

Development and Validation of Word Problems in Chemistry Gas Concepts

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Real world problems promote critical thinking and problem-solving skills (Duch et al. 2001). As such, science teachers should not only be concerned with teaching science principles, but more importantly, with real-world applications of these science concepts. Teachers face the challenge to design sample problems that involve real life situations with sufficient complexity to engage the students in problem-based learning. Problem solving in Chemistry require students to modify and adapt theoretical models to solve word problems, which include invention of the solution, rather than direct use of prescribed sequence of steps.

This paper presents the results of a study on word problems that utilized the Input-Process-Output model of instrument development. The word problems developed involve concepts on gases for the third year high school students. The study used focus group discussion (FGD) to obtain in-depth information on concepts and perceptions of high school science and mathematics teachers about word problems. Based on these discussions, thirty five (35) word problems were constructed integrating various cartoon characters depicting real life situations. The results of the study show that word problems containing illustrations of and story lines about cartoon characters appeal to students. They also generate enthusiasm and enjoyment among the students while on-task. Qualitative evaluation involving high school and college Chemistry teachers showed that the developed word problems were valid in terms of content and structure. Reliability (Cronbach alpha) was found to be 0.870. Readability was established by conducting try-outs among students. Evaluation results indicate that the developed word problems were perceived by the readers as appropriate for the reading level of the students.

Introduction

Word problems should utilize open-ended tasks that lead to creativity and critical thinking (Chamberlain and Moon 2008). Students can achieve higher levels of cognition and skill development when presented with contextualized problems and situations.

Students faced with a learning task give attention to: meeting the problem, defining the problem, gathering facts about the problem, hypothesizing solutions to the problem, researching about the problem, rephrasing the problem, generating alternatives, and advocating solutions to the problem (Fogarty 1997). To assess problem solving, teachers will need to construct problem tasks that require performing and applying the steps successfully in order to arrive at a best solution. The instructor's role during the learning process is that of a metacognitive coach or a facilitator focusing on the thinking skills of the students (Hmelo-Silver 2004).

To promote meaningful learning, word problems must require students to look for alternative solutions as well as integrate and apply concepts learned in other disciplines. Teachers must do away with formula memorization and close-ended exercises. Lewellyn (2005) believes that the goal of teaching chemistry indicates more emphasis on word problems and decision making. Chemistry teachers should show practical applications of chemistry concepts and not just to have students memorize steps in solving word problems.

Educators are faced with the challenge of developing instruments that can effectively assess problem solving skills of students. Textbook and end-of-chapter word problems become a routine and inappropriate for use in the classroom (White 1995). It is therefore necessary to develop and validate new word problems with sufficient complexity to engage students in meaningful problem solving.

Solving problems in chemistry differs from solving math problems (Woods *et al.* 1997). Math problems can be solved by working with the information provided by the instructor (Chamberlain and Moon 2008). Chemistry problems, on the other hand, require students to modify and adapt theoretical models to solve word problems. As such, they often entail invention of the solution rather than direct use of a prescribed sequence of steps to solve the word problem.

Teachers realizing the diversity of skills that students bring to a Chemistry class should see the need to adjust instruction to meet educational goals. One way to address this concern is by introducing unique and novel ways of presenting word problems in Chemistry classes. Rather than the often "choose the formula" approach, more engaging problem tasks allow students to present their knowledge, skills and understanding of the concepts in a new context.

The research aims to develop and validate problem tasks in Chemistry. Specifically, it intends to:

1. develop problem tasks on concepts related to properties of gases, gas laws and stoichiometry of reacting gases for third year high school students,
2. establish the validity of the developed problem tasks in terms of content and structure, and
3. determine the readability of the developed problem tasks.

Methodology and Results

This study is a descriptive developmental research that utilizes the Input-Process-Output model of instrument development. Moreover, the study utilized focus group discussion (FGD) to obtain in-depth information on the perceptions and ideas of high school science and mathematics teachers about word problems.

Preparation and Development of Word Problems

Word problems were developed and formatted by the researchers based on the result of the focus group discussion. The word problems are essential to teaching chemistry as well as mathematics and physics for they enhance critical thinking. Suitable word problems must include real world application, withholding some variables, integrate other subject areas, be challenging, contain illustration/cartoon characters and compose of simple, straightforward words. The group recognized that "add-ons" invite participation and improve engagement of students in problem solving. Examples of "add-ons" are relevant cartoon characters and storylines, famous personalities and names of students in class.

A survey consisting of open-ended questions was conducted to determine the third year high school students' preferences in terms of cartoon characters and story lines which they wished to be included in a problem task in Chemistry. A total of ninety nine (99) students participated in the survey. The seven (7) cartoon characters which ranked the highest on the survey were used in developing the word problems. These are: (1) Spongebob, (2) Phineas and Ferb, (3) Mickey Mouse and friends, (4) Patrick Star, (5) Perry the platypus, (6) the Simpsons, and (7) Pokemon.

The sample preferred SpongeBob SquarePants, a Nickelodeon-produced animated series. The characters in the series resemble sea creatures like sea star, crab, lobster, plankton, whale, and squid. Perhaps, this high preference for the characters in this program may be because they watch this animated series on the television or they can relate to these creatures after having their biology subject in the previous year.

Phineas and Ferb produced by Walt Disney ranked second. The series features plans and inventions of the two characters to stave off boredom. The series is also known for its musical numbers. The classic Disney characters, Mickey Mouse and friends, still appeal to third year high school students. This is followed by Patrick Star (a cast of SpongeBob SquarePants), Perry the Platypus (from the series Phineas and Ferb) and the Simpsons. One anime character, Pokemon made it to the list.

The cartoon characters were incorporated in the tasks described in the word problems. A student illustrator polished the cartoons to make them more appealing. It was hoped that the inclusion of cartoon characters will help students visualize the problem and make them more interesting to the students.

Topics in Chemistry that require the use of word problems were identified. These include real and ideal gases, the gas laws, mixture of gases and stoichiometry of reacting gases.

Well-structured problems from chemistry reference books were identified and modified to fit the target structure of the problem tasks. Careful analysis was done in their design and construction. Other subject areas like tourism, sports, history, economics, atomic physics, education, safety, food, geology, weather, investigative report, sociology, technology and health were included in the word problems as suggested in the focus group discussions. Figure 1 shows a sample word problem involving Bart and Homer Simpson of "The Simpsons" series.

*History***The Gratitude of Bartholomew "Bart" Simpson**

During the 17th century, a young boy named Bart watched his father, Homer as he worked with water pumps. Water pumps had improved a lot since the 16th century. A century ago water pumps could not pull water beyond 18 Florentine yards (10 m) according to a measurement taken around 1635. This limit was a concern to irrigation projects, mine drainage, and decorative water fountains. As Bart says, "Thanks to Torricelli! Indeed air exerts pressure!" How do you think Torricelli solve the issue of the water pump?

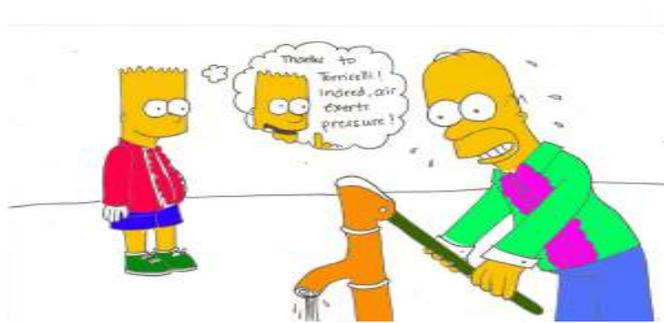


Fig. 2. The Gratitude of Bartholomew "Bart" Simpson.

Word problems were made as engaging and challenging as possible to develop higher cognitive skills. Some specific information in the word problems were deliberately not included. In this way, the students' research and analytical skills were also developed while doing the tasks. Figure 2 presents a problem on counteracting forces

Counteracting Forces

While Detective P is not around, Dr. Heinz Doofenshmirtz got near his plan to spread terror at Tri-State-Area. Dr. Heinz Doofenshmirtz hid Phineas and Ferb in one of the tallest mountains of the world he called "The Biggest Change". To save them, Major Monogram instructed their friends to go on a mission of finding the brothers. Isabella in Mt. Everest, Baljeet in Mt. McKinley and Buford in Ben Nevis carried a 1 L balloon with air at 1 atm and 27^oC. Where could Phineas and Ferb be?



Fig. 2. Counteracting Forces.

Furthermore, cooperative learning played a very important role in solving the problem tasks. The word problems required students to work in small groups within a given time period determined by the subject teacher based on the capability and academic load of students as well as availability of resources for research. As such, the word problems supported the learner in developing ownership for the overall completion of the task. A total of thirty five (35) word problems on chemistry gas concepts were constructed.

TABLE 1 Word problem titles and their corresponding topic about gases

Tasks	Gas Concepts
The Gratitude of Bartholomew "Bart" Simpson	Air Pressure, Barometer
Perry the Platypus' Travel to the Philippines	
Donald Duck and the Balloon	Boyle's Law
The Fall of Plankton	
Help Bart Buy New Shoes	
Counteracting Forces	
The Lobster Lifeguard	
Plankton's Secret Formula	
"We Want To Live!"	
Squeeze It Up Phineas and Ferb!	Charles's Law
Bart Simpsons' Chem Quiz	
Dr. Doofenshmirtz <i>Expandi-Benzinator</i>	
Charizard's Ball	
Party Balloons	Gay-Lussac's Law
Gary Snail's 300	
Professor Oak's New Pokedex	Combined Gas Law
Mickey and Minnie Moonlighting	
Patrick Star's Journalism Career	Diffusion of Gases
Charizard's Explosion!	Henry's Law
Flat Tasting Cola	
Very Pleasing Gary Oak	Mixture of Gases
Team Rocket: Jessie and James	
Sandy Cheeks to Alaska	Molar Volume
Mr. Krab's New Business	Real Gas vs. Ideal Gas

TABLE 1 Word problem titles and their corresponding topic about gases (continued)

Tasks	Gas Concepts
Daisy's Balloon	
Dr. Doofenshmirtz's <i>Nitroglycinator</i>	
"Agent P!"	
Plankton Returns	Stoichiometry of Reacting Gases
Candace Driving Lessons	
Squidward Tentacles and the Pressurized Cash Vault	
Pokemon's Breathing System	
The Hindenburg Mystery	Properties of Gases
Diet of Pikachu	
Patrick Star's Good Buy?	Ideal Gas Law
Bart Bags	

Evaluation

The word problems were evaluated for validity in terms of content and structure prior to the first try-out by seven (7) high school teachers using a five-point Likert type scale. The questionnaire includes seven (7) criteria to describe the content of the word problems in terms of coverage, application to real life situation, and creation of interest and enthusiasm. Five (5) criteria were used to describe the structure of the word problems in terms of illustrations and words used. Appropriate revisions were made before the final try-out of the word problems was conducted involving three (3) classes of fourth year students. The total number of students involved in the final evaluation is eighty six (86). Table 2 shows the matrix used to interpret the mean scores. Table 3 presents the summary of the experts' and students' responses.

TABLE 2 Verbal interpretation of the mean scores

Verbal Interpretation	Letter Symbol	Mean Range
Outstanding	O	4.21 – 5.00
Very satisfactory	VS	3.41 – 4.20
Satisfactory	S	2.61 – 3.40
Poor	P	1.81 – 2.60
Needs Improvement	NI	1.00 – 1.80

TABLE 3 Evaluation of Experts (First Try-Out) and Students (Final Try-Out)

Criteria	Experts		Students	
	Mean	Verbal Interpretation	Mean	Verbal Interpretation
A. Content				
Problem tasks:				
1. are based on lessons about gases in the General Chemistry lecture course syllabus.	4.71	Outstanding	4.55	Outstanding
2. advance the development of higher cognitive skills.	4.43	Outstanding	4.35	Outstanding
3. arouse curiosity and enthusiasm.	4.29	Outstanding	4.30	Outstanding
4. develop interest towards Chemistry.	4.29	Outstanding	4.24	Outstanding
5. enable application of Chemistry gas concepts to real life situations.	4.86	Outstanding	4.36	Outstanding
6. integrates concepts and information from other subjects.	3.43	Very Satisfactory	4.15	Very Satisfactory
7. are self contained with sufficient information to understand each task.	3.86	Very Satisfactory	4.07	Very Satisfactory
Total Mean	4.27	Outstanding	4.29	Outstanding
B. Structure				
Problem tasks:				
1. show real world application of Chemistry gas concepts.	4.86	Outstanding	4.36	Outstanding
2. have illustrations that help visualize the problem.	4.57	Outstanding	4.42	Outstanding
3. have illustrations that are clear and appealing.	4.14	Outstanding	4.33	Outstanding
4. have a friendly tone.	4.57	Outstanding	4.49	Outstanding
5. have words that are within the level of comprehension of students.	4.14	Outstanding	4.41	Outstanding
Total Mean	4.46	Outstanding	4.40	Outstanding

The mean score for content as perceived by the experts and students were 4.27 and 4.29 respectively, which correspond to **Outstanding**. Also, both groups gave comparable scores to the problem tasks in terms of: (a) advancing development of higher cognitive skills, (b) arousing curiosity and enthusiasm, (c) developing interest towards Chemistry and (d) enabling application of chemistry concepts to real life situations. The integration of concepts with other subjects and sufficiency of information contained in each task were rated **Very Satisfactory**.

In terms of structure, the word problems were given total mean scores (4.46 for experts and 4.40 for students) corresponding to **Outstanding**. The word problems showed real world application of Chemistry gas concepts and had clear and appealing illustrations that helped students visualize the problem. The word problems had a friendly tone and the words were

within the level of comprehension of the students. Though the word problems were presented using a cartoon storyline, *real life situations* were included in each word problem. *Real life situations* pertain to existing geographic locations, relevant activities of man, and factual records in history.

The Cronbach's Coefficient Alpha was computed to be 0.870, an indication of a good reliability, which is higher than 0.700 which is the base for good reliability (Cronbach 1951).

The researchers also observed that the students showed enjoyment while working on the word problems. The students found the tasks challenging, engaging and worth answering. Their comments showed their appreciation to the strategy. Also, they expressed their delight upon seeing pictures of their teacher attached to each word problem.

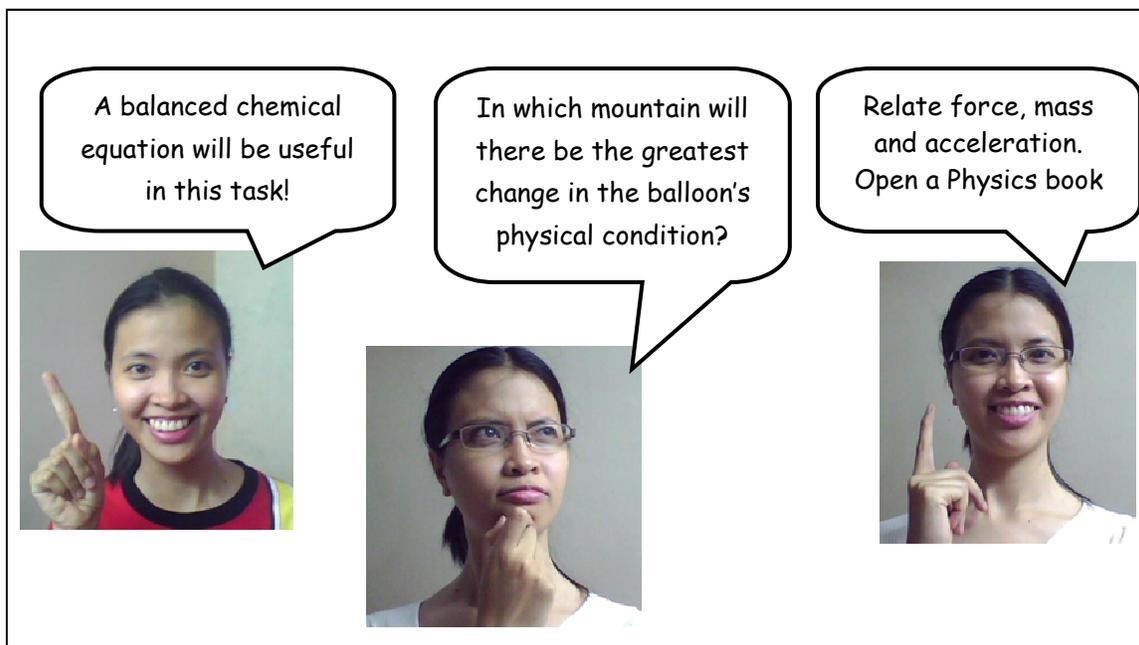


Fig. 4. Sample word problem with picture of teacher.

Words and phrases in the problem tasks which students identified as unclear like *contenders*, *detonation*, *shrouds*, *inert* and *havoc* were changed to *competitors*, *explosion*, *veils*, *unreactive* and *disorder*, respectively. However, names of compounds, science terms and personalities like Florentine, Torricelli, gelatin-latex, absolute temperature scale, benzene, nitroglycerin, sodium azide, hydrogen sulfide, potassium oxide, and Uranium-235 and Uranium-238 were not replaced since students are expected to research on the scientists as well as the concepts, properties and uses of the compounds.

The final revision of the word problems were done to change the words identified by the students as vague or ambiguous in the first try-out. Some sample problems that were revised are shown table 4.

TABLE 4 Comparison of some word problems in their original and revised form

Original Word Problem	Revised Word Problem
Donald Duck and the Balloon	
<p>Mickey Mouse read in the library Torricelli's work involving gases. After learning about Torricelli's work, he <i>took back the idea</i> of the mercury barometer to Donald Duck. To prove the theory of Torricelli and to steal the glory from Mickey, Donald Duck with the help of Daisy Duck carried a balloon up a side of a mountain. What do you think Donald Duck's hypothesis/es about Torricelli's theory when he did this experiment?</p>	<p>Mickey Mouse read in the library Torricelli's work involving gases. After learning about Torricelli's work, he <i>shared the idea</i> of the mercury barometer to Donald Duck. To prove the theory of Torricelli and to steal the glory from Mickey, Donald Duck with the help of Daisy Duck carried a balloon up a side of a mountain. What do you think Donald Duck's hypothesis/es about Torricelli's theory when he did this experiment?</p>
The Hindenburg Mystery	
<p>The <i>Hindenburg</i> was built with an 813-foot long aluminum frame filled with 7,200,000 cubic feet of hydrogen contained in 16 bags made of two layers of woven fabric with a <i>gelatin-latex</i> plastic <i>film</i> cemented between. The <i>silver appearance</i> of the Hindenburg was due to a surface varnish of powdered aluminum in a paint formula. Two <i>30-kilowatt diesel-powered generators</i> carried the regular loads and a stand-by unit could deliver additional electric power if needed.</p>	<p>The <i>Hindenburg</i> was built with an 813-foot long aluminum frame filled with 7,200,000 cubic feet of hydrogen contained in 16 bags made of two layers of woven fabric with a <i>gelatin-latex</i> plastic <i>film</i> cemented between. The <i>silver color</i> of the Hindenburg was due to a surface varnish of powdered aluminum in a paint formula. Two <i>30-kilowatt diesel-powered generators</i> carried the regular loads and a stand-by unit could deliver additional electric power if needed.</p>
<p><i>Donald Duck aboard</i> Hindenburg reported motor silence before a light, dull explosion from above, no louder than the sound of a beer bottle being opened was heard. The next thing is that the ship was <i>afame</i>. Hindenburg had a capacity for 50 passengers in individual cabins or for 70 passengers on day flights. On the evening it burned, the Hindenburg carried 97 persons.</p>	<p><i>Donald Duck on the</i> Hindenburg reported motor silence before a light, dull explosion from above, no louder than the sound of a beer bottle being opened was heard. The next thing is that the ship was <i>on fire</i>. Hindenburg had a capacity for 50 passengers in individual cabins or for 70 passengers on day flights. On the evening it burned, the Hindenburg carried 97 persons.</p>

TABLE 4 Comparison of some word problems in their original and revised form (continued)

Original Word Problem	Revised Word Problem
<p>Although the Hindenburg was designed to use unreactive helium as the lifting gas, U.S. military authorities prevented exportation of helium to Germany. Hydrogen is about fifteen-times lighter than air. <i>Flames traveled upward</i>. What fell to the passengers on the ground were burning veils from the exterior fabric, a large inventory of diesel fuel, and combustible materials that were in the cabins. What would have caused the Hindenburg disaster?</p> <p>Dr. Doofenshmirtz's Nitroglycerinator</p> <p>Dr. Doofenshmirtz managed to steal 1.0 g of nitroglycerin from a secured laboratory. What volume of gas will be produced if Dr. Doofenshmirtz <i>detonates</i> 1.0 g nitroglycerin at 150 kPa at 100°C? Does Agent P have to worry about the safety of Tri-State Area?</p>	<p>Although the Hindenburg was designed to use unreactive helium as the lifting gas, U.S. military authorities prevented exportation of helium to Germany. Hydrogen is about fifteen-times lighter than air. <i>Flames moved upward</i>. What fell to the passengers on the ground were burning veils from the exterior fabric, a large inventory of diesel fuel, and combustible materials that were in the cabins. What would have caused the Hindenburg disaster?</p> <p>Dr. Doofenshmirtz managed to steal 1.0 g of nitroglycerin from a secured laboratory. What volume of gas will be produced if Dr. Doofenshmirtz <i>explodes</i> 1.0 g nitroglycerin at 150 kPa at 100°C? Does Agent P have to worry about the safety of Tri-State Area?</p>

Readability statistics show scores to indicate how easily an adult can read and understand a text. Readability statistics are therefore good predictors of the level of difficulty particularly in technical documents. They present different readability scores that are computed using readability formulas. The readability of the word problems was determined using Flesch-Kincaid Grade level, Flesch Reading Ease and Passive Sentence. Microsoft Office Word was used to facilitate the readability scoring of the instrument.

TABLE 5 Readability scores of the word problems

Count		Average		Readability	
Words	3229	Sentences per paragraph	3.2	Passive Sentences	11%
Characters	15433	Words per sentence	11.9	Flesch Reading Ease	62.7
Paragraphs	121	Characters per word	4.5	Flesch-Kincaid Grade Level	7.4
Sentences	253				

The word problems have a readability ease of 62.7, comparable to the readability ease of Reader's Digest, which is 65 (Flesch n.d). The Flesch-Kincaid Grade level of 7.4 indicates that the material is at the reading level of students in high school. Passive sentence score expressed in percent shows the ratio of passive sentence over active sentence. The low percentage, 11%, of passive sentence in the present material is also a good indicator of readability.

The revised word problems were given to two (2) college chemistry professors for final evaluation. The summary of their evaluations are shown in table 6.

TABLE 6 Evaluation of Experts (Second and Final Try-Out)

Criteria	Mean	Verbal Interpretation
A. Content		
Problem tasks:		
1. are based on gas lessons in General Chemistry lecture course syllabus.	4.0	Outstanding
2. advance the development of higher cognitive skills.	4.5	Outstanding
3. arouse curiosity and enthusiasm.	4.5	Outstanding
4. develop interest towards Chemistry.	4.0	Very Satisfactory
5. enable application of Chemistry gas concepts to real life situations.	4.0	Very Satisfactory
6. integrate concepts and information from other subjects.	3.0	Satisfactory
7. are self contained with sufficient information to understand each task.	3.5	Very Satisfactory
Total Mean	3.9	Very Satisfactory
B. Structure		
Problem tasks:		
1. show real world application of Chemistry gas concepts.	3.5	Very Satisfactory
2. have illustrations that help visualize the problem.	3	Satisfactory
3. have illustrations that are clear and appealing.	3	Satisfactory
4. have a friendly tone.	4.5	Outstanding
5. have words that are within the level of comprehension.	4.5	Outstanding
Total Mean	3.7	Very Satisfactory

The second set of experts found the problem tasks to be **Outstanding** in terms of its congruence to the General Chemistry course syllabus, ability to develop higher cognitive skills and to arouse curiosity and enthusiasm. They regarded the problem tasks ability to develop interest towards chemistry, to enable application of chemistry concepts to real life situations and its sufficiency in the information contained in each task **Very Satisfactory**. Moreover, the integration of concepts and information from other subject areas were considered **Satisfactory**.

The word problems were considered **Very Satisfactory** for the application of chemistry concepts in real world situation in the word problems. The appeal, clarity and usefulness of the illustrations were seen as **Satisfactory**. The friendly tone and comprehension level were **Outstanding** according to experts.

The over-all rating of the second set of experts on the content and structure of the word problems were both **Very Satisfactory** with total mean scores, 3.9 and 3.7 respectively.

Conclusions and Implications

The word problems developed integrating various cartoon characters may be considered valid and reliable based on the evaluation of experts and try-outs to the students. They are perceived by the third year high school students as readable and appropriate for their reading level.

Illustrations and storylines about familiar cartoon characters made the word problems more appealing to students. This approach in word problem construction generated enthusiasm and enjoyment among the students while solving the problem tasks. The illustrations helped the students visualize the problems.

The process of development and validation used in the study may also be used to design and construct word problems in other topics in Chemistry and in other subject areas like Physics. The developed and validated material may be used in future studies concerning learning strategies.

In light of the findings of this study, problem-based learning materials which include the word problems described together with the rubric in assessing students' performance in each task and a teacher's manual should be developed.

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