Evaluation of an intervention instructional program to facilitate understanding of basic particle concepts among students enrolled in several levels of study

David F. Treagust[a], A. L. Chandrasegaran[a], Ahmad N. M. Zain[b], Eng Tek Ong[c], Mageswary Karpudewan[d] and Lilia Halim[e]

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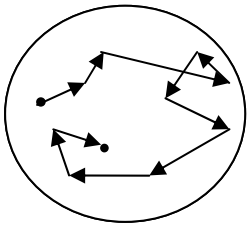
Supplementary materials

The Particle Theory Diagnostic Instrument

Item 1

The diagram represents the random zigzag movement of smoke particles (referred to as Brownian motion) when smoke in a glass container is viewed under a microscope.



random movement of smoke particles

What conclusion can you make from this observation?

A Smoke particles are floating in air.
B Air consists mainly of empty space.
C Air is made up of tiny particles moving randomly.
D Smoke particles are larger than air particles.

The reason for my choice of answer is:

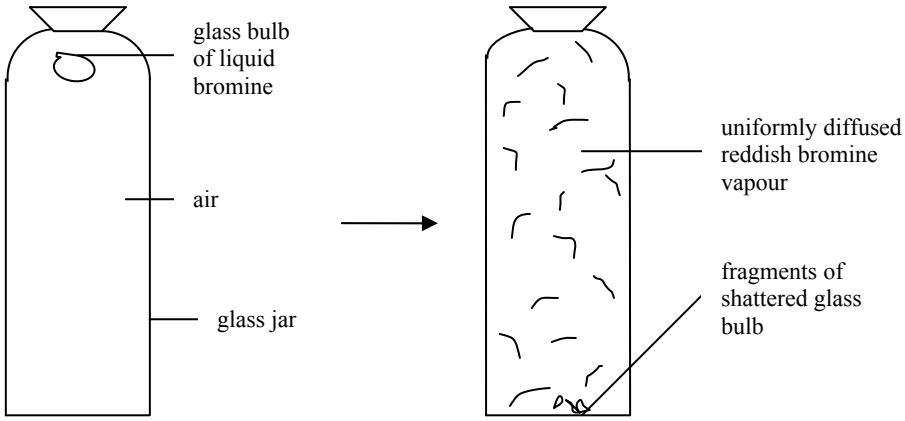
1 Smoke particles are large.
2 There are large spaces between the smoke particles.
3 Colliding smoke particles move in a random zigzag manner.
4 Air particles are constantly colliding with smoke particles.
5 *Other reason*:……

……..

Item 2

A small glass bulb containing liquid bromine was dropped into a tall jar of air and the jar was immediately stoppered. The bulb shattered on hitting the bottom of the jar, releasing bromine vapour. After several hours, reddish bromine vapour had diffused uniformly throughout the jar.

If the experiment is repeated after pumping out most of the air from the jar, we would expect the reddish bromine vapour to diffuse and fill the jar within a few seconds.



A True B False

The reason for my choice of answer is:

1 The heavier bromine molecules will sink to the bottom of the jar.
2 Fewer collisions occur between the bromine molecules in the absence of air particles.
3 Bromine molecules can now occupy the extra space that was previously taken up by the air particles.
4 Bromine molecules diffuse slowly in a random zigzag manner to fill the jar.
5 Bromine diffuses faster because fewer collisions occur between bromine and air particles.
6 *Other reason*:……

……..

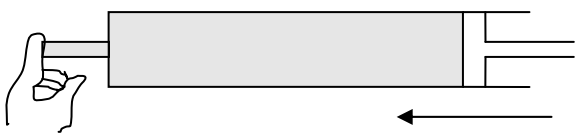
Item 3
When orange juice from a soft drink can is poured into a tall narrow glass, the volume of the liquid remains the same.

A True B False

The reason for my choice of answer is:

1 The particles are able to move about freely.
2 The particles are able to move within a fixed volume.
3 Some of the particles may have escaped as the liquid evaporated.
4 *Other reason*:……
……..

Item 4
The diagram shows a coloured gas being compressed in a gas syringe until the plunger could not be pushed any further.
The experiment was repeated using the same volume of a coloured liquid.



It was found that the final volume of the gas was

A much less than that of the liquid.
B much greater than that of the liquid.

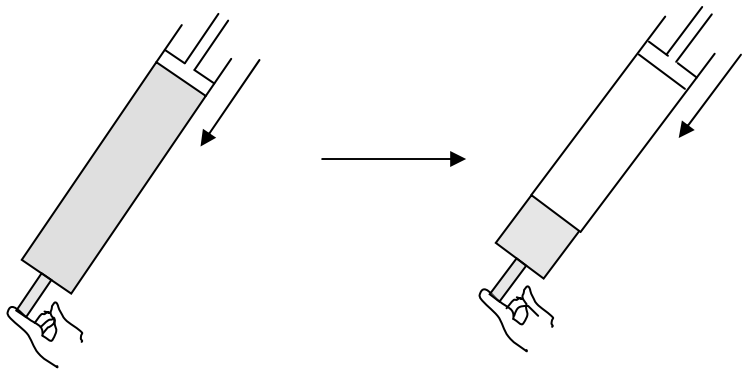
The reason for my choice of answer is:

1 The particles in the gas are more widely spaced.
2 The particles in the gas move more freely.
3 The particles in the gas move randomly in all directions.

4 *Other reason*:……

……..

Item 5
The diagram shows a syringe containing a fixed mass of a coloured gas that is compressed by pushing the plunger down.



We can conclude that

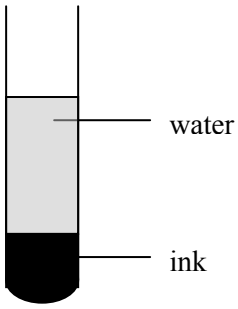
A the volume and mass of gas have decreased.
B the volume of gas has decreased while the mass has increased.
C the volume of gas has decreased while the mass remains constant.

The reason for my choice of answer is:

1 Gas particles can be readily compressed and pushed closer together.
2 The widely-spaced gas particles have been pushed closer together.
3 The number of gas particles has decreased.
4 *Other reason*:……

……..

Item 6
A small amount of blue ink was carefully placed at the bottom of a test-tube containing some water as shown in the diagram.



test-tube containing separate ink and water lavers

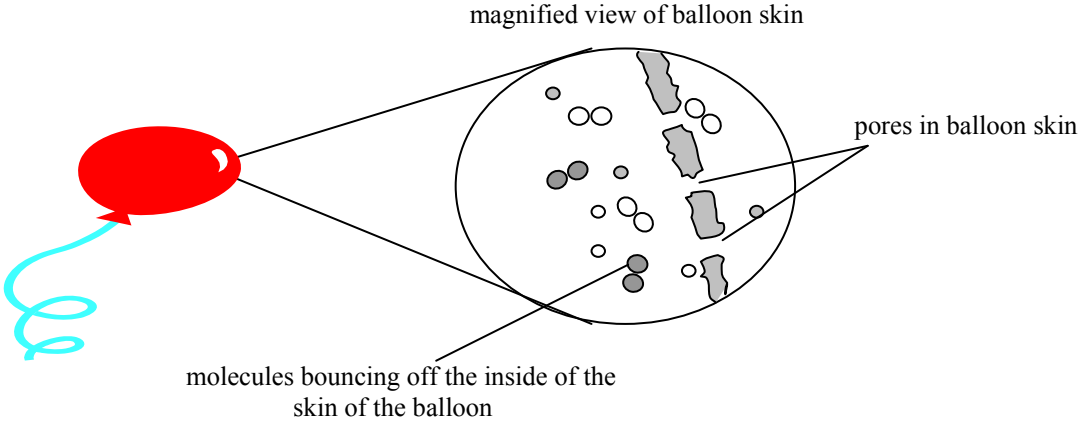
After several hours, the ink would have diffused throughout the water producing a uniformly blue solution.

A True B False

The reason for my choice of answer is:

1 Ink particles readily dissolve in water.
2 The heavier ink particles sink to the bottom of the test-tube.
3 The particles of ink are in constant random motion.
4 Ink and water particles do not mix.
5 *Other reason*:……
……..

Item 7
A balloon is inflated and tied at the neck to prevent it from deflating.
The diagram shows a magnified view of the skin of the balloon and the particles in the inflated balloon.



After several hours, the balloon would be found to remain the same size.
A True B False

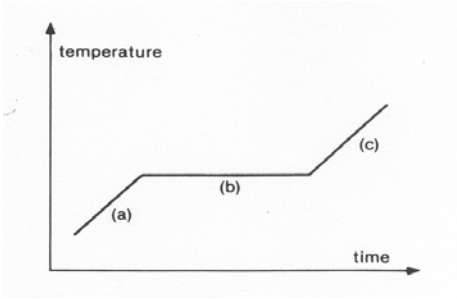
The reason for my choice of answer is:

1 Air molecules bounce off the skin of the balloon.
2 Air molecules diffuse through the skin of the balloon.
3 Air molecules are smaller than the holes in the balloon skin.
4 Air molecules from the outside enter the balloon through the pores.

5 *Other reason*:……

……..

Item 8
The diagram shows how the temperature changes when a solid like naphthalene is heated gently until it melts.
In which section of the curve is the heat energy that is absorbed not heating up the naphthalene?



A (a) B (b) C (c)

The reason for my choice of answer is:

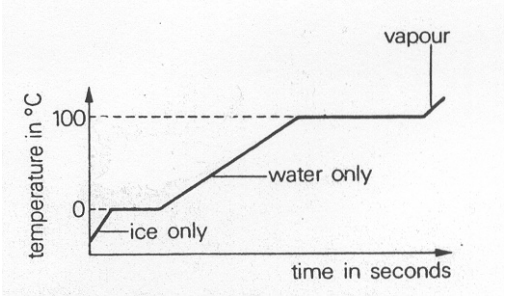
1 The energy absorbed is used to break the bonds in the naphthalene molecules.
2 The heat energy absorbed is used to weaken the intermolecular forces.
3 Heat energy is absorbed to increase the kinetic energy of the molecules.

4 *Other reason*:……

……..

Item 9

The diagram shows how the temperature changes when some ice at a temperature below 0^oC is heated to above 100^oC.



We may deduce that that liquid water cannot exist at its boiling point of 100^oC.

A True B False

The reason for my choice of answer is:

1 It takes time for the water to boil and change the molecules completely into steam.
2 The molecules do not have sufficient energy to change completely into steam.
3 The attractive forces between all the water molecules have to be weakened.

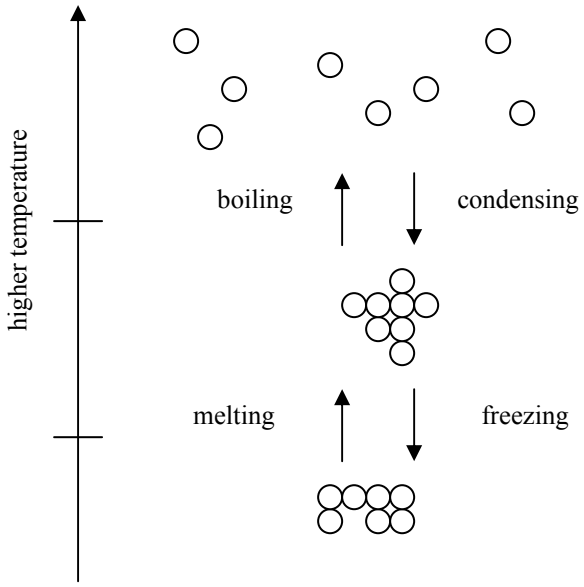
4 *Other reason*:……
……..

Item 10

The diagram shows the arrangement of particles in different states of matter.

In which of the changes of state will heat energy be absorbed?

A solid → liquid → gas
B gas → liquid → solid



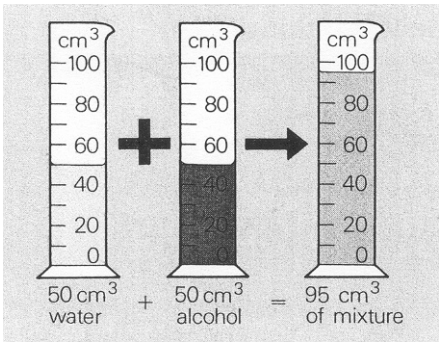
The reason for my choice of answer is:

1 The H_2O molecules are moved further away from each other.
2 The bonds in the H_2O molecules are broken.
3 The attractive forces between the H_2O molecules are weakened.

4 *Other reason*:……

……..

Item 11
The diagram shows that the total volume of liquid decreases when water and alcohol are mixed together.



We can conclude that some of the alcohol has evaporated.

A True B False

The reason for my choice of answer is:

1 The molecules of the two liquids occupy the spaces between each other.
2 The alcohol molecules have dissolved in water.
3 Some alcohol has evaporated as a result of collisions between the molecules.
4 Molecules of the two liquids have mixed together.

5 *Other reason*:……

……..

Table 2 Percentage of correct pre-test-post-test responses to the first tier and combined tiers of items in the *PTDI* (N = 190)

Item no.	Samples	Pre-test		Post-test	
		First tier	Combined tiers	First tier	Combined tiers
1	Form 4 (N = 31)	90.3	29.0	100	67.7
	Form 5 (N = 30)	90.0	16.7	100	66.7
	Form 6 (N = 30)	96.7	33.3	100	60.0
	B.Ed. primary science (N = 54)	100	24.1	96.3	53.7
	B.Ed. biology major (N = 35)	100	8.6	100	60
	M.Ed. (N = 10)	90.0	30.0	80.0	40.0
	Combined sample	**95.8**	**22.6**	**97.9**	**59.5**
2	Form 4 (N = 31)	80.6	48.4	100	54.8
	Form 5 (N = 30)	80.0	20.0	93.3	50.0
	Form 6 (N = 30)	80.0	16.7	83.3	73.3
	B.Ed. primary science (N = 54)	66.6	3.7	72.2	38.9
	B.Ed. biology major (N = 35)	74.3	17.1	94.3	91.4
	M.Ed. (N = 10)	70.0	20.0	100	30.0
	Combined sample	**74.7**	**18.9**	**87.4**	**57.9**
3	Form 4 (N = 31)	83.9	64.5	87.1	87.1
	Form 5 (N = 30)	76.7	60.0	96.7	73.3
	Form 6 (N = 30)	73.3	46.7	100	90.0
	B.Ed. primary science (N = 54)	96.3	88.9	83.3	81.5
	B.Ed. biology major (N = 35)	77.1	74.3	100	100
	M.Ed. (N = 10)	90.0	40.0	90.0	90.0
	Combined sample	**83.7**	**68.4**	**92.1**	**86.3**
4	Form 4 (N = 31)	67.7	16.1	71.0	41.9
	Form 5 (N = 30)	60.0	36.7	83.3	66.7
	Form 6 (N = 30)	83.3	56.7	93.3	73.3
	B.Ed. primary science (N = 54)	94.4	51.9	98.1	90.7
	B.Ed. biology major (N = 35)	71.4	42.9	74.3	65.7
	M.Ed. (N = 10)	80.0	0	100	100
	Combined sample	**77.9**	**42.6**	**86.3**	**72.1**
5	Form 4 (N = 31)	83.9	12.9	90.3	48.4
	Form 5 (N = 30)	73.3	43.3	93.3	53.3
	Form 6 (N = 30)	96.7	43.3	96.7	70.0
	B.Ed. primary science (N = 54)	92.6	33.3	96.3	68.5
	B.Ed. biology major (N = 35)	82.9	51.4	97.1	68.6
	M.Ed. (N = 10)	100	40.0	100	50.0
	Combined sample	**87.4**	**36.8**	**95.3**	**62.1**
6	Form 4 (N = 31)	100	38.7	100	38.7
	Form 5 (N = 30)	93.3	60.0	96.7	80.9
	Form 6 (N = 30)	76.7	33.3	93.3	93.3
	B.Ed. primary science (N = 54)	83.3	27.8	87.0	46.3
	B.Ed. biology major (N = 35)	82.9	17.1	100	97.1
	M.Ed. (N = 10)	70.0	30.0	100	80.0
	Combined sample	**85.8**	**33.7**	**94.7**	**68.9**
7	Form 4 (N = 31)	96.8	35.5	100	83.9
	Form 5 (N = 30)	96.7	73.3	90.0	70.0
	Form 6 (N = 30)	96.7	53.3	100	96.7
	B.Ed. primary science (N = 54)	98.1	77.8	98.1	87.0
	B.Ed. biology major (N = 35)	100	77.1	100	85.7
	M.Ed. (N = 10)	100	70.0	100	60.0

	Combined sample	**97.9**	**65.8**	**97.9**	**83.7**
8	Form 4 (N = 31)	80.6	12.9	100	38.7
	Form 5 (N = 30)	86.7	6.7	100	43.3
	Form 6 (N = 30)	199	23.3	100	70.0
	B.Ed. primary science (N = 54)	98.1	16.7	100	66.7
	B.Ed. biology major (N = 35)	85.7	11.4	97.1	91.4
	M.Ed. (N = 10)	100	10.0	100	0
	Combined sample	**91.6**	**14.2**	**99.5**	**60.0**
9	Form 4 (N = 31)	45.2	3.2	90.3	35.5
	Form 5 (N = 30)	70.0	6.7	56.7	36.7
	Form 6 (N = 30)	66.7	0	73.3	43.3
	B.Ed. primary science (N = 54)	74.1	3.7	85.2	37.0
	B.Ed. biology major (N = 35)	74.3	11.4	100	85.7
	M.Ed. (N = 10)	60.0	20.0	90.0	0
	Combined sample	**66.8**	**5.8**	**82.1**	**44.7**
10	Form 4 (N = 31)	83.9	29.0	96.8	74.2
	Form 5 (N = 30)	96.7	23.3	96.7	56.7
	Form 6 (N = 30)	96.7	40.0	100	86.7
	B.Ed. primary science (N = 54)	92.6	27.8	100	70.4
	B.Ed. biology major (N = 35)	85.7	31.4	94.3	85.7
	M.Ed. (N = 10)	90.0	50.0	100	60.0
	Combined sample	**91.1**	**31.1**	**97.9**	**73.7**
11	Form 4 (N = 31)	74.2	64.5	77.4	83.9
	Form 5 (N = 30)	76.7	66.7	86.7	86.7
	Form 6 (N = 30)	70.0	43.3	93.3	86.7
	B.Ed. primary science (N = 54)	64.8	42.6	100	96.3
	B.Ed. biology major (N = 35)	51.4	45.7	100	91.4
	M.Ed. (N = 10)	60.0	60.0	90.0	90.0
	Combined sample	**68.3**	**51.6**	**92.6**	**90.0**

Table 3 Frequencies of pre-test-post-test responses to the combined tiers of Item 9 in the *PTDI*

(N = 190)

Pre-test		Post-test	
Responses	Percentage	Responses	Percentage
A1	15.3	A1	3.3
A2	1.6	A2	4.7
A3	14.2	A3	11.6
A4	2.0	A4	0.5
B1	47.9	B1	32.1
B2	11.6	B2	2.6
B3	**5.8**	**B3**	**44.7**
B4	1.6	B4	0.5
Total	100.0	Total	100.0

Table 7 Analysis of students who correctly answered all items in conceptual category 1 - intermolecular spacing in matter (Items 3, 4, 5 and 11)

Samples	N	No. of students with correct responses	Percentage of students with correct responses
Secondary school students (Form 4)	31	10	32.3
Secondary school students (Form 5)	30	11	36.7
Post-secondary school students (Form 6)	30	16	53.3
Undergraduates (B.Ed. primary science program)	54	29	53.7
Undergraduates (B.Ed. biology major program)	35	16	45.7
Postgraduates (M.Ed. program)	10	5	50.0
Combined sample	**190**	**87**	**45.8**

Table 8 Analysis of students who correctly answered all items in conceptual category 2 - the influence of intermolecular forces on changes of state (Items 8, 9 and 10)

Samples	N	No. of students with correct responses	Percentage of students with correct responses
Secondary school students (Form 4)	31	5	16.1
Secondary school students (Form 5)	30	3	10.0
Post-secondary school students (Form 6)	30	10	33.3
Undergraduates (B.Ed. primary science program)	54	14	25.9
Undergraduates (B.Ed. biology major program)	35	27	77.1
Postgraduates (M.Ed. program)	10	10	100
Combined sample	**190**	**59**	**31.1**

Table 9 Analysis of students who correctly answered all items in conceptual category 3 – diffusion in liquids and gases (Items 1, 2, 6 and 7)

Samples	N	No. of students with correct responses	Percentage of students with correct responses
Secondary school students (Form 4)	31	6	19.4
Secondary school students (Form 5)	30	6	20.0
Post-secondary school students (Form 6)	30	12	40.0
Undergraduates (B.Ed. primary science program)	54	6	11.1
Undergraduates (B.Ed. biology major program)	35	15	42.9
Postgraduates (M.Ed. program)	10	3	30.0
Combined sample	**190**	**48**	**25.3**