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**Weir, Benjamin M.** ***Using Analogy to Teach: Effect of Analogy Use on Learning in the Chemistry Classroom***


## Abstract

Instructors in many fields wish to engender greater interest and enthusiasm in their classrooms. Chemistry is a subject in school that is known for having abstract concepts that students have difficulty tying to their lives. This study explored the effect lecture style had on the situational interest and performance of college students learning unit conversion material in a chemistry classroom. Two lectures were compared, one lecture taken directly from a published chemistry textbook acted as a control, and the experimental lecture developed by a chemistry instructor to stress using analogies. Performance was measured utilizing students' lab work from the following class, an in-class problem set, the first hour exam and the final test material. Affective disposition of the students was also collected, using a 10 item Likert scale, four open-ended response survey. Overall the hypotheses that the experimental lecture would increase performance in classroom activities did not have support. The hypotheses that student interest and self-efficacy would be positively affected by the analogy lecture did not have support. Implications are discussed with findings.

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# Chapter I: Introduction

In many college chemistry classrooms, students are not interested in or are challenged by the abstract concepts that make up chemistry (Gabel, 1999; Justi & Gilbert, 2006). Students often face feelings of anxiety about passing a difficult but required course (Leon & Revelle, 1985; Young, 1991). When encountering these challenges, many students feel their instructors are not effective in delivering material (James & Scharmann, 2007). Somehow students need a way to learn complex, abstract material. This study examined how teaching with analogies affect performance, interest and self-efficacy of students in a college chemistry classroom. The following sections will address the literature behind the study, the methodology, results of the study and a discussion of the study's results. The analogy enhanced lecture was developed by a chemistry instructor in a Midwestern technical college.

## Statement of the Problem

Instructors who teach chemistry can be frustrated by the alienation the subject can cause students (Cardulla, 1987; Gabel, 1999, Navidi & Baker, 1984; Schmidt, 1997). To address the challenges of teaching chemistry, instructors take complicated processes and reduce them to simple steps, like the Factor Label Method (FLM) (Cardulla, 1987, Navidi & Baker, 1984; Schmidt, 1997). The factor-label method is a process for setting up units so that students can plug them in and get a conversion (Navidi & Baker, 1984). While widely used, the FLM is commonly criticized for allowing students to get the correct answer without understanding the change being made (Cardulla, 1987; Navidi & Baker, 1984; Schmidt, 1997). The purpose of this study is to explore whether or not teaching with analogies can help students understand unit conversions, as well as increase their interest and self-efficacy in unit conversions.

The FLM helps students complete a unit conversion. When you complete a unit conversion, you are changing the units that describe a phenomenon. For example, if you travel 50 miles per hour, a road trip with that speed can be described as half an hour or 25 miles. The units (descriptions) are different, but the trip is the same. In this example, the Factor Label Method is used to help students flip between the miles and time units. It describes the relationship between the units. For many students the trick is recognizing the relationships, and that they can be written either as 50miles/1 hour, or 1 hour/50miles.

The Factor Label Method describes how to solve these unit flipping problems. Start with the known measurement, 25 miles. Multiply by the relationship (also called the conversion factor) to cancel the miles unit and replace it with the desired time unit:

25 ~~miles~~ * 1 hour/50 ~~miles~~ = 25 / 50 = ½ hour

However, some instructors believe that these sorts of broadly applicable processes allow students to complete problems without understanding of the material (Cardulla, 1987; Navidi & Baker, 1984; Schmidt, 1997). Chemistry is filled with units that are abstract, a Mol of material is $6.02214179 \times 10^{23}$ atoms of that material for example. Students can use the FLM to easily move from grams to Mols, but Molarity is so abstract they may not understand what change is being made.

Thoroughly connecting new material to something already understood in the form of an analogy is one strategy to engage students in the classroom. The benefits of using analogies to teach have been demonstrated numerous times (Bulgren, Deshler, Shumaker, & Lenz, 2000; Glynn, 2008; Glynn & Takahashi, 1998; Harrison & Treagust, 2006). Analogies are beneficial in teaching relationships between constructs. The FLM breaks down how units relate to each other. There is a dearth of research on how effective analogy use is on teaching the FLM. The factor-label method of teaching unit conversions gives the students a procedure that they can use for any unit conversion type problem. The analogy uses a familiar scenario like converting between time and distance when driving, as in the example above, to teach the process of the Factor Label Method. This is compared to trying to explain the factor label method in more abstract settings, like converting grams to moles.

**Purpose of the Study**

Analogies are useful tools for teaching the relationships between constructs and applying them to new contexts. The aim of this study was to see if analogies would be useful in teaching the FLM instead of a literal description of the process (Gentner, Loewenstein, & Thompson, 2003). Chemistry is built on many abstract concepts that are difficult to learn and are not interesting to students (Justi & Gilbert, 2006). Elaborate analogies (EA) help students learn by pairing new abstract information with already learned concrete information (Orgill & Bodner, 2004; Thiele & Treagust, 1991). It will be beneficial to understand how EA affect the learning of problem-solving methods like the factor label method. The purpose of this study was to determine if a lecture that utilizes elaborate analogies is more effective at teaching the factor label method than a lecture which does not.

To garner student interest, improve their performance and self-efficacy, instructors enhanced a lecture with EA. There are many benefits to using analogies in the classroom, and the way that they impact learning should be beneficial for this lesson. Unit conversions, and chemistry as a whole, can be hard for students to relate to, analogies should help in this process.

**Analogy Overview**

Analogies help students learn by taking something concrete and familiar and then comparing it with new information (Harrison & Treagust, 2006). Analogies are made of two parts; the analog is concrete and familiar, and the target is material that the student is learning (Aubusson, Harrison, & Ritchie, 2006; Donnelly & McDaniel, 1993; Glynn & Takahashi, 2008). For example, when teaching a class about the sun, it might be useful to use a balloon analogy to explain the sun's expansion against gravity. The air pushes outward against the balloon and the balloon presses inwards against the air. When they reach equilibrium, they form a stable shape. The sun uses fusion as a force to expand against the gravity which, in turn, pulls it together, when they reach equilibrium they are stable in size. In this analogy, an instructor could use a balloon, which is concrete to explain the balancing of forces that exists in our sun.

Analogies are either elaborate or simple. Elaborate analogies systematically map the analog onto the target, explaining the relationship of the familiar analog and the unfamiliar target (Paris & Glynn, 2004; Thiele & Tragust, 1994). This process of mapping the analog onto the target is called elaboration (Paris & Glynn, 2004), the air is the fusion, and the plastic is gravity. In a simple analogy, the analog and target are compared without elaboration (Thiele & Treagust, 1994). Elaborate analogies produce more learning because the elaboration of the target onto the analog explains the relationships of the new material, while a simple analogy does not (Paris & Glynn, 2004). Instructors can ensure better elaboration by using a structured approach and encouraging students to ask questions (Harrison & Treagust, 2006).

For example, a simple analogy could state that mitochondria are like the power plant of the cell. An elaborate analogy would expand on why the mitochondria are like the power plant of the cell. It would explain how the creation of ATP in the mitochondria powers the creation of proteins in a way that is similar to how coal powers a power plant to generate electricity and power a lightbulb. This explanation of similarities is what makes it elaborate and benefits learning.

A simple analogy benefits motivation, however, to have a positive effect on learning it must be expanded and discussed (Paris & Glynn, 2004; Thiele & Treagust, 1994). A benefit of elaborate analogies is they improve a student's ability to answer inferential questions (Donnelly & McDaniel, 1993; Paris & Glynn, 2003). In an elaborate analogy, the relationships between the constructs are the focus, helping students make inferences (Donnelly & McDaniel, 1993). However, for learning basic facts, analogies can be a distraction (Donnelly & McDaniel, 1993; Glynn, 2008; Glynn & Takahashi, 1998).

**The Effect of Analogies on Learning**

There is significant evidence that analogies can have an effect on learning, which is why student performance was captured through the semester. When students are taught with elaborate analogies they frequently score higher on measures of learning than those who are not (Bulgren, Deshler, Shumaker, & Lenz, 2000; Gentner, Loewenstein, & Thompson, 2003; Glynn & Takahashi, 1998; Thiele & Treagust, 1991). Some researchers have found that utilizing a short analogy to explain relationships improved recall over a two-week period (Glynn & Takahashi, 2008). The analogy used in this research compared the similarities between the functioning of a factory, as the analog, and the functioning of a cell which was the target. The instructor and students elaborated on different structures that played similar roles; the membrane of the cell and restricted access to the factory, the control center of the factory and nucleus of the cell, etc. This sort of an intervention suggests that teaching with analogies can be a powerful tool in helping students understand the abstract material.

Elaborate analogies contribute to learning because they create specific connections between what the students already know and what is new (Orgill & Bodner, 2004; Paris & Glynn, 2003). Students at all levels benefit from analogies; for example, rich concrete analogs are used to build knowledge in medical and law professionals (Gentner, Loewenstein, & Thompson, 2003). Analogies are beneficial for students because they learn how things relate to each other (Gentner, Loewenstein, & Thompson, 2003). These relationships can be generalized to other settings, making it "portable knowledge" (Gentner, Loewenstein, & Thompson, 2003, p. 404). In a formula, the student learns how the different numbers relate to each other through multiplication, addition, subtraction, etc. A relational schema describes how these constructs relate to each other through math, or any other way they can relate. For example, when taught negotiation strategies, focusing on drawing similarities and parallels between cases, students were better able to transfer those strategies to new situations (Gentner, Loewenstein, & Thompson, 2003). They took the relationship between the constructs in the cases and applied them to a new setting, using a "formula," of sorts, to transport knowledge of the relationships from one scenario to another. The two groups were compared by their ability to describe negotiation strategies as judged by subject matter experts (Gentner, Loewenstein, & Thompson, 2003). In addition to better understanding the relational schema of the new material, elaborate analogies helped students assess their comprehension of target concepts as well as personal points of relevance for the students (Paris & Glynn, 2003). This more accurate self-assessment can help direct efforts for further learning.

Some strategies can be used to help improve the effectiveness of analogies. The analog needs to be acceptable for the audience, and the instructor needs to map the target onto the analog (Harrison & Treagust, 2006; Glynn, 2008). Also, encouraging students to draw comparisons in the analogy increased the ability to transfer material to novel situations (Gentner, Loewenstein, & Thompson, 2003). Using multiple analogies is important to triangulate meaning, seeing the same schema in multiple examples helps to clarify the lesson (Harrison & Treagust, 2006). Students can get interested and caught up in at least one of these analogies instead of looking at all of them, which is why using multiple analogies is important (Harrison & Treagust, 2006). For example, teaching with multiple case studies, which are a form of elaborate analogy, is already an important way to teach in business, law, and medicine (Gentner, Loewenstein, & Thompson, 2003). This triangulation also prevents the learner from taking any one analogy beyond its probable usefulness (Harrison & Treagust, 2006).

When compared to a literal teaching lesson where the material is not compared to known material and is presented on its own, use of elaborate analogies were more effective than the literal lesson (Gentner, Loewenstein, & Thompson, 2003). Elaborate analogies are focused on teaching relationships between constructs, while details are better taught describing them literally (Donnelly & McDaniel, 1993). For example, if an instructor is teaching a lesson about how leaves create energy from the sun, they must consider the objective of the lesson. For learning about the structures of the leaf and how they interact, the different stages and operations of sunlight moving through the leaf, a lesson heavy in analogy would be appropriate. Using multiple analogies to demonstrate the relationships in the target can help students learn more (Harrison & Treagust, 2006). If the objective is for the students to memorize the different compounds, know the names of the different structures, and list them, they would learn better through literal description, without an analogy. For this reason, instructors should use EA when the students are required to make inferences about the material (Donnelly & McDaniel, 1993). If the students are required to know or repeat facts, it is better not to use EA.

There are other times when instructors should avoid the use of EA. These are when the student already understands the targets, or when the students do not understand the analogies being presented (Orgill & Bodner, 2004). For example, if the students already know that gravity affects objects of different weight the same, then there is no need for the story of Galileo dropping weights from the leaning tower of Pisa. Also, if the analogy for teaching this lesson involves material beyond the knowledge of the students, such as the comparative masses of black holes, then little will be gained from the lesson. Analogies should also be avoided when the student feels the need to memorize basic information for tests, or when they feel overwhelmed (Donnelly & McDaniel, 1993; Orgill & Bodner, 2004). For example, if the students need to learn the contents of the periodic table a literal description of its contents, "metals on the left, nonmetals on the right," would be more beneficial than an analogous one. Since EA do not support the learning of discrete details, a lesson heavy in presenting details and individual facts would not benefit from elaborate analogy (Donnelly & McDaniel, 1993). The proper use of analogies can improve learning, but if used improperly, can inhibit learning. It is important that the learner feel they can relate to the analog. Without this relation the usefulness of the analog to explain the target is minimal (Harrison & Treagust, 2006).

At times, analogies can distract from the target, or students will take the analogies too far, past the point where the comparison breaks down and students will make inferences that are not there (Harrison & Treagust, 2006; Thiele & Treagust, 1991). From in depth discussions with experienced teachers, some problems with analogies are that they can confuse students, create cognitive distortion, and may take extra time to go over (Simons, 1982). For these reasons EA should be used judiciously when instructing material.

**The Effect of Analogies on Interest**

Interest is an important component of the student experience, and many instructors struggle to get students interested in the classroom material. Interest is defined as feeling positive and energized towards completing a task and is an integration of affect, motivation, and cognition (Ainley, 2006; Tanaka & Murayama, 2014). Student self-reporting indicates increased interest, positive feeling and willful engagement in classroom material with the use of analogies (Glynn & Takahashi, 1998; Schraw & Lehman, 2001). When analogies relate to the student they increase learning, which in turn increases interest. (Ainley, 2006). Students like, pay extra attention to, and remember analogies (Orgill & Bodner, 2004). Part of this may be that analogs are interesting and relatable to students so they better map the analog onto the target (Glynn, 2008).

Not all analogies affect student interest in the same way. Graphic analogies were demonstrated to have a more positive effect on student attitude than purely verbal analogies (Rigney & Lutz, 1976). A graphic analogy was one that was presented with imagery, the relationships mapped out visually, instead of purely explored verbally or through text. Concrete analogies use language that is easy for the student to understand and visualize mentally. Concrete analogies were more vivid for the students, and vividness supports situational interest in a topic (Schraw, Flowerday, & Lehman, 2001; Simons, 1982). Research demonstrated that EA increased learners' interest in the conceptual topic of the text and the text itself (Paris & Glynn, 2008). Interest can provide the student with energy and persistence in learning the classroom material (Ainley 2006; Hidi & Renninger 2006). Persistence can help the students perform better over the course of the class (Ainley 2006; Hidi & Renninger 2006).

**The Effect of Analogies on Student Self-Efficacy**

In addition to being interested in the classroom, it is important that students feel they can accomplish the tasks given to them, they need to have self-efficacy. Self-efficacy is defined as an evaluative judgment about how well an individual believes they can perform a specific task (Gist & Mitchell, 1992). This is in contrast to self-esteem which is a much larger appraisal of ability, or self-respect (Gist & Mitchell, 1992). The current study measures the confidence students have in completing unit conversions, or their self-efficacy, on this task. There are four categories that affect someone's feelings of self-efficacy. They include: (1) enactive mastery- a feeling of success from one's experiences; (2) vicarious modeling- observing other's actions being successful; (3) verbal persuasion- positive feedback from peer and supervisory groups; and (4) physiological arousal- anxiety, fatigue, and mood (Gist & Mitchell, 1992). Elaborate analogies that are easy for the students to picture should help increase their feelings of self-efficacy. The interaction between affect and learning has been well established (Bandura, 1982; Kort, Reilly, & Picard, 2001). When a student is more comfortable, they learn the material better (Bandura, 1982; Kort, Reilly, & Picard, 2001). This should tie directly to supporting student self-efficacy (Bandura, 1982; Gist & Mitchell, 1992). Researchers have found that anxiety, stress, and dread negatively affect learning (Kort, Reilly, & Picard, 2001; Leon & Revelle, 1985; Young, 1991; Young, 1991). Elaborate analogies may be an effective way to challenge the negative mood and anxiety that students face, and increase learning and confidence (Hackett, Betz, O'Holloran & Romac, 1990). Research by Hackett, Betz, O'Hollaran and Romac (1990) suggests that learning the material more thoroughly can result in greater interest and self-efficacy.

There are many aspects of EA that can benefit the self-efficacy of students, decreasing the negative emotions that inhibit learning. Concrete language, like that used in creating the analogs for analogical encoding, was beneficial in reducing anxiety (Young, 1991). Language that provides specific connections between the material and imagery for the student to visualize is concrete (Sadoski, 2001). Take, for example, using the number of slices derived from a pizza can help explain fractions. In this example, the pizza acts as a common visual cue that the students are familiar with.

In their study, Rigney and Lutz (1976) found that analogies that utilize imagery resulted in more positive attitudes. This study was presented to 40 undergraduate students who were randomly assigned to verbal or pictorial lessons. Based on classroom tests, students performed better, reported the graphic version as more enjoyable, and had a better overall attitude. The students who received the pictorial treatment also reported more mental imagery, suggesting they may have more internal processing. When instructors were encouraged to use analogies to teach chemistry, it was found that students enjoyed it, felt they understood more and were entertained by the analogies (Orgill & Bodner, 2004). These positive feelings may increase student self-efficacy.

Some research suggests students develop their own analogies after a lesson (Glynn & Takahashi, 1998; Rigney & Lutz, 1976). This study focused on middle school students, and examined a lesson enhanced with elaborate analogy with graphic and text components, compared to one that was not. There was greater recall for both the graphic and text based EA immediately following the treatment and after two weeks. The study conducted by Glynn and Takahashi, (1998) focused on middle school students, and examined a lesson enhanced with elaborate analogy with graphic and text components, compared to one that was not. There was greater recall for both the graphic and text based elaborate analogies immediately following the treatment and after two weeks. The research conducted by Rigney and Lutz (1976), while using computer terminals and undergraduate students instead of middle school students found graphic versions of the analogies were more enjoyable and improved learning. The research suggests this exercise can help students develop feelings of confidence and self-efficacy in regards to the material (Glynn & Takahashi, 1998; Rigney & Lutz, 1976). In addition, this kind of exercise could help students take ownership of the material and better learn the relational schema of the lesson (Glynn & Takahashi, 1998; Rigney & Lutz, 1976).

**Instructor Performance**

The way that instructors present information can affect student learning and perception of instructors' success (Thiele & Treagust, 1994; Nye Konstantopoulos, & Hedges, 2004). Teachers can increase the perception of their performance in the classroom by modifying the language they use to be more concrete and relatable (Abedi & Lord, 2001). A way of modifying language is the use of analogies; many experienced teachers suggest having a repertoire of useful analogies that relate to the students' experiences (Thiele & Treagust, 1994). Analogies may be more helpful for students from less academically rigorous backgrounds (Thiele & Treagust, 1994). Analogies improve the perception of instructor performance most when the mapping of the analog to the target is easy for the students to understand (Thiele & Treagust, 1994).

In the classroom, the ability of analogical reasoning to affect learning can be quite strong (James & Scharmann, 2007). A study by James and Scharman (2007) used low-performing instructors, instructors with little knowledge of the material, to teach material based on definitions and jargon. The purpose of this study was to instruct elementary teachers on how to instruct students. When presented with a 15-minute elaborate analogy, there was a learning effect that lasted seven weeks after this treatment (James & Scharmann, 2007). In addition to increased student performance, difference measures of instructor success were found as well (James & Scharmann, 2007). The instructors who started with the lowest reviews actually saw the largest gains when teaching with analogies. (James & Scharmann, 2007).

A study by Bulgren, Deshler, Schumaker, and Lenz (2000) examined how teaching with an analogy routine affected student performance and instructor performance. Specifically the study focused on using a table, the Concept Anchoring Table, to compare the analog and the target information. This allows a formal way to see how the two constructs are similar, and where the similarities end. Instructors who used a structured routine to go over analogies, like the Concept Anchoring Table, felt more satisfied with the routine than without (Bulgren, Deshler, Schumaker, & Lenz, 2000). Instructors that used the Concept Anchoring Table also felt that their students paid better attention and that their skills are increased (Bulgren, Deshler, Schumaker, & Lenz, 2000).

There are many ways that using analogy in the classroom can benefit the student and teacher performance. Addressing unit conversions is important because of its difficulty and ubiquity. Unit conversions, are one of the most frequently used calculations in chemistry. One of the most utilized methods of teaching unit conversions is the Factor Label Method (FLM) (Cardulla, 1987; Navidi & Baker, 1984; Schmidt, 1997). However, this method of presenting unit conversions has been criticized for its unintuitive setup; it has abstract reasoning, and for producing students who mechanically complete the operations without understanding how the process relates to the larger field of chemistry (Cardulla, 1987; Navidi & Baker, 1984; Schmidt, 1997). Using analogies which help students understand the interactions of abstract material may help address this criticism of the FLM.

**Research Statement and Hypotheses**

The purpose of this study was to provide evidence for the benefits of teaching using EA. This was accomplished by comparing a plain description lecture, statements of fact without comparison, with lectures that used EA to explain the material. The material covered in the control and experimental lecture was the factor-label method of unit conversion. Analogies may be beneficial for teaching the factor label method because they have been shown to increase the students' understanding of the relationships of constructs, which is essentially what the factor label method does. In addition this study explored the effect teaching with EA has on interest and self-efficacy. Previous research has found EA to be an effective tool in increasing student performance in the classroom (Gentner & Loewenstein, 2003; James and Scharmann, 2006; Orgill & Bodner, 2004). Some researchers found that even a limited intervention could have long-term learning benefits (James & Scharmann, 2007).

The lecture styles were compared in two ways. First, the performance of the students in graded class activities was compared. Second, a survey aiming to collect data on affective response was completed. This survey used Likert scale questions, and open-ended questions to gauge interest, confidence, instructor performance, and overall responses of the students.

Research has suggested that interest is the result of an integration of affect, motivation, and cognition (Ainley, 2006). Increasing student interest helps them persevere in difficult work, and can help them succeed in the classroom (Ainley, 2006). Other research suggests that using analogies can help encourage positive attitudes in the classroom (Rigney & Lutz, 1976). Students themselves have reported they like, pay attention to and remember analogies well (Glynn & Takahash, 1998; Orgill & Bodner, 2004). Analogies can also directly help students build interest in the topic being taught, improving persistence and performance in the classroom (Paris & Glynn, 2004). By using EA, students may be more interested in their classwork and increase their desire to succeed.

**Hypothesis 1.** Overall, it was expected that participants exposed to the experimental lecture would score higher on performance measures through the semester. Specifically, it was expected that:

1a. The experimental lecture participants would have higher grades on their lab work following the lecture than those who were in the control.

1b. The experimental lecture participants would score higher grades on the in-class problem set than those who were in the control.

1c. The experimental lecture participants would score higher on the first-hour long exam than those who were in the control.

1d. The experimental lecture participants would score higher on the final exam than those who were in the control.

**Hypothesis 2.** Overall, it was expected that the experimental lecture would lead to higher ratings in interest, confidence (self-efficacy) and affect. Specifically, it was expected that:

2 a. The experimental lecture would lead to higher ratings of self-efficacy compared to those in than the control.

2 b. The experimental lecture would lead to higher ratings on interest compared to those in the control.

2 c. Using qualitative analysis with multiple raters, the open-ended responses of the participants will be judged to be more positive in the experimental lecture than in the control lecture.

Open-ended questions included in the survey were designed to collect the overall affect and perceived success of the students. Due to the overall effect that EA have on the classroom, it was believed that the responses in the experimental lecture would be more positive than the control.

# Chapter II: Methodology

The purpose of this study was to explore the effects teaching with EA has on performance, interest and the self-efficacy of students. In order to explore this effect, two lecture styles were compared across graded class assignments, as well as a survey collecting affective response, interest, and self-efficacy. To improve methods and instrumentation, two pilot studies were conducted with limited sample sizes. In the present study, two instructors volunteered five class sections, two receiving the experimental lecture while three class sections were control. The control class sections were given a lecture delivered with the course text, *Fundamentals of General, Organic, and Biological Chemistry, 7$^{th}$ Edition* by McMurry, Hoeger, and Peterson. The experimental class sections contained the same material, but were presented in lectures that used EA developed by their instructors. Students were assessed before and immediately after the lecture, and then throughout the semester, on performance. The affect, interest, and self-efficacy of the students was measured using a survey delivered after the lecture.

Two pilot studies were conducted to hone the survey and data collection methods. The present study included revised data collection and experimental methods procedures informed by the pilot studies. The following sections discuss the two pilot studies, and then the methodology, analysis and discussion of the present study. The methods section will break down the specific ways the research was carried out. The analysis section will include an in depth exploration of the data, and the results and discussion section will apply those findings outside of the study.

## Material Covered

Both the control and experimental the experimental lectures covered the factor label method of teaching unit conversions. Converting a unit means taking one phenomenon and changing the way it is described. The Factor Label Method is the approach used by both lectures to accomplish this conversion, and is the objective of the chapter. The Factor Label Method lines up and then cancels units in an efficient formula to complete a unit conversion. In this study, the experimental lecture focused on using EA to teach this formula utilizing analogs that were familiar to students.

An example of the EA lecture was when asking students a question such as, "Over the river and through the woods, how long does it take to get to grandma's house? She lives 25 miles away; you're in a car driving 50 miles per hour" most students are able to provide the correct answer. They are then shown mathematically how that answer can be set up as a factor label process:

25 miles * 1 hour/50 miles

After you have the equation like this set up, you multiply to cancel the miles units and replace it with the desired unit:

25 ~~miles~~ * 1 hour/50 ~~miles~~ = 25 / 50 = ½ hour

The control lecture would utilize the same methods but showing the conversion from grams to volume using density as the conversion factor or relationship. An example given with the original lecture looks like this:

What is the mass of a zinc bar of volume 43.5 $cm^3$ and density 7.2 $g/cm^3$?

Setup: volume is the measurement, grams is the answer sought, and density is the conversion factor (relationship):

$$43.5\ \cancel{cm}^3 * 7.2\ g/1\ \cancel{cm}^3 = 313\ g$$

As you can see the formula remains the same, and the process of converting units with the FLM is the same in both examples. However the second example is considerably more abstract while the first example is more concrete and familiar. The difference here is not in the objective of the lesson, or the formula being taught, but the material that is used to convey the formula.

**Pilot Study 1**

The first pilot study was conducted on three separate classes in an introduction to chemistry course mid-sized technical college in the Midwest during the spring semester of 2015. This pilot was conducted only by one instructor, instructor A. There were three sections of 14, 15, and 16 students each. One section received the experimental lecture ($n$ = 14), the other two sections were given the control lecture ($n$ = 30). The methods followed the script shown in Appendix B.

The survey was initially developed for the pilot study and contained six five-point Likert scale questions that were phrased to capture the affective response, interest, and the self-efficacy of the students. There were two open-ended questions included as well. See Appendix A for the full survey. In the course of the spring of 2015 semester, the professor made notes from the experimental lecture available to the control participants. There was no way of correlating survey responses to performance measures of the participants. There were difficulties comparing qualitative responses because the control and experimental groups differed in size (experimental $n$ = 30, control $n$ = 14). This study informed new methods and survey development for the second pilot study

**Pilot Study 2**

A second pilot study was held during the summer semester of 2015 at the same Midwestern Technical College. This pilot study included two sections under instructor A. Two sections were used in this pilot: the control with $n$ = 13 students and the experimental with $n$ = 11. The same control lecture was delivered, and the experimental lecture included a larger stress on EA to explain the material. To address the weaknesses in the initial pilot survey, student ID numbers were included in the survey as well as all the performance measures to better track performance through the semester. A pre-test was also given to control for any pre-existing knowledge the participants had on the factor label method or unit conversions in general.

The survey was modified from the first pilot study to better measure the interest and confidence of the participants. The survey now included ten questions, as well as four open-ended questions. The revised survey is seen in Appendix C. The same measures and data collection procedure were used in Pilot 2 as were used in Pilot 1. The same script (Appendix B) was used to collect data.

While the Pilot Studies were beneficial by refining the appropriate data collection methods improving the survey, they had their own limitations. There were not enough participants to reach normality and limited analysis could be run. There were issues with data collection method, and availability of data that confounded the results as well. The pilot studies were useful for refining the survey and data collection methods, but little else of value can be reported from them.

## Present Study

The pilot studies were influential in the present study in a couple of ways. First they helped polish the survey used to measure interest, and self-efficacy. They also helped inform methods. In the first pilot, there was no way of linking the survey data to the student's performance over the semester. To make up for this, in the present study the student identification number was recorded to track performance and tie it to the survey responses.

**Participants.** Participants consisted of college students (n = 154) attending a Midwestern technical college during the fall semester of 2015 who were enrolled in an introductory chemistry class. There were five sections, delivered by two professors. Students self-selected for the different class times and professors based on availability. Students chose their classes based on their convenience; there was no random assignment.

There were 95 participants for instructor A. They were broken into three classes: two experimental lecture classes with 32 and 19 students each. One class of 36 participants for the control. Instructor B had one experimental class of 34 and one control group of 27. Two students were absent for the day of the survey collection, and one of the students took the final exam with a different professor, their material was removed from the study. No demographic data was collected, so the age ranges, gender, and other demographic data is unknown. This data was not collected to save time and minimize the effect the study had on the classroom experience.

**Instrumentation**

There were two methods of collecting data from the participants in regards to their performance and affective responses. A survey was created to collect data on affective responses, and included Likert scale questions and open ended questions. In addition the performance of the participants in numerous classroom activities were also compared. A more thorough explanation of the types of instrumentation is given below.

**Survey.** The revised survey (Appendix C) was used in this experiment. This survey was composed of ten Likert scale questions and four open-ended questions. The Likert scale questions were chosen to measure the instructor performance, student interest, and self-efficacy. In addition to the Likert questions there were four open response questions designed to gather data that the Likert questions missed. The survey was given immediately after the lecture to gather affective response.

The Likert scale questions were developed three constructs, interest, confidence, and instructor performance. The first two questions of the Likert scale were intended to gauge perception of instructor performance. These questions were “The instructor explained the material thoroughly,” and “The instructor was enthusiastic in presenting the material.” This construct would help identify if there was a perceived difference in instructor performance for the experimental and control groups.

The next construct captured by the survey was for the third through seventh items, which were “I was interested in the lecture,” “I found the material relatable,” “I paid attention to the lecture,” “I was engaged in the lecture,” and “I lost track of time while following the lecture.” This construct was intended to capture the interest of the students. This construct was intended to address Hypothesis 2b, that the students in the experimental lecture would rate themselves as more interested.

The last construct that was captured by the survey contained questions eight, nine and ten, “I understand unit conversions,” “I can explain unit conversions to a fellow student,” “I improved my ability to solve unit conversion problems.” These three questions were labeled confidence, and were intended to measure the self-efficacy between the two groups. This construct addressed Hypothesis 2a, that the students in the experimental would score higher in ratings of self-efficacy.

The four open ended questions of the survey were “How did you feel about unit conversions after the lecture?” “How could this lecture be improved?” “Describe the Professors teaching style.” And What are the biggest take a ways from this lecture?” These questions were written to address hypothesis 2c, that the experimental lecture respondents will be more positive.

**Performance.** The measures of performance were lab work, an in-class problem set or homework assignment, an hour exam and a final exam. There was a pretest given as well as these measures of performance, to establish a baseline of performance between instructors. The various measures of performance were compared to address hypotheses 1a-1d. The instructors each had their own versions of the lab, problem set, exam and final. The tests and answer banks for all of the assignments were original and developed by their respective instructors. The student's interest and self-efficacy were compared with the survey. This set of data collection included a pre-test that was part of the classwork.

**Data collection procedure.** The lectures were given for the first 45 minutes of the class as per normal classroom procedure. The last 10 minutes of class were reserved for filling out and collecting the survey. Students were verbally reminded that the survey was used for classroom improvement and participation was not mandatory in accordance with a data collection script (Appendix B). Data from the survey was collected at the end of the 10 minutes as per direction of the script (Appendix B). The instructor was not in the room for the collection. One student was asked to volunteer to collect the surveys, place them in an envelope and given to the instructor. The sealed envelope containing the surveys was then given to the researcher.

To measure performance throughout the semester, the student’s grades were given to the researcher. The grades on the different measures of performance were organized by student ID number. The students were then given a new identification number to ensure the grades could not be traced back to them. The scores on performance were reported in percent to make comparison between time series easier.

## Chapter III: Results

This study was conducted to determine if there was a difference in performance as well as interest and self-efficacy between a lecture provided with a textbook and an analogy enhanced lecture developed by the instructor. There were 154 participants between two instructors and five classes in a mid-sized Midwestern Technical College. The aim of the experimental lecture was to improve student performance, affect, and self-efficacy. The performance of the students was measured through various in-class activities, homework, and tests. The affect and self-efficacy was measured with a survey given after the lectures were performed. Outlined in this chapter are the analysis of the survey and the performance measures.

### Data Analysis

The analysis has been broken up by hypothesis, with descriptions of the analysis used explained thoroughly below. Included with the reported numbers are several tables to help illustrate conclusions drawn from the data. The first hypothesis contained greater statistical analysis, while the second hypothesis focuses on qualitative data that was summarized here.

**Hypothesis 1.** The first hypothesis was that the students in the experimental lecture would score higher on lab work (hypothesis 1a), an in-class problem set (hypothesis 1b), the first hour exam (hypothesis 1c), and the final exam (hypothesis 1d). To prepare the data, the scores on each of the performance measures were transformed to represent the percent correct for that assignment. In order to reduce familywise error the four performances measurements, and the pretest scores were compared using a 2 (Instructor) x 2 (Lecture Type) x 5 (Performance Measure) Mixed Factorial ANOVA displayed in Table 1. A main effect of Instructor was found $F(1,130) = 28.401$, $p < .000$. Students in Instructor A's class performed significantly better ($M$ = 80.61) then student's in Instructor B's class ($M$ = 72.35). There was no main effect of Lecture

Type $F(1,130) = .699$, $p = .405$ suggesting the experimental lecture failed to elicit a change in performance. A main effect of Performance Measure was found, $F(3.227, 419.526) = 173.583$, $p < .001$, meaning that performance varied throughout the semester. Post hoc Bonferroni tests revealed that all performance measures were significantly different from each other, all *p's* < .05 (See Table 2). There were significant differences between the pretest and all the other measures of performance and they can viewed in Table 2. This means that while scores varied through the semester, they were not improved in the experimental lecture hypotheses 1a-d do not have support.

Table 1

*Lecture Type x Instructor x Performance ANOVA*

| Source | *df* | *F* | η2 | *p* |
|---|---|---|---|---|
| Instructor | 1 | 28.401 | .96 | .000 |
| Lecture | 1 | .699 | .02 | .405 |
| Performance | 3.227* | 173.583 | .92 | .000 |
| Instructor x Lecture | 1 | .582 | .02 | .447 |
| Instructor x Performance | 3.227* | 21.69 | .07 | .000 |
| Lecture x Performance | 3.227* | 9.656 | .003 | .943 |
| Instructor x Lecture x Performance | 3.227* | 9.758 | .009 | .107 |
| Error | 419.256 | | | |

*Note- Greenhouse-Geiser correction was used because the assumption of sphericity was violated, as measured by Mauchly's Test of Sphericity.

Table 2

*Main Effect of Performance*

| Performance level | Means | Standard Deviations |
|---|---|---|
| Pretest | 36.77 | 20.6 |
| Homework | 70.40 | 22.63 |
| Lab | 80.11 | 17.62 |
| Exam 1 | 79.31 | 13.34 |
| Exam 2 | 74.94 | 17.95 |

There was however a significant Instructor x Performance interaction, $F$ (3.227, 419.526) = 21.691, $p < .001$. This means that while there was not a significant difference in performance based on experimental or control lectures, there was a difference in performance based on the instructor that the students had. To explore the differences in performance a post-hoc simple effects test was conducted and found that Instructor A's students had higher scores on all performance measures except for Exam 1. There was no significant difference in scores on Exam 2 (See Table 3).

Table 3

*Simple Effect Test Performance by Instructor*

| | Means and Standard Deviations | | |
|---|---|---|---|
| Performance by Instructor | Instructor A | Instructor B | Simple Effects: *F df* (1,130) |
| Pretest | 42.62 (21.76) | 32.02 (12.06) | .007 |
| Homework | 84.75 (13.49) | 55.45 (22.60) | .000 |
| Lab | 84.33 (12.03) | 76.02 (23.17) | .002 |
| Exam 1 | 77.13 (13.83) | 82.32 (12.00) | .012 |
| Exam 2 *Df*(1,130) | 76.83 (15.67) | 73.23 (21.03) | .290 |

Note. Standard deviations appear below means in parentheses.

**Hypothesis 2.** The second hypothesis was that the experimental lecture would lead to more positive affective responses in interest, confidence, and open-ended questions. To analyze the Likert scale questions, composite scores were created by combing the items for each subscale (Appendix C).

The first two items, "The instructor explained the material thoroughly," "The instructor was enthusiastic in presenting the material," were combined to create the Instructor variable, and had a Cronbach's $\alpha = .56$.

The third through seventh items, "I was interested in the lecture," "I found the material relatable," "I paid attention to the lecture," "I was engaged in the lecture," "I lost track of time while following the lecture," were combined into the variable called interest. This variable had a Cronbach's $\alpha = .82$.

The remaining three questions, “I understand unit conversions,” “I can explain unit conversions to a fellow student,” “I improved my ability to solve unit conversion problems.” were labeled Confidence, with a Cronbach’s $\alpha = .79$.

To analyze the difference between the experimental and control lecture on the three variables Confidence, Interest, and Instructor a series of one-way ANOVA’s were conducted. There was a significant effect of Lecture Type on Confidence Ratings, $F(1,127) = 4.466$, $p = 0.037$. Contrary to Hypothesis 2a, students who received the experimental lecture ($M = 3.62$, $SD = .81$) reported lower confidence than students who received the control lecture ($M = 3.91$ ($SD = .70$). There was no difference in reported Interest based on Lecture Type (Hypothesis 2b), $F(1,126) = 2.50$, $p = .117$, and no difference in perceptions of Instructor $F(1,130) = .30$, $p = .863$.

In addition to the Likert response questions, there were four open-ended questions included with the survey. The responses to these questions were put into tables and can be viewed in Appendix E. The responses were themed, with frequencies provided. The frequencies of the individual responses are given and not reflective of the total number of participants. There are those who answered some questions and not others, so while there were 154 participants total, there were fewer who answered all of the qualitative questions. The percentage of each theme is derived from the total number of responses for that individual theme, and not the total number of respondents for the question. The definitions and theme names were agreed upon, and inter-rater reliability of 95% was established for all of the given themes. The major themes that emerged from each question are compared below. The responses to the open-ended questions shown below indicate that there was not a significant difference in responses, meaning hypothesis 2c did not have support.

Table 4

*Comparison of Major Qualitative Themes*

| Question | Experimental Lecture | Control Lecture |
|---|---|---|
| Q1. How did you feel about unit conversions after the lecture? | More Comfortable, 42% | More Comfortable, 50% |
| Q2. How could this lecture be improved? | More Examples, 43% | More Examples, 36% |
| Q3. Describe the Professors teaching Style. | Other Positive, 32% | Positive, 33% |
| Q4. What are the biggest take a ways from this lecture? | Conversions, 40% | Conversions, 56% |

# Chapter IV: Discussion, Limitations, Conclusion and Recommendation

The purpose of this study was to examine the effect teaching with analogies would have on interest, self-efficacy, and performance of students in the classroom. In this section, the conclusions and recommendations regarding the conclusions of the study are discussed. These were measured using various graded assignments throughout the semester, and through a survey with Likert scale questions and open-ended questions.

## Discussion

To better understand the material being discussed, the conclusions and recommendations are separated by hypotheses. There are limitations, conclusions, and recommendations listed after the hypothesis are discussed. These sections are not divided by hypothesis because it would detract from the overall discussion.

**Hypothesis 1.** The first hypothesis, that the analogy enhanced lecture would increase student performance was not supported. It was discovered through the analysis that there was an instructor main effect, with the students in Instructor A's class scoring higher on the first four of the five measures of performance compared to instructor B. The difference in performance between instructors is noted from the pretest assignment until the last exam where the scores are no longer significantly different. This could have been caused by several factors, either the difference in actual student performance, as indicated by the pretest, or perhaps the instructors grade their students work at differing levels. This could explain the differences continuing throughout the semester except for the last measure. The instructors created their own assignments and graded them individually, and this disparity may also contribute to the instructor effect. For future research using standardized tests and having one party grading all the assignments could help avoiding this kind of issue.

**Hypothesis 2.** The survey was broken into three constructs, Instructor Performance, Interest and Confidence. In analyzing the difference between responses on the survey, it was found that there was not a significant difference between the experimental and control groups in regard to perceived instructor performance. This lends support to the idea that the instructors performed the experimental and control lectures with the same perceived effort and enthusiasm. There also was no significant difference in the Interest. This suggests that using EA to enhance the lecture did not increase student's interest in the material. There are many factors that affect interest, and this intervention may not have been enough to affect it. The students may have walked into the classroom with their level of interest already decided. There was a significant difference between experimental and control groups in self-reported scores of self-efficacy in favor of the control group. This may have been because of a Dunning-Krueger effect. The Dunning-Krueger effect occurs when a person cannot accurately estimate the amount they don't know about a given subject. Specifically, it causes people to overestimate their or knowledge or to, in effect, be more confident than accurate (Ehrlinger, Johnson, Banner, Dunning & Kruger, 2008). Students that may have understood the material better have an appreciation of what they still needed to learn, making them less confident. Students who did not understand the material were unable to properly estimate what they know and needed to learn.

For the qualitative portion of the survey, there were four open ended questions. They included "How did you feel about unit conversions after the lecture?" "How could this lecture be improved?" "Describe the Professors teaching style." And "What are the biggest take a ways from the lecture?" By examining the largest themes in each of these questions, one can see that they are extremely similar in name, definition and percentage response. There seems to be little discernible difference between groups on any of the questions. This suggests that there is no discernible effect from the lecture on how students respond to these questions. In addition, the themes are positive, with constructive comments revolving around more time. This suggest that in either condition the students were comfortable and engaged in the lecture.

**Limitations**

There was no significant difference measured between the experimental and control lectures. A reason for this could be that the greatest source of variance in learning comes from the student (Hattie, 2015). It is possible that no change in the presentation of the lecture would be enough to change the level of learning, self-efficacy or interest in the student. This study examined an intervention of one lecture, which in the chemistry classroom is a minimal intervention. Perhaps a longer intervention could produce different results, or perhaps the orientation of the student walking into the classroom makes the largest difference.

Limits of the environment may be present as well. The mid-western Technical College offers no chemistry majors. The chemistry courses are offered in support of other majors such as nursing and fire-fighting. Most students are taking the course to meet program requirements, not from personal interest in chemistry. Students that have a personal interest in chemistry as a major would not likely be attending a technical college in the first place. In addition, if they became interested in chemistry as a personal, future interest it is unlikely this is where they would stay. There are benefits to interest besides potential performance gains, and a technical college could benefit from having students who are more interested. Students who are interested are able to work for longer periods of time without experiencing fatigue for example (Shirey & Reynolds, 1988).

There were two instructors who volunteered their classroom for the study. In an ideal world, there would be more instructors to help control for instructor difference. While the survey in part attempted to detect if there was an instructor effect, a larger sample would allow for instructor differences to be controlled for. As indicated in the analysis, an instructor effect was found. There instructors developed their own measures of performance and graded them individually. This represents a large weakness of the study and could be rectified in future research with either more instructors, or standardizing performance measurements and grading throughout.

A larger sample of students would benefit the study. While 154 students is beyond the bare minimum required to meet normality, a larger sample would better represent the population and allow for a more credible application to other classrooms. This is also a limitation of using a technical college setting, the chemistry department can only be so large.

A potential limitation could also have been the length of the intervention since the intervention was only a one hour lecture. To really measure the long-term effects of teaching with EA it would be beneficial to lengthen the intervention. The performance measures lasted throughout the semester, it would make sense that the intervention also last through the semester. This could also give a better indication of how EA based teaching works for instructing chemistry as a whole.

**Conclusions**

The results of this study did not identify a significant difference between a basic lecture prepared by a publisher and one enhanced with EA. However, there is research that suggests we look for not “What works?” but “What works best?” (Hattie, 2015). What this research suggest is that using material that is comfortable and intuitive for the instructor has value in and of itself. In the qualitative responses, positive themes about the delivery of the material, the interestingness of the instructors and the enthusiasm they brought to the classroom were present.

This implies that both methods of instruction were well received by the students. The instructors do a good job of maintaining interest in either method and have the freedom to experiment with teaching method without being overly concerned about harming the students' learning. Further experimentation and refining of the teaching process is encouraged, it keeps the instructors engaged and has the potential to greatly affect the students.

**Recommendations**

Both of the lectures seem to work for these instructors, perhaps the lack of change in student performance and interest means the instructors could choose what works best for them. In the spirit of doing what works best, and the general finding that either lecture engenders positive affective responses from the participants, instructors should choose a method that meets their needs.

Future research should further examine the connection between analogy and performance, as well as the interest of the student and delivery method of the material. Greater emphasis should be placed on making the two lectures different. In addition, the experimental lecture would benefit from a greater focus on mapping the analog material onto the target material. Using a Concept Anchoring Table, or similar exercise to illustrate the similarities and differences between the target and the analog, could be beneficial. When this is completed, the student could then be assigned to create their own analogies to explain the target. This would allow the students to take ownership of the material and understand the connections better.

In addition to modifying the type of intervention, the length of the intervention should be reconsidered in future studies. One lecture may not be enough to detect a difference in lecture style, so a semester's worth of analogy-rich lectures, or at least several lectures in that design could better detect a difference.

This study aimed to help instructors understand strategies to improve their instruction. Without support for the hypotheses, this study was not able to illuminate direct strategies. However, there were not significant losses experienced by the students either. For these instructors, it means greater freedom for delivering their material, and greater experimentation to find better teaching methods.

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# Appendix A: Initial Survey

In order to improve the instruction of Chemistry, we are collecting feedback on the instruction of material in the mathematical manipulation of units. Please answer the following questions to the best of your ability, and to the greatest extent of your knowledge.

| For the following questions, please check the box that best describes your opinion of the presentation. | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| The instructor explained the unit conversion material thoroughly. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The instructor was enthusiastic in delivery of the material. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The format of the presentation was helpful to the way that I learn. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Prior to the presentation, I considered my math skills to be strong. | ☐ | ☐ | ☐ | ☐ | ☐ |
| This presentation will improve my ability to solve word-type chemistry math problems. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I would feel comfortable explaining unit conversions to a fellow student. | ☐ | ☐ | ☐ | ☐ | ☐ |

What did you enjoy most while learning about unit conversions?

______________________________________________

______________________________________________

______________________________________________

______________________________________________

How could this material be presented differently to improve the teaching of this content in the future?

______________________________________________

______________________________________________

______________________________________________

______________________________________________

**Appendix B: Script for Data Collection**

# Script for Data Collection

Please read the following script to your classroom upon completion of the lecture. The major concern is that the students are requested to put identifying information on their surveys. For this reason, you should not be present while participants fill out this survey. Choose one student to collect the surveys when they are finished, and seal them in an envelope. Read the following prompt in its entirety, hand out the surveys, then exit the room. When 10 minutes are over return to the room and collect the sealed envelope from the chosen student.

Script:

The purpose of the following Survey is being to examine the effectiveness of the lecture styles in the classroom. Your feedback will help the Chemistry Department improve the course and/or instruction for other students taking this class in the future. You will be allowed 10 minutes to complete the survey. Please put your student ID number in the upper right hand corner of the survey. When 10 minutes are finished, I will return to the classroom and collect the envelope from ________ (Chosen student).

- Your participation in this evaluation is important, but entirely voluntary. There are no penalties for choosing not to participate.
- This survey is not a test and will not affect your grades in this class.
- You may skip questions you do not want to answer.
- All of your answers will remain confidential. There will be no way to track your survey responses, or connect you with your responses. Your answers are private.
- It is really important that your answers are based on what you actually think. Please answer the questions as honestly as you can.
- Please do not discuss the questions while taking the survey. The survey is intended to capture your responses, and your responses only.
- If you have a question about the meaning of an evaluation question, do your best to answer it as I will be outside the classroom, and will be unable to assist you.
- For each of the questions on the evaluation, select the appropriate bubble that matches what you think. Please completely fill the Bubble that best reflects your answer. You may use pencil or pen to fill the bubble.
- The survey will take 5-10 minutes to complete.
- Once completed, please hand the evaluation to __________. S/he will put the surveys into this yellow envelope and be responsible for returning them to me.

Thank you for your participation in the data collection!

## Appendix C: Revised Survey

In order to improve the instruction of Chemistry, we are collecting feedback on the instruction of material in the mathematical manipulation of units. Please answer the following questions to the best of your ability, and to the greatest extent of your knowledge.

| For the following questions, please check the box that best describes your opinion of the presentation. | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
|---|---|---|---|---|---|
| The instructor explained the material thoroughly. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The instructor was enthusiastic in the delivery of the lecture. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I was interested in the lecture. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I found the material relatable. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I paid attention to the lecture. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I was engaged in the lecture. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I lost track of time while following the lecture | ☐ | ☐ | ☐ | ☐ | ☐ |
| I understand unit conversions. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I can explain unit conversions to a fellow student. | ☐ | ☐ | ☐ | ☐ | ☐ |
| I improved my ability to solve unit conversion problems after the lecture. | ☐ | ☐ | ☐ | ☐ | ☐ |

How did you feel about unit conversions after the lecture?

______________________________________________________________________________
______________________________________________________________________________
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How could this lecture be improved?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Describe the professors teaching style.

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What are the three most important take a way's from the lecture?

**Appendix D: Factor Label Method Examples**

WORKED EXAMPLE 1.11: A child is 21.5 inches long at birth. How long is this in centimeters?

BALLPARK ESTIMATE—It takes about 2.5 cm to make 1 in., so it should take 2.5 times as many centimeters to make a distance equal to approximately 20 in., or

about 20 in. × 2.5 = 50 cm.

SOLUTION

STEP 1: Identify given information. Length = 21.5 inches

STEP 2: Identify answer and units. Length = ?? cm

STEP 3: Identify conversion factor. 1 in = 2.54 cm

STEP 4: Solve: 21.5 in × 2.54 cm/in = 54.6 cm

BALLPARK CHECK—54.6 cm is close to the estimate.

**Appendix E: Theme Tables**

*Instructor Peregrine Control Group*

| Category | Thematic Category | Key Phrases | Characteristic Level 3 Responses | Frequency |
|---|---|---|---|---|
| Question 1 | | | Q1. How did you feel about unit conversions after the lecture? | |
| 1 | Okay or confident | Participants felt that confident, or at least okay, about unit conversions walking away from the lecture. | "I feel mostly comfortable completing conversions" | 13 (46%) |
| 2 | Better Understanding | The students felt they walked away from the lecture with a better understanding of Unit Conversions. | "A lot better, understanding them more." | 9 (19%) |
| 3 | Confused or Lost | Participants felt confused or lost walking away from the lecture. | "I feel lost and stressed out." | 4 (8%) |
| 4 | Other | There respondent's comments did not fall into any of the other themes. | "Still as boring as they were before I learned about them." | 2 (4%) |
| Question 2 | | | Q2. How could this lecture be improved? | |
| 1 | More Time | Participants felt that more time would have benefitted the lecture. | "Being slower paced and more time to process information." | 12 (48%) |

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| 2 | Good as is | Participants felt that the lecture could not reasonably | "She did a very good job-nothing to be improved ☺" | 5 (20%) |
| 3 | More Examples | Participants felt more examples would have improved the lecture. | "Give more problems to work out together." | 4 (16%) |
| 4 | Other | These respondent's comments did not fall into any of the other themes. | "Cover all topics for the chapter; show us types of questions on the test." | 4 (16%) |
| Question 3 | | | Q3. Describe the Professors Teaching Style. | |
| 1 | Enthusiastic | Described the professor as enthusiastic. | "The professor has a very enthusiastic and relatable teaching style." | 11 (39%) |
| 2 | Other Positive | Had a positive description that did not fit into the other themes that were presented. | "She repeats herself and its helpful so we don't move on before we all understand what she just talked about." | 6 (21%) |
| 3 | Examples | Highlighted Examples as a key part of the instructors teaching style. | "Powerpoints are used to introduce new ideas & examples are given after each topic." | 5 (18%) |
| 4 | Other | These responses did not fit into a theme. | "Eccentric" | 6 (21%) |
| Question 4 | | | Q4. What are the biggest take a ways from this lecture? | |
| 1 | SigFigs | They felt Significant figures were an important take away. | "The importance of sigfigs, precision, and accuracy" | 17 (40%) |

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| 2 | Conversion | They felt unit conversions were an important take away. | "Conversions, sigfigs, & importance of units" | 14 (33%) |
| 3 | Other | They felt a different construct was an important take away. | "Stop overthinking draw line or chart" | 11 (26%) |

*Instructor Peregrine*
*Experimental Group*

| Category | Thematic Category | Key Phrases | Characteristic Level 3 Responses | Frequency |
|---|---|---|---|---|
| Question 1 | | | Q1. How did you feel about unit conversions after the lecture? | |
| 1 | Slightly Confident | Participants felt more confident, and also expressed trepidation. | "I feel as if I still do not know as much as I feel that I could have learned." | 15 (49%) |
| 2 | More Confident | Students felt more confident after the lecture. | "They are super easy once you get the hang of it" | 12 (38%) |
| 3 | Needs more practice | Participants felt they needed more practice to full understand unit conversions. | "I get it just need to keep working on it." | 3 (9%) |
| 4 | Other | They felt a different construct was an important take away. | "It was explained a little fast at points. I did not understand at the end because she did go back over points" | 2 (6%) |
| Question 2 | | | Q2. How could this lecture be improved? | |
| 1 | More Time | More time to go over material. | "Spending more time doing practice problems" | 9 (39%) |

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| 2 | Good as is | Could not think of a way to improve on the lecture. | "Was the best it could be" | 6 (26%) |
| 3 | More Examples | Additional examples or practice requested to understand the material. | "More practice less talking." | 3 (13%) |
| 4 | Other | Responses did not fit into a theme. | "Group work to solve problems." | 5 (22%) |
| Question 3 | | | Q3. Describe the Professors Teaching Style. | |
| 1 | Positive Comments | Positive comments were expressed about the teaching style. | "Bubbly, easy to understand," | 12 (44%) |
| 2 | Enthusiastic | Commented on the teachers enthusiasm during instruction | "Very upbeat, enthusiastic, loud, not monotone." | 9 (33%) |
| 3 | Power point | Respondents described the literal method of disseminating information. | "Powerpoints with examples then practice problems which I find helpful." | 4 (15%) |
| 4 | Other | They felt a different construct was an important take away. | "Do your homework, book readings, study lots of listening, she tries to get us involved" | 2 (7%) |
| Question 4 | | | Q4. What are the biggest take a ways from this lecture? | |
| 1 | Conversions | The Conversion material was an important take away from the lecture. | "How to properly convert units," | 18 (32%) |
| 2 | SigFigs | Significant figures were an important take away from the lecture. | "SigFigs are important for accuracy & precision." | 14 (25%) |
| 3 | Notes | The importance of note taking is an important take away from the lecture. | "Take better notes." | 6 (11%) |
| 4 | Other | These responses did not fall into one | "Practice often, get help early, know what your doing." | 19 (33%) |

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| | | category, but were far more general. | | |

*Instructor Weir Control Group*

| Category | Thematic Category | Key Phrases | Characteristic Level 3 Responses | Frequency |
|---|---|---|---|---|
| Question 1 | | | Q1. How did you feel about unit conversions after the lecture? | |
| 1 | More Comfortable | Participants felt more comfortable with the material when the lecture was finished. | "After the lecture I felt the conversions would be much easier to solve." | 15 (50%) |
| 2 | More Practice | Additional examples or practice requested to understand the material. | "I NEED A LOT OF PRACTICE" | 8 (27%) |
| 3 | Understood | Felt they understood the material to a greater degree. | "I feel that I understand unit conversions on a better level then I did previously" | 4 (13%) |
| 4 | Other | Responses did not fit into a theme. | "I knew about them prior to class" | 3 (10%) |
| Question 2 | | | Q2. How could this lecture be improved? | |
| 1 | More examples | More examples would improve the lecture. | "More examples on how to convert to get more practice." | 8 (36%) |
| 2 | No improvement | There was no way that the lecture could have been improved. | "I DO NOT THINK THAT IT CAN BE IMPROVED." | 3 (14%) |
| 3 | More time | Allowing more time to work through, or understand the material would benefit the lecture. | "More time to work through problems in class" | 3 (14%) |
| 4 | Other | Responses did not fit into a theme. | "Less book explinations more own word definitions" | 8 (36%) |

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| Question 3 | | | Q3. Describe the Professors Teaching Style. | |
| 1 | Positive | Participants described the professors teaching style in a positive way. | "Very straight forward, detailed, and helpful." | 10 (33%) |
| 2 | Enthusiastic | The professors teaching style was called enthusiastic. | "He is very enthusiastic about chemistry which makes it easier to enjoy my learning experience." | 9 (30%) |
| 3 | Interested | The participants described the professors teaching style as interesting. | "The professor is interested in the topic it self and that makes learning easy." | 3 (10%) |
| 4 | Other | Responses did not fit into a theme. | "Lecturing" | 8 (26%) |
| Question 4 | | | Q4. What are the biggest take a ways from this lecture? | |
| 1 | Conversions | Focused on importance of conversions. | "Understanding how to convert & define problems." | 19 (56%) |
| 2 | SigFigs | Significant figures were one of the most important take a ways from the lecture. | "How to identify sigfigs" | 10 (19%) |
| 3 | Other | Responses did not fit into a theme. | "Chemistry has a lot of math" | 24 (45%) |

*Instructor Weir Experimental Group*

| Category | Thematic Category | Key Phrases | Characteristic Level 3 Responses | Frequency |
|---|---|---|---|---|
| Question 1 | | | Q1. How did you feel about unit conversions after the lecture? | |
| 1 | More Comfortable | Respondents felt more comfortable with unit conversions after the lecture. | "I feel as though I can use them in a relatable way to | 21 (42%) |

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| | | | solve problems in real life situations" | |
| 2 | Confused | Respondents felt confused by unit conversions after the lecture. | "I get confused on some, but not all" | 14 (28%) |
| 3 | Understood More | The students felt they understood more about unit conversions after the lecture. | "I understand it better. By the instructor showing me a easier way to convert problems" | 8 (16%) |
| 4 | Other | Responses did not fit into a theme. | "I feel the lecture got the basics across on what units are." | 7 (14%) |
| Question 2 | | | Q2. How could this lecture be improved? | |
| 1 | More Examples | Respondents suggested the lecture could be improved with more examples. | "Maybe more problem sets to figure out together" | 18 (43%) |
| 2 | Good as is | The lecture did not need to be changed or modified. | "Im not sure how it could be improved" | 10 (24%) |
| 3 | More Time | More time to understand/process the material would improve the lecture. | "Slow down during the practice problems" | 5 (12%) |
| 4 | Other | Responses did not fit into a theme. | "More hands on" | 9 (21%) |
| Question 3 | | | Q3. Describe the Professors Teaching Style. | |
| 1 | Other Positive | Positive comments that did not fall into a different theme. | "very laid back and open to questions, very informative as well." | 16 (32%) |
| 2 | Enthusiastic | Described the professors teaching style as enthusiastic. | "Enthusiastic, Engrossing" | 15 (30%) |
| 3 | Engaging | Describe the professors teaching style as engaging | "I enjoy Dr. Weir. He is enthusiastic and keeps us engaged. He presents the info and | 5 (10%) |

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| | | | gives "real life" examples" | |
| 4 | Power Point | Describe the methods the professor used to deliver the material. | "Use of power point as well as examples done as a class" | 4 (8%) |
| 5 | Interesting | Describe the professors teaching style as interesting. | "He kept it interesting and I didn't lose interest." | 3 (6%) |
| 6 | Other | Responses did not fit into a theme. | "Unique." | 7 (14%) |
| Question 4 | | | Q4. What are the biggest take a ways from this lecture? | |
| 1 | Conversions | Understanding unit conversions was reported as an important take away from the lecture. | "Better understanding on Conversion factors." | 16 (40%) |
| 2 | SigFigs | Being able to correctly use significant figures was reported as an important take away from the lecture. | "Better understanding of Sig Figures." | 9 (23%) |
| 3 | Measurements | Minding and following the correct measurements was an important take away from the lecture. | "unit of measurements." | 4 (10%) |
| 4 | Other | Responses did not fit into a theme. | "Confidence in my ability to perform the materials equations." | 11 (28%) |