Journal of the Serbian Chemical Society
JSCS-info@shd.org.rs • www.shd.org.rs/JSCS
J. Serb. Chem. Soc. 85 (4) S194–S201 (2020)
Supplementary material

SUPPLEMENTARY MATERIAL TO

Effects of a 5Es learning model on the conceptual understanding and science process skills of pre-service science teachers: The case of gases and gas laws

FETHIYE KARSLI BAYDERE[1], ALIPAŞA AYAS[2] and MUAMMER ÇALIK[3]*

[1]Giresun University, Faculty of Education, Department of Science Education, Giresun, Turkey, E-mail: fethiyekarsli28@gmail.com, [2]Bilkent University, Graduate School of Education, Ankara, Turkey, E-mail: alipasaayas@yahoo.com and [3]Trabzon University, Fatih Faculty of Education, Department of Elementary Teacher Education, 61335 Trabzon, Turkey

J. Serb. Chem. Soc. 85 (4) (2020) 559–573

DETAILED TABLES, SAMPLE TEACHING DESIGNS AND QUESTIONS

TABLE S-I. Students' alternative conceptions of the "gases and gas laws" subject

Alternative conceptions	Studies
1. While gas molecules are combining, denser gas or gas with more molecules presses the other gas molecules and throws them out.	9
2. When some oxygen gas molecules are released from an oxygen gas container, the oxygen molecules in the container move to the top of the container.	
3. If oxygen and nitrogen gases fill a container, the oxygen gas descends, and the nitrogen gas ascends. I do not think the gases will mix with each other.	
4. Gas molecules at the edges of a flask are more compressed.	7, 10
5. Gases cannot be compressed. They move to the top of the container in the form of droplets.	
6. Heating rises gas molecules in a container up and shrinks them.	
7. A hot air balloon condenses and becomes heavier in hot environments. This is why it swells.	
8. Cold environment condenses air molecules and so, the balloon swells more. Hot environment shrinks the balloon.	
9. Cold environment increases the volume of the balloon and decreases its pressure.	
10. Although students know '*PV=nRT*' formula, they do not articulate its meaning. Additionally, they often cannot use it appropriately.	2, 5, 7, 8, 10, 11, 12
11. Students possess pitfalls in understanding relationships amongst pressure, temperature, volume, and mole.	
12. Gas molecules expand and flow upward when heated.	
13. If gas molecules use up their energies, they stop moving.	
14. Gas molecules in a container are scattered.	

* Corresponding author. E-mail: muammer38@hotmail.com

15. An increase in the temperature does not change the volume of gas.	
16. Changes in pressure and volume affect the temperature of a compressed gas.	2, 11

TABLE S-II. The criteria, scores and descriptions of the gas laws questionnaire

The First-Tier of the item			The Second-Tier of the item		
Criteria	Score	Description	Criteria	Score	Description
Correct Option	4	Marks the correct response among options	Sound understanding	8	Includes all components of the validated response.
Incorrect Option	1	Marks a distracter among options	Partial understanding	6	Includes at least a component of the validated response, but not all components.
Blank	0	No option	Partial understanding with alternative conception	2	Includes a component of the validated response and specific alternative conception(s).
			No understanding	0	Repeats question; irrelevant or unclear response; blank.

TABLE S-III. A sample rubric for analyzing the questions 'identifying variables and formulating hypotheses'

Category	Description		Score
Identifying variables	Depicting at least five variables within the experiment.		3
	Depicting three or four variables within the experiment.		2
	Depicting only one or two variables within the experiment.		1
	Irrelevant variable(s) and/or leaving blank		0
Formulating hypotheses	Writing a meaningful sentence for the effect of the independent variable on the dependent variable.		2
	Writing a purpose or question sentence for the effect of the independent variable on the dependent variable.		1
	Writing an irrelevant sentence and/or an overly general statement or leaving blank		0
Dependent variable	Defining correctly a dependent variable.	If hypothesis is incorrectly formulated, these parameters are scored with zero point.	1
	Defining incorrectly a dependent variable or leaving blank.		0
Independent variable	Defining correctly an independent variable.		1
	Defining incorrectly an independent variable or leaving blank.		0
Controlled variable	Defining at least two controlled variables, except for dependent and independent variables.		2
	Defining only one controlled variable.		1
	Defining dependent and /or independent variable(s) instead of controlled one(s) or non-descriptive variables or leaving blank.		0

TABLE S-IV. Percentages of the pre-service science teachers' alternative conceptions of "gases and gas laws" subject in the pre- and post-gas laws test

Guide material(s) handling the alternative conceptions within the 5Es learning model	Targeted conceptions	Alternative Conceptions*	Control Group			Experimental Group		
			PrT	PoT	CC	PrT	PoT	CC
The worksheets, analogy and experimental activities	The relationship between the temperature and pressure of a fixed quantity of gas (Gay–Lussac Gas Law)	1. When a gas-filled piston injector is firstly submerged into ice water and then hot water, respectively, its pressure firstly decreases and then increases.	48	32	+8	40	13	+27
The computer animations and experimental activities	The relationship between the temperature and pressure of a fixed quantity of gas (Gay–Lussac Gas Law)	2. An increase in the pressure of gas into an injector decreases the pressure of the balloon, which is placed into the injector.	–	–	–	17	–	+17
The computer animations and experimental activities		3. If the volume of the gas increases, its pressure increases as well.	–	–	–	17	–	+17
The computer animations	The relationship between the volume and pressure of a fixed quantity of gas (Boyle Gas Law)	4. Filling a liquid into a closed container causes a decrease in a gas pressure.	4	4	–	4	–	+4
The analogy and experimental activities	The relationship between the temperature and volume of a fixed quantity of gas (Charles Gas Law)	5. An increase in the temperature boosts the volumes of gas molecules.	8	–	+8	4	–	+4
The analogy and experimental activities		6. Dipping an injector-filled gas into ice water will shrink the gas molecules.	8	–	+8	–	–	–
The worksheets and computer animations	The relationship between the temperature and pressure of a fixed quantity of gas (Gay–Lussac Gas Law)	7. Gas molecules in a closed container will concentrate at its upper side when heated.	32	28	+4	17	–	+17
The computer animations	Gas behavior (Kinetic Theory)	8. As gas molecules are cooled, their energy decreases and they stop moving.	12	8	+4	–	–	–
The computer animations	Gas behavior (Kinetic Theory)	9. Gas molecules in a container will concentrate at its upper side when heated because their density decreases.	4	8	–4	–	–	–
The computer animations and the experimental activities	Gas behavior (Kinetic Theory)	10. An increase in temperature decreases kinetic energy of gas molecules.	4	–	+4	–	–	–
The analogy and experimental activities	The relationship between the temperature and volume of a fixed quantity of gas (Charles Gas Law)	11. A decrease in air temperature will decrease size of gas molecules in a balloon, so the balloon shrinks.	4	–	+4	–	–	–

PrT: Pre-test; PoT: Post-test; CC: Conceptual change. The (+) sign represents positive conceptual change in students while the (–) sign represents negative conceptual change. *: Alternative conceptions 1, 4, 6 and 10, unlike related literature, have firstly been identified in the pre-test

TABLE S-V. Descriptive statistics of the performances of the pre-service science teachers on the gas laws test and science process skills test

Groups	Descriptive Parameters	Pre-test		Post-test	
		Gas Laws Test	Science Process Skills Test	Gas Laws Test	Science Process Skills Test
Experi-mental group	Mean	27.54	68.84	59.54	130.84
	Standard deviation	11.34	11.66	7.37	12.75
	Minimum score	8.00	45.00	43.00	92.00
	Maximum score	47.00	91.00	70.00	145.00
Control group	Mean	24.60	66.32	42.68	88.76
	Standard deviation	10.71	14.91	13.83	18.99
	Minimum score	5.00	44.00	9.00	51.00
	Maximum score	50.00	95.00	64.00	129.00

APPENDIX 1. A sample part of the worksheets

1. Given the tools/materials, please design an experiment about how the volumes of a fixed quantity of the gases change in hot and cold environments.

Tools/Materials:
Thermometer. Tripod, Large size syringe, Packing tire, Beaker, Asbestos wire
....
....
....

2. Please, carefully follow the guidelines in designing the experiment.

Please, write down your hypothesis/hypotheses of the experiment.

Hypothesis 1:

Hypothesis 2:

Hypothesis 3:

Please depict your variables of the experiment

All variables affecting your experiment:

Dependent variable:

Independent variable:

Controlled variable(s):

3. After measuring any change in the volume of a fixed quantity of gas in the injector with a change in the temperature, please create your data chart.

Chart 1:..

4. Please, draw your graph on the relationship between the temperature and volume of a fixed quantity of gas using your data chart.

Graph 1:..

5. What happened to the gas molecules in the injector with increasing temperature? How did the injector level change? Please defend your response

....

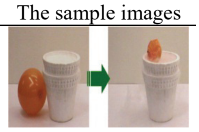
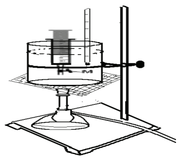
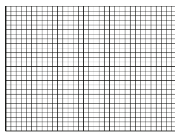
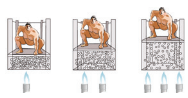
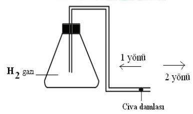
6. If you were able to see the gas molecules in the injector, how could you imagine the gas molecules with increased and decreased temperatures?

....

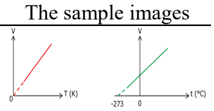
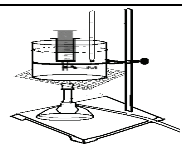
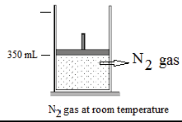
7. Please, mathematically explain the relationship between the temperature and volume of a fixed quantity of gas at a constant pressure.

....

APPENDIX 2. A sample teaching design for the experimental group

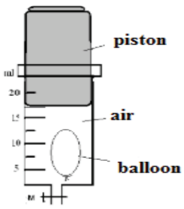
Phase	Pre-Service Teacher's role	Lecturer's role	The sample images
Engage	Asked them to carefully watch the computer animations and respond provocative questions. Thus, this phase purposed to enhance their awareness of "Gas Laws" concept throughout their pre-existing ideas.	Passed the worksheets over to the PSTs. Then, she requested them to follow guidelines in the worksheet (*e.g.*, the computer animations and provocative questions). Sample provocative questions are as follows: if an inflated balloon is placed into a liquid nitrogen-filled container, what happens to the balloon? How does the volume of the hot air balloon change with increasing altitude? Hence, an interactive discussion environment was created.	
Explore	Called them for discovering the Charles law of gases in their small groups of 3–4. Thereby, they used such Science Process Skills (SPS) such as *observing, measuring, identifying variables, formulating hypotheses, doing experiments, interpreting data and defining operationally*. In addition, they wrote their observations/measurements down on the worksheet.	Requested them to carry out relevant experiment concerning the Charles law of Gases. She called the PSTs to create and present their own data tables to the whole class. She asked such inquiry-based questions: What happens to the gas particles over an increase in the temperature? Please draw your own graph. How does an increase in the temperature influence the pressure and volume of a fixed quantity of gas? Is there any mathematical equation to address these relationships? Please defend your response given your data.	 
Explain	Required to present their arguments. Hence, they were able to decide whether their arguments were consistent with the scientific one.	Encouraged them to present their arguments. Then, she summarized and compared them with the scientific one. Additionally, she used the analogy to advocate their newly generated knowledge into long-term memory.	
Elaborate	Asked them to examine the computer animations and discuss its daily life relationship(s) in their small groups. Hence, they were able to transfer their newly structured knowledge into daily life questions.	Called them for watching the computer animations. She aroused a group discussion to handle its daily life relationship(s).	 
Evaluate	Applied their newly generated abilities and knowledge/ideas to novel cases.	Asked them to solve related problems *via* their newly generated knowledge.	

APPENDIX 3. A sample teaching design for the control group

Phase	Pre-Service Teacher's role	Lecturer's role	The sample images
Theoretical knowledge	Asked them to carefully listen to the lecturer's explanations and respond to her questions. Thus, this phase purposed to provide fundamental knowledge of the subject and to attract their attention to the topic.	Probed some questions (*i.e.* How does an increase in the temperature influence the volume of a fixed quantity of gas?) and explain the effect of temperature on the volume of a fixed quantity of gas (Charles' Law of Gases).	
Experiment	Called them for proving the effect of the temperature on the volume of a fixed quantity of gas in their small groups of 3–4. They confirmed the knowledge with experiments.	Requested them to prove the effect of temperature on the volume of a fixed quantity of gas. She asked such inquiry-based questions: Is there any mathematical equation to address a temperature–volume relationship of a fixed quantity of gas?	
Evaluate	Required them to answer the related questions using their knowledge.	Asked them to solve related problems (*i.e.* At room temperature, there is 350 mL of gas in a free-piston injector. If the gas is heated to 600 Kelvin at a constant pressure, please calculate the volume of the gas).	

APPENDIX 4. A sample question for the gas laws test

Question 6.



In this figure, a moderately swollen child's balloon has been placed within a free-piston injector that contains a little air and a closed end. Accordingly, which of the following statements are true?

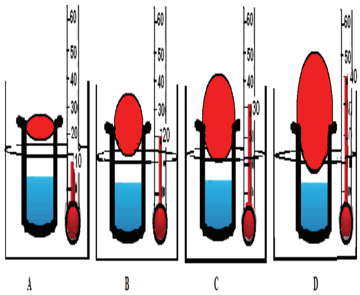
If the injector is kept within a hot-water-filled-container, the volume of air will increase, and the volume of the balloon will remain the same.
If the injector is placed within a liquid nitrogen-filled-container, the pressure of the air within the balloon will increase.
If the piston of the injector is hardly pushed, the temperature of the air within the balloon will increase.
If the piston of the injector is pulled upward, the pressure of the air within the balloon will increase.
If the injector is kept within a refrigerator for some time, the balloon will shrink.

Please write down your reason for selecting this option:

…………………………………………………………………………………………………

APPENDIX 5. Sample questions for the science process skills test

Question 19. A student blows some air into a child's balloon and then places it into water-filled beaker. Later, the experimental setup in figure is established. When the water temperature is at 10 °C, the diameter of the balloon is measured to be 5 cm. When the water temperature is at 20 °C, the diameter of the balloon is measured to be 7 cm. When the water temperature is at 30 °C, the diameter of the balloon is measured to be 10 cm. When the water temperature is at 40 °C, the diameter of the balloon is measured to be 12 cm. Given this experiment, please answer the following questions



What is the hypothesis of the experiment? Please write it down.

....

Which variable(s) are involved in the experiment? Please write down.

....

What is the dependent variable of the experiment? Please write it down.

....

What is the independent variable of the experiment? Please write it down.

....

What are the control variables of the experiment? Please write them down.

....

Question 28. Four identical beakers are half-filled with pure water, sea water, alcohol and milk, respectively. These beakers were heated with identical heaters for some time. Afterwards, it is observed that all beakers are empty. How do you interpret this observation? Please select one of the following inferences.

Alcohol evaporates earlier than other liquids.
The boiling point of pure water is lower than that of sea water.
All liquids evaporate when they are placed in open beakers.
The intensity of the heater does not affect the boiling points of the liquid.
Liquids need to be heated for evaporation at a certain time.