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Assessing the Development of Chemistry Students' Conceptual and Visual Understanding of Dimensional Analysis via Supplemental Use of Web-Based Software

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ABSTRACT: This study was designed to evaluate the effects of a proprietary software program on students' conceptual and visual understanding of dimensional analysis. The participants in the study were high school general chemistry students enrolled in two public schools with different demographics (School A and School B) in the Chattanooga, Tennessee, metropolitan area. Using a "treatment group" and a "control group" (no treatment), a mixed-methods design was used in the data collection and analysis to provide a holistic view of the impact of the software on student learning. The resulting qualitative and quantitative data confirmed that the software enhanced the treatment groups' conceptual and visual understanding of dimensional analysis. In fact, when all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating use of the software into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. The enhanced conceptual understanding was verified by quantitative data, which indicated a significant difference between the overall pretest and posttest scores of the treatment group ($n = 14$, $t = -2.896$, $p = 0.008$). On the basis of the descriptive statistics, it is evident that all students benefited from using the software. The qualitative data showed that students' visual understanding was enhanced and that they valued their experiences using the software and were able to enhance their knowledge of all aspects of dimensional analysis. The researcher takes the lessons learned from this study and provides practical best practices on effectively integrating elements of the software to enhance conceptual and visual understanding in traditional chemistry classrooms.

KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Chemical Education Research, Computer-Based Learning, Internet/Web-Based Learning, Multimedia-Based Learning, Problem Solving/Decision Making, Analogies/Transfer, Stoichiometry, Student-Centered Learning*

FEATURE: Chemical Education Research

INTRODUCTION

Many high school general chemistry teachers have observed that today's students are having difficulty making connections to their prior knowledge of concepts such as algebra and its connection to dimensional analysis. Dimensional analysis is one of the major fundamental concepts high school chemistry students must grasp. It is also a topic that is taught early in the curriculum; if students have a hard time comprehending this concept, it could taint their view of chemistry as a whole. Typically, this concept is taught by the teacher presenting simple problems on the board that the class works together, after which students work similar problems in the book individually. Most students have a hard time with the conceptual and visual understanding of units in general, and struggle even more with the process of converting units. Too many students, for example, have no concept of size, making it difficult for them to determine whether a yard is bigger than a centimeter. Traditional methods provide students with a simple conversion chart that just presents units. However, students often struggle with conceptually visualizing the meaning behind the units and only view them as numbers with no value or relevance. It is precisely these students who have a hard time understanding dimensional analysis.

Ideally, presenting dimensional analysis via an educational technology tool specifically designed to enhance student conceptual and visual understanding of that content should results in improved learning. This tool would present traditional dimensional analysis problems, while allowing students to "see" what the numbers mean and how the units interact. This tool would be used as a supplemental resource, similar to how traditional worksheet activities are integrated into lessons so that students apply their dimensional analysis problem-solving skills.

BACKGROUND

Dimensional Analysis

Dimensional analysis, which is also referred to as unit conversions, conversion factors, the factor-label method or the unit factor method, is a problem-solving method of manipulating unit measures algebraically to determine the proper units for a

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quantity. As such, it is one of the critical skills beginning chemistry students must master because it enables students to move from one unit of measure to another. Dimensional analysis is a required skill throughout general chemistry courses: some of the common applications that rely on such skills include introductory unit conversions, stoichiometry, and concentration units.

Dimensional analysis is a very powerful analytic method; however, it does have some limitations. As noted by McClure (ref 1, p 1093):

> *[W]hile most students quickly develop an understanding of the properties of conversion factors, a significant number have difficulty grasping dimensional analysis as a problem solving technique (i.e., linking information given to information sought through conversion factors).*

Although a student can be "successful" in solving a simple dimensional analysis problem by simply matching units, this same logic is insufficient when a student is required to recognize when and where to apply unit conversions. Prior to solving the sample problem, students should be able to understand the proportional implications between kilometers and feet. They should comprehend that because the final answer will be in feet, and they are starting with kilometers, their final answer must be a large number because there are 3280 feet in 1 km. Conversely, if students reach an answer that is smaller than the starting kilometer number, they should recognize that they have made a calculation error or applied the wrong conversion factor(s).

Although dimensional analysis is considered to be a powerful and highly efficient method, it is unsuitable as an initial teaching tool because it can yield the correct answer by perfunctory unit cancellation, rather than understanding why and how the units are being canceled due to scientific principles.[2−5] Once students grasp the concept of dimensional analysis, a general chemistry course can begin to make sense because dimensional analysis problems contain all of the logical quantitative ideas that students need to succeed in chemistry.

McClure[1] proposed using the game of dominoes to help students link information with respect to dimensional analysis. Games provide an attractive framework for learning activities and students tend to react positively to such approaches.[6] Capps writes[7] "Using games in the chemistry classroom can provide engaging and alternative methods of instruction." The study described herein expands McClure's domino analogy into the world of educational technology. Specifically, an interactive software program was created to enhance students' conceptual understanding of dimensional analysis, because, as Hennessey et al. note:[8]

> *[A]ppropriately designed software materials can help students build mental links to strengthen their logical framework of conceptual understanding and to achieve a mastery level understanding of chemical concepts.*

Technology-Mediated Learning

Effective integration of technology into the classroom has been shown to lead to a number of important outcomes, such as effective learning, improved critical thinking, better problem-solving skills,[8,9] as well as development of other innovative learning tools that can enhance related scientific abilities.[10] Technology also fosters interactive, self-directed learning[11−13] and higher-order thinking skills.[11,13,14] Technology increases student-centered learning[11,14] and increases student interest in learning.[15]

The graphics, animations, video clips, and interactive nature of computer-aided learning help to actively engage students in the learning process. Schar and co-workers state,[16]

> *Current research on computer-aided learning is very focused on how to represent the learning content and tends to neglect the impact of the user-interface in the learning process.*

The computer-aided learning project developed for this study focused on how to most effectively represent the learning content, and what supportive material was needed to best assist students in the successful completion of solving dimensional analysis problems.

The findings of Mayer and Anderson support a dual-coding model in which a student's understanding and retention require the construction of new representational connections and problem solving for referential connections.[17] Dual coding theory[18,19] emphasizes that information should be presented with proper regard to the functional importance of verbal and visual inputs.[20] Theoretical principles from several multimedia studies have helped to explain how information presented as texts and animated sequences interact to encourage learning.[21,22] This study will support the use of a dual-coding theory, emphasizing that information presenting the functional importance of verbal and visual inputs can enhance student learning.[20]

Assessing Conceptual and Visual Understanding

Conceptual understanding, as defined by the author, is the ability to apply knowledge across a variety of instances or circumstances.[11] Researchers have concluded that computer-based environments are effective in facilitating conceptual understanding in student learners, thereby improving mastery of both content and process.[23] Effective science educators—who understand that meaningful conceptual understanding in science goes far beyond knowing facts and labels and only becomes meaningful when it can be used to explain or explore new situations—have begun to develop a range of assessment instruments that focus on conceptual understanding rather than the recall of isolated bits of information.[24] To assess the conceptual understanding of students in this research project, a qualitative strategy derived from the work of Mintzes, Wandersee, and Novak[25] was used in the form of structured interviews to assess science understanding.

The structured interview provides an opportunity to interpret a student's explanation of his or her conceptual understanding. Essentially, the goal of a structured interview is to create an environment in which students feel comfortable enough to share their thought processes while they are solving problems, analyzing data, and performing other tasks, with the goal of enabling the researcher to better understand the students' understanding.

"Sorting interview" guidelines were employed to assemble a more detailed understanding of the student's visual and conceptual understanding of a specific concept. Visual understanding, as defined by the author, is the ability to understand graphical representations of subjects or concepts that demonstrate how the concepts relate to each other. Southerland et al.[26] explain

> *In a sorting interview the student is presented with a group of objects to be sorted according to specific instructions that can be structured in many different ways to match the purpose of the assessment.*

For this study, students were asked to determine which of the units was larger or smaller, an exercise resembling an element of the software program.

Problem solving and process interviews were also incorporated in this study as an interview qualitative assessment tool.

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Problem solving is a formative assessment used in all chemistry classes where the main emphasis is on the final answer, which is either marked "right" or "wrong". The problem-solving interview is designed to focus on the thought processes students used in reaching their final answer. For this portion of the research, the problems that were chosen were very similar to the problems used in the pretest and posttest as well as the software program; one problem from each of the three levels.

■ RESEARCH SUMMARY

The following principal research question drove this study's design, execution, and analysis: Can supplemental use of interactive proprietary software enhance high school chemistry students' conceptual and visual understanding of dimensional analysis? The software program was designed using the ASSURE model.[27] All graphics were created by the researcher with respect to Tufte's principles of graphic design[28,29] to ensure images enhanced and did not detract from learning. The software program, named Conversionoes,[11] consisted of four major sections: Smaller or Larger, Dimensional Analysis, Conversionoes Game, and Hints. Every element of Conversionoes was created and designed by the author and critiqued by general high school chemistry teachers and students in the Chattanooga metropolitan area.

To determine whether the Conversionoes software program and corresponding curriculum enhanced student understanding, the author enlisted the help of two teachers as participants. Each participant teacher has over 20 years of experience teaching high school chemistry. Both teachers used the same textbook and supplemental worksheet activities during the dimensional analysis unit. The general chemistry class was a part of each student's four-block schedule of classes, with each class block lasting approximately 80 min. Each teacher spent four weeks early in the semester covering key concepts that served as prerequisite knowledge for the use of the Conversionoes software program (e.g., SI system, metric system, scientific notation, volume and density, etc.).

School A, the primary research site, was a medium-sized, suburban, grade 9−12 public high school located in the Chattanooga metropolitan area. The general chemistry classroom demographics reflected that of the school—approximately 65% White and 35% African-American students.

School B, the comparison school, had different demographics. Although it was also located in the greater Chattanooga metropolitan area, it was a brand new school that served a more affluent population. The general chemistry classroom demographic was 100% White.

The primary instructional methods used in both schools were lecture and the completion of worksheets and textbook problems, using the textbook as a reference. At the chemistry coursework level, the students' principal use of dimensional analysis was to solve various dimensional analysis problems and then use those same concepts in future lessons in stoichiometry and molar equations. Prior to the research, Teacher A (from School A) and Teacher B (from School B) covered dimensional analysis during class lecture and the students had ample opportunities to apply the problem-solving skills; further, students were assessed on numerous occasions prior to the introduction of the supplemental activity.

The participant teachers were tasked with the responsibility of creating the groups with respect to gender, race, socioeconomic status, and academic ability and standing in an effort to avoid skewing the data. School A had 16 students total (8 students in the control group and 8 students in the treatment group) and 6 of those students (3 from the control group and 3 from the treatment group) also participated in the interview portion of this study. The control group contained 3 White females, 2 White males, 2 African-American males, and 1 African-American female. The treatment group contained 3 White females, 3 White males, 2 African-American females, and 1 African-American male. School B was also equally distributed and contained 12 students total (6 students in the control group and 6 students in the treatment group) and 6 of those students also participated in the interview portion of this student. The control and treatment groups contained 3 White males and 3 White females.

Because of the supplemental purpose of Conversionoes, the treatment group was allowed to use the software program for 45 min during a regular class period while the control group participated in a paper-based manipulative dimensional analysis activity under their teacher's supervision. The control group's activity mirrored mainly one element of Conversionoes, the dimensional analysis problem-solving aspect of the software program, and required students to use paper dominoes to help them solve their problems, cut and tape the selected dominoes in the provided spaces on their worksheet as shown in Figure 1 to solve dimensional analysis problems, such as converting a distance of 9.5 feet to centimeters.

9.5 ft							
12 in.	1 ft	1 in.	2.54 cm				
1 ft	12 in.	2.54 cm	1 in.				

Figure 1. Sample manipulative dimensional analysis problem.

Students were given a pretest and posttest to determine the effectiveness of the Conversionoes software program. The dimensional analysis unit was completed by their respective teachers (two months after initial instructor), the posttest after students received supplemental intervention via the software or the alternative in-class worksheet activity (a week after the intervention). At both schools, 6 students from each class (3 from each respective group), 3 females and 3 males, were interviewed before and after each test. During the interviews, students were asked to rank items based on size, solve problems, and explain their problem-solving strategy with respect to dimensional analysis problems. The tests were evaluated with the rubric shown in Figure 2.

The rubric was designed to capture the requirements of the Conversionoes software program that students must meet to receive the feedback of "Correct" and credit toward their level certification (at least 90% accuracy). To receive full credit (6 points) the final answer must contain proper significant figures, scientific notation, and units. Partial credit was given and examples of how the points were allocated along with examples of acceptable answers are also given in Figure 2.

The rubric was reviewed (including the examples) and it was confirmed with both participant teachers that they use a similar rubric to grade dimensional analysis problems. The intent was that the expectations for successful completion of dimensional analysis problems were consistent with what students were required to do with respect to showing their work when solving problems. In an effort to ensure the tests were graded fairly, the author initially graded the test and had the grades verified by the participant teachers for accuracy.

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Points for Assessing the Responses

	6	4	2	0
Answer Description	Correct answer: Proper units, significant figures, and scientific notation	Proper units, coefficient/base unit, significant figures or scientific notation	Proper units, coefficient/base unit	Wrong answer, no answer, no units
Possible Examples (Rationale)	2.02×10^{-2} m	2.023×10^{-2} m	0.0203 m	0.00203 m or 0.0202 (no units)

Figure 2. Pretest and posttest grading rubric with applied examples for a dimensional analysis question. (Adapted from ref 11.).

Conversionoes Alignment with Dimensional Analysis Literature

According to the literature on effective ways of teaching dimensional analysis, many strategies could be implemented in this research to enhance student learning of dimensional analysis. This research focused on three key areas: (i) helping students understand dimensional analysis as a problem-solving process;[1,3,30−33] (ii) helping students better understand the relationship between conversion factors;[1−5,34] and (iii) helping students visualize units and understand what the numbers represent.[28,29]

The software program addressed the first area through the Hints video tutorial on dimensional analysis problem-solving strategies. This video tutorial was created after analyzing four general chemistry textbooks (including the textbook used by both schools), and focused on providing students a seven-step strategy of solving problems, as shown in Box 1.

Box 1. Seven-Step Strategy for Solving Problems

1. Read and understand the problem or question.
   a. What are you asked to do?
   b. What type of unit of measure is being used?
   c. What information is given?
2. Understand and visualize the units that are used in the problem.
   a. Is the given unit larger or smaller than the final unit?
   b. Should the final answer be a larger or smaller number?
3. Write a mathematical expression of the problem.
4. Use your knowledge to figure out what conversion factor(s) will help you solve the problem.
5. Map out your strategy to solve the problem and set up your conversion factors accordingly.
6. Set up your solution and do the arithmetic.
7. Check your final answer to see whether it is reasonable.
   a. Does it answer the initial question?
   b. Does the answer pass the larger or smaller test?
   c. Is the final answer in significant figures?
   d. Is the final answer in scientific notation?
   e. Does the answer have the proper units?

In addition to providing this seven-step plan, the animated narrated video walks students through an example they can solve along with the video. The tutorial also provides students with additional strategies to apply when solving problems that address some of the other major areas of effective instruction of dimensional analysis: strategies on visualizing units, and understanding the relationship between the conversion factors and how this relationship applies to the current problem.

To ensure students were provided quick tips that addressed effective instruction of dimensional analysis, supporting elements were also included to help students successfully provide a correct answer for the dimensional analysis portion of the software. Video tutorials on putting the final answer in proper scientific notation and significant figures were created. Detailed instructions were provided on how to successfully apply these skills; animation was used where applicable to show students how to perform certain elements, such as counting significant figures.

It was observed by the author and mentioned by the participant teachers that many students knew how to set up their problems correctly but had difficulty using their calculators to produce the proper coefficient and base units and using the functions in their calculators to put their final answer in proper scientific notation. Both teachers spent time demonstrating how to properly use calculators, although some students still had trouble grasping the concept. The Hints video on using a scientific or graphing calculator to solve dimensional analysis problems was created to assist students with this problem.

The curriculum created for the Hints section of the Conversionoes software program was designed to reinforce material taught by the participant teachers as well as providing a different vehicle for students who could not comprehend the concepts in a traditional setting. Students in the treatment groups were informed of the availability of the Hints video but were not required to review the material prior to using the software. It was observed that 85% of students in Treatment Group A and 75% of students in Treatment Group B referred to the videos after they unsuccessfully solved dimensional analysis problems and were prompted by the software to review the material. A few students in each group reviewed the material prior to starting the dimensional analysis portion of the software. Students had quite favorable comments about the Hints section, which are best summarized by this quote: "I didn't understand it [dimensional analysis] very well, but I do now after watching the video." This could be further quantified after reviewing the software data that showed an increase in problem-solving proficiency within the software.

The Conversionoes Game was created to help students learn how units were related and how they linked together. In addition to focusing on the linking relationship between units, the instructor added another level of detail and showed students the relationship between conversion factors and what type of measurement classification they belong to. Students could play three types of Conversionoes Games: length, mass, and volume. As students played the different types of Conversionoes Games, they could see what units belonged in each category while they interacted with the different conversion factors and how all of the units within that category were related.

The Conversionoes curriculum aimed to help students visualize units and understand what the numbers represent.

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Pretreatment Interview Questions for Students

1. What is dimensional analysis?
2. Which is smaller: 1 cup of brown rice or 1 tablespoon of brown rice? (Students are asked first and then shown the image at the right after they provide their response.)
3. Can you convert this problem?
   a. There are 2.5 days to a normal weekend. How many hours does that include?
   b. How many micrometers are in 0.026 centimeters?
      i. What steps do you use when you solve these problems?
      ii. Why did you use that conversion factor there?

Posttreatment Interview Questions for Students

1. Do you think you have a better understanding of dimensional analysis? Why or why not?
2. Which is smaller: 5 ounces of soy sauce or ¾ cups of soy sauce? (Students are asked first and then shown the image at the right after they provide their response.)
3. Can you convert this problem?
   a. What is 6.05×10^3 cubic centimeters in liters?
   b. A beaker contains 588 mL of water. What is the volume in quarts?
      i. What steps did you use to solve these problems?
      ii. Why did you use that conversion factor there?

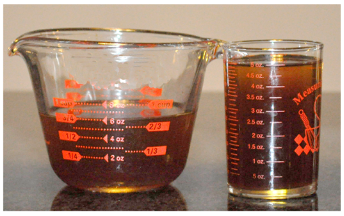

Figure 3. Sample questions used in interviews with students before and after the treatment.

This area was mainly addressed in the Larger or Smaller portion of the software. Here, students were given two units of measure of the same item and were asked to determine which was smaller or larger. Once students made their selection they were able to "see" the numbers and what types of real-world products are measured with that type of unit. This portion of the game provided students with a visual connection to what types of units represent a particular category of measurement (e.g., volume) and what types of units correspond to that category (e.g., liters, gallons). The Smaller or Larger section essentially required students to visualize units prior to seeing the images of the items. One of the questions asks students to select which is smaller, 12 oz. of soda or 237 mL of soda, and then a picture of the two products is displayed to verify their initial answer and make a real-world connection to the units of measure.

Conversionoes Effect on Conceptual and Visual Understanding

The Conversionoes software program features several elements that can assess a student's conceptual understanding (Dimensional Analysis) and visual understanding (Smaller or Larger). In addition, Conversionoes helps students understand the linking nature of units (Conversionoes Dominoes), as well as reinforcing skills already taught in previous lessons (Hints). During the 45 min the treatment groups of students were allowed to use the software, the majority of their time was spent on the Dimensional Analysis portion of the software, which addressed student conceptual understanding.

Although the majority of students spent their time in the dimensional analysis section of the software, many of them began their exploration of the software in the Smaller or Larger area. While using this portion of the software, students expressed their delight with actually being able to see the units. They said it helped them better understand what types of items are measured in "those types of units". Students could see what units were used in volume problems. One student in the interview said,

> *I didn't know that there were different types of units on items like Coke, I only thought it came in ounces. I'm going to play this game with my parents to see if they can tell [which is smaller or larger]. It's fun!*

Students were asked about their perception of the impact of the Smaller or Larger segment on their overall understanding of dimensional analysis. They replied that it helped them think about the units and what they looked like. "It also makes units more real, which made the problems more real", said a student from School B during the interview. Although students (control and treatment) were not required to visualize units in the same way in their formal assessments (pre- and posttests), they were asked to do so during their pre- and postinterviews. Many of the treatment group students indicated that even though the posttest was a "traditional" dimensional analysis test, many of them closed their eyes to help visualize what the numbers meant prior to solving the problem and were thus able to transfer this same skill and added it to their problem-solving strategy. In so doing, they were able to determine whether their final answer should be smaller or larger, depending on what information was given in the problem, as well as to determine which conversion factors were applicable for the particular problem.

The visual understanding was best assessed during the interview portion of this study. Figure 3 provides a few excerpts from the pre- and posttreatment interview questions. It was during these interviews that students in both groups indicated that seeing the products helped even if they answered the question incorrectly. It was quite evident that in the posttreatment interviews the treatment group students from both schools had a higher proficiency level in answering the Smaller or Larger questions and, more importantly, could articulate their visual understanding owing to their confidence in their answers. The visual cues confirmed the students' conceptual understanding and served as a mental reference for use in solving future problems.

Dimensional Analysis Problem Solving Proficiency

The pretest and posttest were administered at the end of formal instruction and after the supplemental activities. The students were provided a conversion chart to help them focus on the problem-solving process versus trying to memorize various conversion factors. Students were instructed to show their work orally prior to beginning the assessments and Show Your Work was written at the top of each test as another reminder to all students. The students were familiar with the format of the questions from previous problems solved in textbook and worksheet activities and the requirements of showing their work to receive full credit. The participant teachers administered the pretest and the author administered the posttests in the presence of the participant teachers. Sample pretest and posttest questions are given below.

Pretest Sample Questions

1. The recommended adult dosage of an over-the-counter pain reliever is 5 mg/kg of body mass. Calculate the dosage in milligrams for a 175-lb person.
2. A football field is exactly 100 yards long. What is its length in inches?

Posttest Sample Questions

1. The mass of a gemstone is measured in carats, where 1 carat equals 0.215 g. If the annual worldwide production of aquamarine is 6.5 million carats, how many kilograms does this represent?
2. The distance walking around the average high school three times is 0.75 miles. Convert that distance into feet.

Students were given 20 min to complete six problems, and had no problem completing the test in the allotted time. The tests were separated by school and group, and then graded, with the grades serving as input data for the inferential and descriptive analysis. The grades were recorded in a Microsoft Excel spreadsheet, which was used as the input data for the SPSS analysis. The technique used to determine whether a significant difference existed between the control and treatment group gains in dimensional analysis problem-solving proficiency was via inferential statistics and an independent *t*-test. The null hypothesis stated that no significant difference existed between the pre- and posttest results of the respective groups. The results of the tests have been summarized in Tables 1 and 2. The null hypothesis assumed that there was no significant difference between the groups.

The Levene's test indicates that equal variances are assumed (as evidenced by the *F* value not being significant at $p < 0.05$). In this case, the results indicated the equal variances assumed data should be used in the analysis. Based on the *p* value ($t = -2.896$, $p = 0.008$), the null hypothesis was rejected. Regarding the difference between how the groups performed, a significant difference between control and treatment groups emerged. Thus, the individuals in the treatment experienced significantly better gains than the control groups. From these data it appears that the supplemental use of the Conversionoes software program did enhance student understanding of dimensional analysis.

Table 1. Inferential Statistics for Pretest and Posttest Data[a]

	Group Statistics ($N = 14$)			
Instrument	Variable	Mean	Standard Deviation	Standard Error of the Mean
Pretest	Control	14.7	8.05	2.15
	Treatment	15.9	8.37	2.24
Posttest	Control	14.0	13.81	3.69
	Treatment	29.3	14.14	3.78

[a]Adapted from ref 11.

CONCLUSION

The main research question posed in this study asked whether the supplemental use of an interactive proprietary software program could enhance high school chemistry students' conceptual and visual understanding of dimensional analysis. A mixed-methods study was conducted. The resulting qualitative and quantitative data confirmed that the Conversionoes software program enhanced the treatment groups' conceptual and visual understanding of dimensional analysis. The comparisons were conducted at two schools with different demographics, both resulting in similar positive effects on students' overall understanding.

When all of the quantitative and qualitative data were viewed as a whole, the advantages of integrating Conversionoes into the general chemistry classroom proved to have significant impact on student conceptual and visual understanding of dimensional analysis. This was verified by the quantitative data, which indicated a significant difference as well as the descriptive statistics that verified that the treatment group benefited from using the software program. The qualitative data showed that students valued their experiences using the Conversionoes software, and were able to demonstrate their visual understanding and how their overall conceptual understanding of dimensional analysis was enhanced.

In an effort to quantify the effects of using the software program, a grading rubric was created that included all of the required elements of a correct answer in Conversionoes: proper use of units, significant figures, and scientific notation (Figure 2). The treatment groups' proficiency on the posttest was higher than the control groups', and the inferential statics verified that the use of the software program had a significant impact on enhancing student learning.

Applying Conversionoes Best Practices

Although the strategies designed to enhancing conceptual and visual understanding of dimensional analysis for Conversionoes are highlighted in this study, the results of this study are not limited to the integration of Conversionoes in the curriculum in particular.[11] Results of this study could be advantageous for any chemistry teacher facing the dilemma of identifying effective ways to engage students and help them understand the process of

Table 2. Comparative Results of Independent Samples Test[a]

	Group Statistics ($N = 14$)								
	Levene's Test for Equality of Variances		*t*-Test for Equality of Means						
								95% Confidence Interval of the Difference	
Conditions	*F* Values	Sig.	*t* Values	df	Sig. (Two-Tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pretest: Equal variances assumed	0.105	0.748	−0.315	26	0.711	−1.16	3.10	−7.54	5.21
Pretest: Equal variances not assumed			−0.375	26	711	−1.16	3.10	−7.54	5.22
Posttest: Equal variances assumed	0.003	0.959	−2.896	26	0.008	−15.30	5.28	−26.17	−4.44
Posttest: Equal variances not assumed			−2.896	26	0.008	−15.30	5.28	−26.16	−4.44

[a]Adapted from ref 11.

solving dimensional analysis problems. Integrating technology such as Conversionoes and the principles used in the development of the curriculum into general chemistry classrooms offers one example of how teachers can engage students, as well as present material in a different medium that may be more effective for technology-savvy students. Teachers can take concepts used in Conversionoes and integrate them into their curriculum to supplement their lectures as well as allow students to use images to serve as visual cues to help them link units.

Mayer and colleagues conclude that:[35]

> *For meaningful learning that supports problem-solving transfer, the learner must build an internal verbal representation from the presented verbal information, an internal visual representation from the presented visual information, and referential connections between these verbal and visual representations.*

The most beneficial finding from the supplemental integration of Conversionoes into the curriculum was that it identified how practical concepts such as dimensional analysis are used by integrating common images found in the real world to enhance students' visual and conceptual understanding, which can serve as a scaffold for future applications of similar problem-solving skills needed later in the curriculum. In addition, providing students with tutorials of key concepts can be extremely beneficial.

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Notes

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