elements (atoms) DO NOT need a pipe cleaner.
   c. One of the lab partners should use his/her beads to simulate the left side of the balanced equation on a piece of copier paper, and the other person should simulate the right side on a separate piece of paper. DO NOT split up molecules/formula units! This is why they are on a pipe cleaner.
   d. Using an index card, draw several (+) and (→) and cut out to use in your balancing.
   e. Make sure that there are the same number of pieces of each kind and color on each side of the equation.
   f. When you and your lab partner have completed an equation, have your instructor check the balanced equation and the candy arrangement to verify that everything is correct.

<table>
<thead>
<tr>
<th>Element</th>
<th>Color</th>
<th>Quantity in bag</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>white</td>
<td>12</td>
</tr>
<tr>
<td>Cl</td>
<td>green</td>
<td>8</td>
</tr>
<tr>
<td>O</td>
<td>Red</td>
<td>12</td>
</tr>
<tr>
<td>N</td>
<td>purple</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>black</td>
<td>8</td>
</tr>
<tr>
<td>Na</td>
<td>Yellow</td>
<td>8</td>
</tr>
<tr>
<td>Fe</td>
<td>blue</td>
<td>8</td>
</tr>
</tbody>
</table>

I will then initial in the space provided so that you will get credit.

(1) ____ Na + ____ Cl₂ = ____ NaCl  
   initials _____
(2) ____ Na + ____ H₂O = ____ NaOH + ____ H₂  
   initials _____
(3) ____ CO + ____ NO = ____ CO₂ + ____ N₂  
   initials _____
(4) ____ Fe₂O₃ + ____ CO = ____ Fe + ____ CO₂  
   initials _____
(5) ____ C + ____ Fe₂O₃ = ____ CO + ____ Fe  
   initials _____
III. The drawings for equations (6) - (10) on the next sheet represent **unbalanced** chemical equations. For these equations, first use the drawings and the key provided to write the **unbalanced** equation, and then follow the same procedure for balancing, simulating with beads, and having your results initialed that you used for equations (1) - (5) above.

**KEY:**

<table>
<thead>
<tr>
<th></th>
<th>HYDROGEN</th>
<th>CHLORINE</th>
<th>OXYGEN</th>
<th>NITROGEN</th>
<th>CARBON</th>
</tr>
</thead>
</table>

(6) \[ \text{HYDROGEN} \quad \text{+} \quad \text{CHLORINE} \quad = \quad \text{OXYGEN} \]

______________________________ initials_____

(7) \[ \text{HYDROGEN} \quad \text{+} \quad \text{NITROGEN} \quad = \quad \text{CARBON} \]

______________________________ initials_____

(8) \[ \text{HYDROGEN} \quad \text{+} \quad \text{NITROGEN} \quad = \quad \text{CARBON} \]

______________________________ initials_____

(9) \[ \text{CARBON} \quad \text{+} \quad \text{CHLORINE} \quad = \quad \text{CARBON} \quad \text{+} \quad \text{HYDROGEN} \]

______________________________ initials_____

(10) \[ \text{NITROGEN} \quad \text{+} \quad \text{NITROGEN} \quad = \quad \text{NITROGEN} \quad \text{+} \quad \text{NITROGEN} \]

______________________________ initials_____
Lesson Name: Chemical Reactions

Unit: Chemical Reactions and Stoichiometry

Intended grade level: 10-11

Lesson number: 4

CE rating*: High  Medium  Low

PLAN:

Main Question/Concept:

How do chemicals react to form products?

Supporting ideas to LEARN:

1. Types of chemical reactions

Prior Skills/Knowledge to KNOW:

1. Able to recognize element symbols and common compounds
2. Moles
3. Ratio
4. Balancing equations

SPECIFY:

Learning Objectives:

- Students will be able to write a sentence describing what is happening in a given chemical reaction
- Students will be able to balance a simple chemical reaction

Standards covered:

NYS Chemistry Standards – Standard 4

3.3 Apply the principle of conservation of mass to chemical reactions.

i. balance equations, given the formulas for reactants and products
ii. interpret balanced chemical equations in terms of conservation of matter and energy

Assessments:

Informal:

- Observation of students and their conversations throughout the lesson
- Posters

Formal:

- Review worksheet
**IMPLEMENT:**

*Lesson outline (step by step)*

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Have students collaborate in groups to make a list of the steps to balancing an equation (ex. “rules” listed previously)</td>
<td>Work in groups to complete the activity.</td>
<td>Low</td>
<td>Recall information from previous day</td>
<td>N/A</td>
</tr>
<tr>
<td>10 min</td>
<td>Discuss the idea that there are different types of reactions that we can recognize. Use notes.</td>
<td>Follow along/complete notes; ask questions as necessary.</td>
<td>Low</td>
<td>N/A</td>
<td>Notes packet</td>
</tr>
<tr>
<td>15 min</td>
<td>Guide students through poster activity as needed.</td>
<td>Create a poster that describes one of the four types of reactions discussed. Participate in a gallery walk after all are completed.</td>
<td>Low</td>
<td>Information from the lesson</td>
<td>Poster Activity</td>
</tr>
<tr>
<td>20 min</td>
<td>Hand out the Chemical Reactions/Balancing Equations Review sheet and help students as needed. Collect once finished.</td>
<td>Complete practice individually. If complete at the end of class, hand in. If not, finish for homework.</td>
<td>High</td>
<td>Balancing equations and identifying types of reactions</td>
<td>Chemical Reactions/Balancing Equations Review</td>
</tr>
</tbody>
</table>

**Resources/Materials needed:**

Scrap paper, Notes packet for students to follow, poster paper and markers/colored pencils, worksheet.

**REFLECTION:**

What went well? What did not go well? What would you improve for next time?
**Activity Name:** Types of Reactions Poster

**Objective:** Students will create a poster showing one of the four types of reactions discussed in class.

**Activity outline (step by step)**

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose a type of reaction from the notes packet. Create an analogy and illustrate it in a poster.</td>
<td>Understanding of the chosen reaction type.</td>
<td>Low</td>
<td>Teacher may provide examples of analogies, or may allow students to simply draw whatever representative picture they choose.</td>
</tr>
<tr>
<td>Gallery walk of posters made by the class.</td>
<td>Students should be reminding themselves of each type of reaction based on the poster.</td>
<td>Low</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Commentary:** This lesson was chosen as a low CE practice activity for the different types of chemical reactions. The concept is not very complicated, but since it comes directly after a more difficult concept (balancing equations), it is helpful to reinforce the new idea so it can be combined with previously learned ideas. This activity also allows students to show their personality and to have others appreciate their work.

**Strategies used:** Gallery Walk – students get to see and appreciate each other’s work while reinforcing the concepts learned.

**Differentiation:** N/A

**Assessment:** The only assessment in this activity is teacher observation of students and students’ work. The activity should be graded as participation or classwork.

**Materials:** Colored paper, markers/colored pencils

**Reflection:**

- What went well? /What did not go well (why)?
- Did students achieve the objective?
- Were additional modifications needed?
- Were students motivated and interested?
POSTER PROJECT!

Once you are finished, tape it on the wall around the room. Once everyone is done, we will have a gallery walk to share our work!

For example: Decomposition

![Image of egg decomposition](image-url)
**Activity Name:** Types of Reactions/Balancing Equations Review

**Objective:** Students will complete at least 80% of the types of reactions questions correctly, and at least 70% of the balancing equations questions correctly.

**Activity outline (step by step)**

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete the worksheet by first balancing the equation and then determining what type of reaction is occurring.</td>
<td>Knowledge from the last two lessons.</td>
<td>Variable</td>
<td>Problems may be read aloud, printed on colored paper or with large font, or adapted for individual students’ needs.</td>
</tr>
</tbody>
</table>

**Commentary:** This activity contains questions of varying CE level, and each question has two parts (Knaus et al, 2009). Students must first balance the equation, then determine the type of reaction. Students should be reasonably comfortable with determining the type of reaction, and students of many CE levels should excel. The number of questions pertaining to each CE level should be proportional to the CE level of the class. This way, students should be able to complete at least 70% of the questions correctly. Students will work independently, which can be shown to result in higher cognitive efficiency (Luftenegger et al, 2012).

**Strategies used:** This activity is intended as a benchmark to measure students’ progress as well as develop a cognitive efficiency rating that can be used to help inform teaching and help students understand how they learn.

**Differentiation:** As this assignment is meant as a progress assessment, differentiation should only be made to the extent that it preserves the fairness of the assessment for all students.

**Assessment:** This is an individual, graded assignment. Students will receive one point for a correct categorization of the reaction and one for the correct balancing of the equation.

**Materials:** Pencil, scrap paper, quiz

**Reflection:**

What went well? /What did not go well (why)?

Did students achieve the objective?

Were additional modifications needed?

Were students motivated and interested?
TYPES OF REACTIONS

Write and balance the equations for each reaction as they are assigned. Then tell what type of reaction each one is.

1. ___ KClO₃ → ___ KCl + ___ O₂  
   Type______________________

2. ___ Al(NO₃)₃ + ___ NaOH ----> ___ Al(OH)₃ + ___ NaNO₃  
   Type______________________

3. ___ NH₄NO₂ ----> ___ N₂ + ___ H₂O  
   Type______________________

4. ___ FeBr₃ + ___ (NH₄)₂S ----> ___ Fe₂S₃ + ___ NH₄Br  
   Type______________________

5. ___ CaO + ___ P₂O₅ ----> ___ Ca(H₂PO₄)₂  
   Type______________________

6. ___ Al + ___ CuCl₂ ----> ___ AlCl₃ + ___ Cu  
   Type______________________

7. ___ Ca(OH)₂ + ___ HNO₃ ----> ___ Ca(NO₃)₂ + ___ H₂O  
   Type______________________
8. ___ Br + ___ MgI₂ ----> MgBr₂ + I₂
Type____________________

9. ___ NaHCO₃ ----> ___ NaOH + ___ CO₂ + ___ H₂O
Type____________________

10. ___ Al + ___ O₂ ----> ___ Al₂O₃
Type____________________

11. ___ Fe + ___ CH₃CO₂Ag ----> ___ Fe(CH₃CO₂)₃ + ___ Ag
Type____________________

12. ___ NaOH + ___ H₂SO₄ ----> ___ Na₂SO₄ + ___ H₂O
Type____________________

13. ___ AlCl₃ + ___ H₂SO₄ ----> ___ Al₂(SO₄)₃ + ___ HCl
Type____________________
Lesson Name: Stoichiometry Lab

<table>
<thead>
<tr>
<th>Unit: Chemical Reactions and Stoichiometry</th>
<th>Intended grade level: 10-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson number: 5</td>
<td>CE rating*: (High) Medium</td>
</tr>
</tbody>
</table>

**PLAN:**

Main Question/Concept:

How do scientists use stoichiometry and mole-mole calculations in experiments?

Supporting ideas to LEARN:

13. Predict and calculate the amount of hydrogen gas produced from the reaction.
14. Find the percent yield of your experiment.

Prior Skills/Knowledge to KNOW:

5. Stoichiometry calculations
6. Converting from moles to grams and back
7. Calculating percent yield
8. Balancing equations

**SPECIFY:**

Learning Objectives:

- Students will be able to complete calculations to predict the amount of hydrogen gas produced from a chemical reaction.
- Students will be able to perform the given experiment using proper safety procedures.
- Students will be able to calculate the amount of hydrogen gas produced in reality from their experiment.
- Students will be able to calculate the percent yield of their experiment.

Standards covered:

NYS Science Learning Standards for Chemistry:

**Standard 1, Key Idea 1:** Abstraction and symbolic representation are used to communicate mathematically

M1.1 Use algebraic and geometric representations to describe and compare data.

- measure and record experimental data and use data in calculations
  - choose appropriate measurement scales and use units in recording
  - show mathematical work, stating formula and steps for solution
• estimate answers
• use appropriate equations and significant digits
• show uncertainty in measurement by the use of significant figures
• identify relationships within variables from data tables

**Standard 4, Key Idea 3.3** Apply the principle of conservation of mass to chemical reactions.

i balance equations, given the formulas for reactants and products

ii interpret balanced chemical equations in terms of conservation of matter and energy

iv calculate simple mole-mole stoichiometry problems, given a balanced equation

viii calculate the formula mass and gram-formula mass

ix determine the number of moles of a substance, given its mass

**Standard 1, Key Idea 3**: Critical thinking skills are used in the solution of mathematical problems.

M3.1 Apply algebraic and geometric concepts and skills to the solution of problems.

**Assessments**:

**Informal**:
- Observation of students and their conversations while working on the lab activity

**Formal**:
- Laboratory worksheet

**IMPLEMENT**:

*Lesson outline (step by step)*

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirement</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>Direct students to the introduction activity – reading activity with the lab worksheet.</td>
<td>Read the introduction to the lab and complete the reading activity.</td>
<td>Medium</td>
<td>N/A</td>
<td>Lab Worksheet</td>
</tr>
<tr>
<td>5 min</td>
<td>Introduce the lab, go through a short mockup of the procedure so</td>
<td>Take notes as necessary on the lab worksheet to prepare for the lab.</td>
<td>Low</td>
<td>N/A</td>
<td>Lab Worksheet</td>
</tr>
</tbody>
</table>
students can observe.

<table>
<thead>
<tr>
<th>10 min</th>
<th>Circulate while students complete the lab. Answer questions and assist as necessary.</th>
<th>Work in pairs to complete the lab.</th>
<th>Relative (see lab commentary)</th>
<th>Knowledge from previous classes (see lab commentary)</th>
<th>Lab worksheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Collect the finished lab worksheets for grading.</td>
<td>Hand in lab worksheet for grading.</td>
<td>N/A</td>
<td>Supporting ideas for this lesson.</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Resources/Materials needed:**

Lab worksheet

Equipment and chemicals listed in the lab worksheet

Pencil

**REFLECTION:**

What went well?

What did not go well? (why?)

What would you improve for next time?

Were further modifications needed?

Were students motivated?
Activity Name: Stoichiometry Lab: Vanishing Aluminum

Objective: Predict the amount of hydrogen gas that will be produced from the given reaction. Perform the experiment with a partner, observing proper safety procedures. Determine the amount of hydrogen gas actually produced, and determine the percent yield of the experiment.

Activity outline (step by step)

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predict the amount of hydrogen gas</td>
<td>Balancing equations, stoichiometry and finding formula mass, converting from grams to moles</td>
<td>High</td>
<td>Students work in pairs for this lab. When pairing students, they should be matched according to CE level. Low CE and high CE should be paired together, while medium CE students can ideally work with any pairing.</td>
</tr>
<tr>
<td>Perform the experiment as listed on the worksheet.</td>
<td>Safety requirements for chemistry lab</td>
<td>Low</td>
<td>N/A; see above.</td>
</tr>
<tr>
<td>Complete the laboratory analysis questions – including determining the actual amount of hydrogen gas produced, and the percent yield.</td>
<td>From PREDICT section: Balancing equations, stoichiometry and finding formula mass, converting from grams to moles Other: Percent yield calculations</td>
<td>Medium</td>
<td>See above.</td>
</tr>
</tbody>
</table>

Commentary:

This lab was chosen to allow students to experience a practical application of the skills they have learned in this unit. The chemical reaction involved in this lab was chosen because it is relatively simple and is easy to perform in a high school laboratory. Students do not need complex laboratory skills or knowledge to experience the reaction. The lab makes use of a variety of skills they should be comfortable with from this unit.

The three sections of this lab are applicable to three different levels of CE. The first section (predict), rates the highest CE since it requires starting from scratch and applying ideas such as balancing equations and converting various units, each of which are somewhat complex processes. In order to ensure all students succeed in this area, students will work in pair, since
research by Kirscher et al. (2009) has shown that when students work together, they combine their CEs and raise the CE of the group.

The second task, completing the given procedure, should be easily achievable by all students. They should already have a basic understanding of the laboratory safety procedures and uses of the equipment in this experiment. The analysis questions at the end of the lab are classified as medium CE level because half of it has already been done by students in the Predict portion. Students must do the calculations with different numbers, but the procedure is the same. The second half of the questions use an equation they should have seen before, that of percent yield. The math involved is basic, and students then must only speculate as to why their percent yield resulted what it did, and they will have completed the lab. The familiarity with math techniques will support students who already possess that knowledge and help them reapply it to succeed (Sweller, 1994).

**Strategies used:**

Predict, Experiment, Analyze; Student Pairing.

**Differentiation:**

Students are paired by CE in this lab. This allows all students to progress at a similar rate and gives students who may struggle an extra resource to draw on. Students are expected to work together equally within their groups.

**Assessment:**

This lab will be graded for completeness and correctness. Since students work with a partner, each should have the same grade. However, each student will turn in their own worksheet, so each will receive a grade for what is shown on their paper.

**Materials:**

Laboratory materials listed on worksheet, pencil and paper or lab notebook.

**REFLECTION:**

What went well?
What did not go well (why)?
Did students achieve the objective?
Were additional modifications needed?
Were students motivated and interested?
Stoichiometry Lab: Vanishing Aluminum!

Introduction:

Aluminum metal reacts with hydrochloric acid to form hydrogen gas and an aluminum chloride solution. In this investigation, you will predict the mass of hydrogen gas produced by a given amount of reactants, then measure the amount and compare them.

Hydrochloric acid is an aqueous solution of hydrogen chloride. The concentration is usually described in terms of “moles per liter” which is abbreviated “mol/L” or “molar” or “M.” The most concentrated hydrochloric acid is 12 M, but for safety reasons we will be using a solution that is 3.0 M.

Predict:

Start with the following unbalanced chemical equation:

\[ \text{Al (s) + HCl (aq) } \rightarrow \text{AlCl}_3 (aq) + \text{H}_2 (g) \]

If you use 0.25 grams of aluminum, how any moles of hydrogen gas will be produced?

SHOW YOUR WORK BELOW!

Adapted from www.dbbooth.net/mhs/chem/stoichiometry-al.html.
Procedure:

1. Put on a pair of safety goggles.
2. Obtain approximately 0.25 grams of aluminum foil. Record the exact mass, and tear it into tiny pieces.
3. Put 50.0 mL of the hydrochloric acid into a small beaker. Record the mass of the beaker with solution in it.
4. Place the foil pieces on the balance tray next to the beaker of acid, and record the total mass. [If this total mass does not equal the sum of number 2 and 3, you should remeasure.]
5. With the beaker still on the balance, drop the foil into the acid and observe. What happens to the overall mass?
6. When the aluminum is gone, record the final mass of the beaker with the solution.
7. Dispose of the materials in the beaker according to your teacher’s instructions.

Data:

Exact mass of foil: ______________

Mass of beaker with solution: ______________

Total mass of foil plus beaker with solution: ______________

Final Mass (after combining foil and solution): ______________

Analysis: (on a separate paper)

1. Write the chemical equation for the reaction that took place. Don’t forget to include the states of matter (s, l, g, or aq). Balance it.
2. Calculate the number of moles of (clean) aluminum used.
3. Predict the number of moles of hydrogen that should be produced by this much aluminum reacting.
4. Calculate the mass of hydrogen gas produced during your reaction.
5. Calculate the number of moles of hydrogen gas actually produced.
6. Calculate the “percent yield” for your reaction. If your prediction (#3) and calculation (#5) were the same, your percent yield was 100%.
7. Why was your percent yield what it was? In other words, if you got 100%, why was it so perfect? If you got less than 100%, what happened?
Lesson Name: Empirical Formula

Unit: Chemical Reactions and Stoichiometry

Intended grade level: 10-11

Lesson number: 7

CE rating*: High (Medium) Low

PLAN:

Main Question/Concept:

How can we draw information from different types of chemical formulas (empirical and molecular)?

Supporting ideas to LEARN:

1. What is an empirical formula?
2. How does empirical formula relate to molecular formula?
3. How can we convert between empirical and molecular formula?

Prior Skills/Knowledge to KNOW:

1. Molecular formulas show the relative amount of each element in a molecule.
2. The **formula mass** is the mass of all the atoms in the molecular formula (units = grams)
3. The **gram formula mass** is the mass of the atoms in one mole of the compound (units = grams/mole)

SPECIFY:

Learning Objectives:

- Students will be able to identify the difference between a molecular and empirical formula.
- Students will be able to determine empirical formula from a given molecular formula.
- Students will be able to determine the molecular formula from a given formula mass and empirical formula.

Standards covered:

NYS Science Learning Standards for Chemistry:

**Key Idea 3.3** Apply the principle of conservation of mass to chemical reactions.

- v determine the empirical formula from a molecular formula
- vii determine the molecular formula, given the empirical formula and the molecular mass
Assessments:

Informal:

- Observation of students and their conversations while working on the race activity and while working on practice questions from the notes.
- Practice questions
- Performance during race activity

Formal:

- Exit activity

IMPLEMENT:

Lesson outline (step by step)

<table>
<thead>
<tr>
<th>Time</th>
<th>Teacher Role</th>
<th>Student Role</th>
<th>CE level (if applicable)</th>
<th>Working memory requirements</th>
<th>Activity Plan (if applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>Introduction puzzle: (setup – place premade flashcards on each table) Direct student groups to open the first set and try to find what the three words have in common. Ask groups to share out once everyone has a guess. Continue through until students reach set 4.</td>
<td>Determine the commonalities between the sets of words. Share with class when prompted.</td>
<td>Medium</td>
<td>N/A</td>
<td>Flashcards</td>
</tr>
<tr>
<td>5 min</td>
<td>At set 4, students should be stumped. Move on to set 5 and lead students into a discussion about how the molecular formulas show are multiples of each other.</td>
<td>Hypothesize why the three items in set 4 and 5 are similar. Ideally, students should realize that their molecular formulas are very similar (have the same empirical formula).</td>
<td>High</td>
<td>Knowledge of molecular formula from previous classes.</td>
<td>Flashcards</td>
</tr>
<tr>
<td>Time</td>
<td>Activity</td>
<td>Support</td>
<td>Notes</td>
<td>Resources/Materials needed</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>10 min</td>
<td>Notes packet on empirical/molecular formula. Complete example problems from packet together</td>
<td>Low</td>
<td>Knowledge from previous classes.</td>
<td>Notes packet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Follow along with notes, ask questions, complete practice problems.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 min</td>
<td>Explain and guide race activity. Score and referee.</td>
<td>High</td>
<td>Supporting ideas for this lesson.</td>
<td>Race activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work on activity in small groups. Winners get a prize.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Resources/Materials needed:**
- Notecards for introduction activity
- Notes packet for students to follow
- Race activity

**REFLECTION:**
- What went well?
- What did not go well? (why?)
- What would you improve for next time?
- Were further modifications needed?
- Were students motivated?
**Comparison Flashcards for Lesson 6:**

<table>
<thead>
<tr>
<th>Polar</th>
<th>Brown</th>
<th>Kodiak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doughnut</td>
<td>Notebook</td>
<td>Golf Course</td>
</tr>
<tr>
<td>Blue</td>
<td>Cake</td>
<td>Cheese</td>
</tr>
<tr>
<td>Ethyrose</td>
<td>Formaldehyde</td>
<td>Glycolaldehyde</td>
</tr>
<tr>
<td>C₄H₈O₄</td>
<td>CH₂O</td>
<td>C₂H₄O₂</td>
</tr>
</tbody>
</table>
Activity Name: Race Activity

Objective: Students will participate in the group to answer questions and “race” other teams to finish the questions.

Activity outline (step by step)

<table>
<thead>
<tr>
<th>Task</th>
<th>Working memory requirements</th>
<th>CE Rating (high, medium, or low)</th>
<th>Scaffolds/Modifications for different CE levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a group, complete each question in order. Obey race rules.</td>
<td>Knowledge from the day’s lesson, as well as previous classes.</td>
<td>Questions are from a range of CE levels</td>
<td>Problems may be shown on the board so every group may see each problem at the same time. Groups should contain an even distribution of CE levels from the class.</td>
</tr>
</tbody>
</table>

Commentary: This activity uses a collaboration of students of various CE levels for each team (Kirschner et al, 2009). The list of questions involves several different difficulties, which should allow all students to participate and feel that they are able to contribute. Questions include topics from throughout the lesson, so all students are using their previous knowledge in order to succeed. This activity also functions as a review of topics from the entire unit, rather than solely a review of empirical formula.

Strategies used: Relay activity, group work

Differentiation: The game may be adapted for less physical activity by introducing a “buzzer” or hand raising to answer questions. Different difficulty of questions may be worth different points. Each student may be “assigned” a question so that all are participating.

Assessment: The only assessment for this activity is the teacher’s observation of the students’ progress with the problems. The purpose of this assignment is review.

Materials: Pencil, scrap paper

Reflection:

What went well?
What did not go well (why)?
Did students achieve the objective?
Were additional modifications needed?
Were students motivated and interested?
# Percent Composition and Empirical/Molecular Formula Race

<table>
<thead>
<tr>
<th>What percentage of methane, CH₄, is carbon?</th>
<th>What percentage of methane, CH₄, is carbon?</th>
<th>What percentage of methane, CH₄, is carbon?</th>
<th>What percentage of methane, CH₄, is carbon?</th>
<th>What percentage of methane, CH₄, is carbon?</th>
</tr>
</thead>
<tbody>
<tr>
<td>What percentage of water is hydrogen?</td>
<td>What percentage of water is hydrogen?</td>
<td>What percentage of water is hydrogen?</td>
<td>What percentage of water is hydrogen?</td>
<td>What percentage of water is hydrogen?</td>
</tr>
<tr>
<td>What is the empirical formula of a compound which is 30.4% N and 69.6% O?</td>
<td>What is the empirical formula of a compound which is 30.4% N and 69.6% O?</td>
<td>What is the empirical formula of a compound which is 30.4% N and 69.6% O?</td>
<td>What is the empirical formula of a compound which is 30.4% N and 69.6% O?</td>
<td>What is the empirical formula of a compound which is 30.4% N and 69.6% O?</td>
</tr>
<tr>
<td>What is the empirical formula of a compound which is 60.3% C and 39.7% H?</td>
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<td>What is the empirical formula of a compound which is 60.3% C and 39.7% H?</td>
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<td>What is the empirical formula of a compound which is 60.3% C and 39.7% H?</td>
</tr>
<tr>
<td>What is the molecular formula of a compound which is 80% C and 20% H, with a molar mass of 30 g mol⁻¹?</td>
<td>What is the molecular formula of a compound which is 80% C and 20% H, with a molar mass of 30 g mol⁻¹?</td>
<td>What is the molecular formula of a compound which is 80% C and 20% H, with a molar mass of 30 g mol⁻¹?</td>
<td>What is the molecular formula of a compound which is 80% C and 20% H, with a molar mass of 30 g mol⁻¹?</td>
<td>What is the molecular formula of a compound which is 80% C and 20% H, with a molar mass of 30 g mol⁻¹?</td>
</tr>
</tbody>
</table>

---

4 Adapted from www.chemteach.ac.nz.
Teacher’s Instructions

Make one or two copies of this page depending on class size.

Cut into vertical strips.

Give each team a strip.

Have a list of the answers ready!

RULES:

- In groups of 3, 4 or 5.
- Calculate each answer in turn – bring your answer to me.
- I will only accept one answer at a time – and I will not accept any subsequent answers until the one you are on is correct. Between correct answers you must run around the room to your desk (to make the distance fair for all.)
- I will only say “yes” or “no” regarding your answer
- The first team to finish the race wins!
Chapter IV: Discussion

The concept of applying theories about cognitive efficiency to teaching is not a new one, but it can still be used effectively to inform modern teaching. There is a twofold benefit to making teachers aware of the cognitive efficiencies of their students. The first is that it allows teachers to predict what topics, activities, and lessons their students are likely to struggle with, then act accordingly. The second is the fact that students are invited to actively participate in understanding how they learn best, and then can use this knowledge to improve the way they study and practice. Both teacher and students work together to create the best learning situation for each student.

Chemistry teachers in particular can take advantage of this technique. The complexity and fast-paced nature of the course tend to make this a tough transition for students who are often diving in to several difficult courses at once. Science courses tend to be able to stand alone; that is, they do not necessarily build upon each other, and this may throw students who believe that success in one science course will indicate automatic success in another. Using information about their students’ cognitive efficiency, teachers can ease the transition for struggling students as well as provide them with techniques to improve their learning.

Using cognitive efficiency-based methods in the classroom requires a year-long commitment. Teachers must be willing to put in the initial effort to create a wide variety of materials that encompass a range of cognitive efficiency levels. Once in place, however, teachers will be able to draw upon the appropriate problems or activities from their pool. Students wishing to study on their own can be given access to an array of differently leveled problems and help themselves increase their skill by solving higher level problems as they continue. This lessens the need for the teacher to individually assist each student; ideally, students with higher cognitive efficiency levels could act as resources for others who are struggling.

Documentation is another important part of using this method to its full benefit. Students must be able to keep track of their own progress regarding cognitive efficiency. It is not just for the teacher’s benefit; students who are able to see the goal they are working toward will be more motivated to strive for it. This does add an additional task to assessments in the classroom. In this sample, a straightforward quiz was used; teachers planning to use this method will need to come up with a cognitive efficiency assessment that works for their classroom. Ideally, it would double as a content-based assessment. Periodic evaluations would need to take place during the year in order for students to chart their growth and to provide teachers with continually accurate information.

This is only one interpretation of adapting cognitive efficiency research to benefit a high school classroom. Each teacher will lend their unique style when using this method in their classroom. It is applicable to all subjects, not science along; in fact, it would be especially suitable for courses with a large amount of reading work, due to the variety of materials available to work with and the flexibility with which to approach questions about the text. Cognitive efficiency can be applied throughout the school, and throughout a students’ life. It is not limited
to academics alone; it provides insight into how students think and approach problems. Such knowledge can only help students grow both in the classroom and in life.
Chapter V: Resources


http://doi.org/10.1002/tea.21213


http://doi.org/10.1080/09500690903183741


http://doi.org/10.1007/s10972-014-9406-z


http://doi.org/10.1007/s10972-007-9052-9


