

CANDLE BURNING IN AN INVERTED JAR OVER WATER IN A TROUGH EXPERIMENT: SCIENCE TEACHERS' CONCEPTIONS

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Abstract. This experiment is commonly conducted in lower secondary classes to prove wrongly that air contains about 20% oxygen despite our knowledge that burning in a closed environment does not consume oxygen completely. The aim of this study was to evaluate (a) science teachers' conceptions associated with this experiment and (b) their confidence in the accuracy of their conceptions. Data were collected administering a multiple choice question test (MCQ) to, and by conducting interviews with, teachers. The MCQ test also asked them to record their confidence that their responses were correct. The teachers were shown to have many misconceptions about this experiment but they are highly confident that their conceptions are correct. For example, they reported that all oxygen in the jar is used up completely before the candle is put out. They also believed that water rose in the jar to take up empty space created by (a) used up oxygen or (b) dissolved carbon dioxide without considering molar ratio between oxygen and carbon dioxide during burning of carbon in oxygen (air) and the solubility rate of carbon dioxide in water. They are highly confident in these responses. It appears that conceptual knowledge stored in a teacher's brain is not properly connected, therefore they are unable to pool it together effectively to solve simple problems as described in this experiment. The study will also discuss some simple experiments that could help teachers to correct their misconceptions and improve the connectivity of concepts in their brains for effective teaching. Teachers in schools and teacher educators in teacher training institutions should target teaching for understanding. More research on how to make the teachers more flexible in thinking and in pooling their information to solve simple problems confidently and accurately is recommended.

Introduction

According to the Nobel Laureate, Rabindra Nath Tagore, teachers can never truly teach unless they are still learning as well. It has been reported from different countries that many high school students', adults', and teachers' conceptions of science concepts differ from the accepted measure (Dhindsa, 2000; Kesidou & Duit, 1993; Lewis & Linn 1994). More specifically, Bruneian studies also suggest that pre-service as well as school teachers have inadequate science content knowledge (Dhindsa, 2000; Tan, 1995; Yong 2000). The impact of this level of understanding of content knowledge of the prospective and working teachers on future students is a real concern.

Constructivist theory highlights (a) the role of prior conceptions and knowledge structures in the process of science learning (Anderson, 1992; Bodner, 1986; Novak, 1977) and (b) the role of active learning and plasticity of thinking in construction of knowledge through learners' mental and physical involvement (Ausubel, Novak and Hanesian, 1978; Bolton, 1977; Bruner, Goodnow and Austin, 1965; Mitchell and Lawson, 1988). Constructivist teaching is a process of helping students mobilize their prior understandings and reorganize them in the light of current experience. In practice, this may involve, among other approaches, small group discussions to foster contrasting ideas, encourage reflection on experimental data, and motivate a reevaluation of prior ideas in relation to emerging evidence. This is an active construction of new knowledge. It can be enhanced or hindered by the students' and teachers' conceptions and organization of extant knowledge structures. During information construction, the teachers help students to actively interpret new experiences based on stored information (Anderson, 1992). Therefore, in the process of encoding new information, previous knowledge structures will be: (a) partly supplemented or broadened (conceptual growth) or (b) rearranged and newly structured (conceptual change). In the process, the range of knowledge applications and the richness of network connections in memory and their linkages to sensory input are often enhanced (e.g., Duit, 1994). However, a major concern is if the teachers' conceptual knowledge is not acceptable (wrong) and teachers are confident in it as acceptable (correct).

Research in the area of students' confidence in their knowledge revealed that the students' confidence in their responses to the content questions varies greatly (Lundeberg, Fox & Puncochair, 1994, Monaliza, 2001). These

studies support that students' prior knowledge could also be classified into two categories based on what students know with and without confidence. Using these two modes of classification of students' prior knowledge, four categories of knowledge could be obtained. Category 1: students perceive the knowledge as scientifically acceptable (correct) and it is acceptable, category 2: students perceive the knowledge as scientifically unacceptable (incorrect) but it is acceptable, category 3: students perceive the knowledge as scientifically acceptable but it is unacceptable and category 4: students perceive the knowledge as scientifically unacceptable and it is unacceptable. Shimomura, Oda and Senda (1982) analyzed students' prior knowledge and confidence in it using mathematics content and interpreted category 1 as reliable understanding, category 2 as unreliable understanding, category 3 as misunderstanding and category 4 as no understanding. This classification is also applicable to teachers' knowledge. The interactions between 4 types of knowledge from teachers and from students could be chaotic. The category 4 is very limited and generally is not involved in construction of knowledge. Teachers teach category 1 and 3 knowledge confidently, and their students use prior knowledge representing categories 1 and 3 effectively for the construction of new knowledge. The category 1 favours construction of scientifically acceptable knowledge, whereas category 3 hinders the construction of scientifically acceptable knowledge and if it leads to misconceptions and confusions. Assuming that teachers knowledge is acceptable and teacher teaches it confidently, the learners might use category 2 prior knowledge to construct scientifically correct new knowledge without much confidence in its accuracy, whereas, they might use category 3 prior knowledge to construct scientifically incorrect knowledge, with a false confidence in its accuracy. However, the learners use category 1 more effectively than the category 2 during the construction of new knowledge because of confidence differences in the two categories. This argument is based on discussion reported by Dhindsa and Wimmer (2003).

Identification of the preconceptions, however, precedes correction. Although various methods, including objective type tests, interviews, and flow maps for identifying students' preconceptions have been proposed, all these methods have limitations (Anderson & Demetrius, 1993; Bar & Galili, 1994; Lee, Eichinger, Anderson, & Berkheimer, 1993; Wenzel & Roth, 1998). A major problem with objective types of tests and interviews in identifying preconceptions is that the questions in them direct the students' thinking towards the examiners' point of view. The others are time consuming and labour intensive, therefore, not efficient for collecting data from large samples. Recent developments show that the students' own statements, rather than expert guided statements, should be used to evaluate students' points of views (Aikenhead & Ryan, 1992). Schmidt (1991) used multiple-choice questions and asked the students to describe reason(s) for their decision. This method is still efficient and is a preferred way of collecting large quantities of data quickly, though its limitation is in language. Students with language deficiencies often cannot explain their logic in making a decision. Conceptual Understanding Mapping (Doig, 1995) and Structure of Observed Learning Outcome (SOLO) Taxonomy (Levins 1997) methods have been used to analyse students' preconceptions. However, in this study number of respondents is relatively not large and in-depth exploration of understanding was required, therefore multiple choice questions and interview data were used to triangulate the results.

Analysis of ERIC and other related data bases revealed a few studies on conceptions of primary and lower secondary students of combustion have been reported during the second half of the last century (BauJaoude, 1991; Meheut, Saltiel & Tiberghiem, 1985). These studies show that students believe that oxygen is finished by the candle burning in the jar and water rushes into the jar to take up empty space created as oxygen is consumed during burning. However, it appears that very little attention has been paid to teachers' conceptions of this concept. Moreover, much less is known about teachers' confidence in the correctness of their conceptions. Furthermore, most of the studies conducted in teachers understanding of the scientific concepts are centered on the theoretical concepts (Dhindsa, 2002; Yong 2000), however understanding practical application of theoretical knowledge also needs further attention. In this study, teachers' understanding of burning in a closed environment and their confidence in their conceptions to be correct were investigated using the candle burning in an inverted jar over water in a trough experiment.

Method

Sample

The subjects of this study were 60 science teachers teaching in Government schools in Brunei and 20 pre-service teachers studying in the final year of their degree program. All the teachers were trained. The majority of them have

an undergraduate degree, but some only have diploma qualifications. The number of females was about double of males. Their teaching experience at secondary schools varied from 3 to 10 years.

Instrument, and Procedure

The instrument used in this study consisted of 7 MCQ questions. The seventh question was linked to question 6. Depending upon the response to question 6, the respondent was asked to respond to 7a or 7 b. The question 7a was MCQ, whereas 7b required a written description of why did they choose the specific choice that is “water rises to equal level in all the three jars.” The description of questions is reported in the following paragraph below. Teachers’ confidence in their response scale was embedded in the MCQ test. The sample is demonstrated in Figure 1. Participation was voluntary. The instrument was given to teachers in their staffroom and to pre-service teachers in their classes.

Instrument	
Test item	Confidence item
Q5. What would you estimate about the time before the candle(s) in Figure 3 is/are goes out?	I'm certain I'm right. —
A. Candles in x, y and z will go out at the same time	I think I'm right —
B. Candle in x will be the last to go out	I think I'm wrong —
C. Candle in y will be the last to go out	I think I'm wrong —
D. Candle in z will be the last to go out	I'm certain I'm wrong —

Figure 1. Sample test item and embedded confidence scale.

Description of questions in the instrument

The MCQ test items were based on information in Figure 2 and Figure 3.

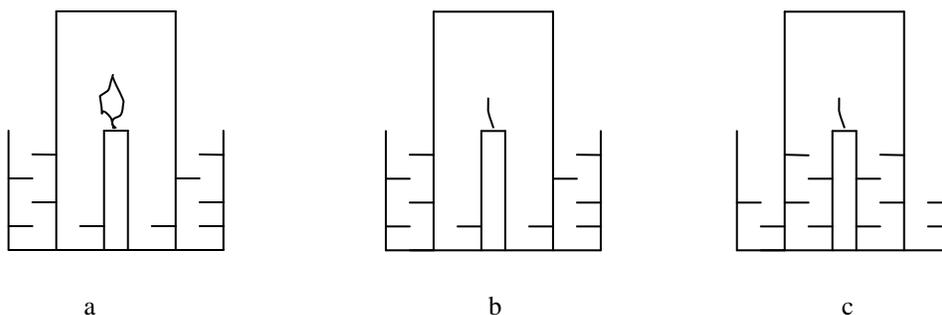


Figure 2. Three experimental stages: A candle burning in an inverted jar over water in a trough.

There were four questions based on information in Figure2. First question asked about the reaction taking place in the jar, second why candle goes out after some time, third, why water moves into the jar and fourth, if hot air escaped from the jar before it touched the water. The expected answer to the first question was: hydrocarbon reacting with oxygen to produce CO₂ and H₂O (easy question), and to the second: oxygen is reduced in the jar. The third question investigated common misconceptions that are (i) all oxygen is used up or (ii) CO₂ is dissolved in water and answer was that air escaped during the process of placing the jar on the candle. In the third question it was expected that the respondents will response to oxygen is finished or carbon dioxide is dissolved and it happened. The fourth question expected them to concentrate on thermal expansion and the expected them to answer that water moves in the jar to compensate for decreased in air pressure after cooling as some air escaped from the jar due to thermal expansion during the process of placing the jar on the candle.

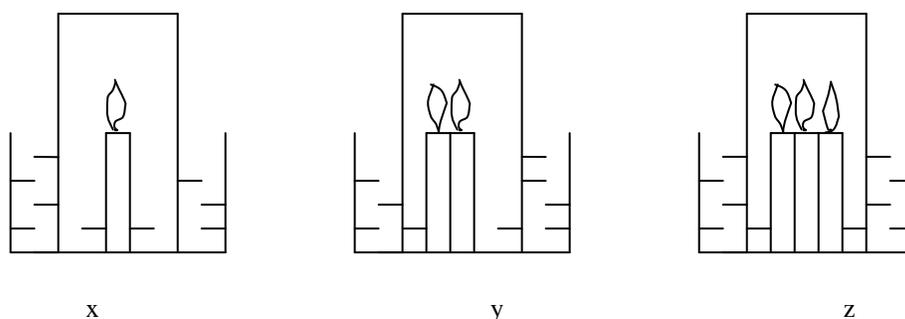


Figure 3. Three experimental conditions: A candle burning in an inverted jar over water in a trough.

The questions four to seven were based on information in the Figure 3. Question 5 asked in which jar the candle(s) will go(es) out last (easy question) and the expected answer was x. The question 6 asked in which jar (x, or y, or z) the water will rise highest. The fourth choice for this question was equal level in all the three. The expected answer was z because more air escaped from the jar in the beginning due to large amount of heat released by three candles. Question 7 asked them to give reason for their choice in question 6. If they chose x or y or z they were asked to respond the MCQ 7a, if they chose equal level in all jars for question 6, they were then asked written describe: why did they think so? The questions 1 and 5 were considered easy questions as more than 90% responses were correct. The other questions were treated as difficult as the percent of correct responses were less in the range of 10% to 27%. The responses to easy and difficult questions are discussed separately.

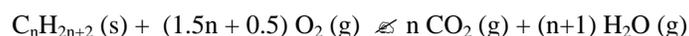
What is happening in this experiment?

When we ignite the candle, the hydrocarbon reacts with oxygen (in excess) to produce carbon dioxide and water. The burning sets an air current which gives dome shape to candle flame and it helps to get complete combustion at the bottom and the outer surface of the flame. The hot air and products of combustion rise up above the flame. As soon as the gas jar comes over the flame, the hot gases moving upward enter the jar and air inside the jar expands pushing some of the air out of the jar. This process goes unnoticed. As soon as the jar touches the water, the burning occurs in a closed environment. Further pressing the jar into water helps to retain the air in jar which is less in quantity than at room temperature and pressure. However, due to thermal expansion, the pressure is higher than atmospheric pressure which is balanced by pressure from the water. The burning of hydrocarbon in the jar produces about 30% more molecules of carbon dioxide and water than the molecules of oxygen consumed in the reaction (see below the title expected chemical reaction). The increased heat and number of molecules increases the pressure in side as a result if not careful some bubbles of gas will escape from the jar. Over the time the oxygen in the jar is reduced and conditions for burning are changed. Burning under reduced oxygen may not produce carbon dioxide rather carbon monoxide (very little). When the candle is put out, the temperature decreases followed by also a decrease in pressure due to condensation of water vapour and decreased quantity of air due to thermal expansion during the process of placing the jar on the candle. The overall situation is a decrease in pressure inside the jar as compared to atmospheric pressure. Therefore, despite water is heavier than air, it is pulled into the jar. How much water rises as a result of dissolving of carbon dioxide? Very little practically negligible during 30 - 40 minutes, the time the experiment usually takes for performing in a classroom situation.

If the number of candles is increased in the jar, the heat produced is more therefore more air is likely to escape from the jar due to thermal expansion during the process of placing the jar over them. Therefore, more water will rise in the jar with more candles.

Expected chemical reaction

The nature and quantity of the products will depend upon the composition of candle material. However, it is assumed that combustion of saturated hydrocarbons is taking place during burning.



For $n = 1$, two moles of oxygen reacts with a mole of CH_4 to produce three moles of product molecules. Assuming that supply of methane was controlled and it is stopped as soon as the flame is put out, otherwise there will be an explosion. The number of moles of the product molecules is 1.50 times that of oxygen. As n increases, the multiple factor decreases from 1.50 and approaches 1.0 at $n = ?$. For $n = 30$ (a typical paraffin wax), the factor will be 1.34.

The overall understanding of the experiment is that all the oxygen is not used up (I have rested the presence of oxygen after the candle is put out in our laboratory using yellow phosphorus) and the consumption of oxygen does not create empty space rather the number of product molecules in the jar increases over that of the consumed oxygen. Thus giving rise to an increase in overall pressure in the jar (see above equation). Moreover, almost equal number of molecules of CO_2 and H_2O are produced. A quick rise of water in the jar after the candle is extinguished is mainly due to a decrease in pressure as a result of a decrease in amount of air in the jar due to thermal expansion during the process of placing the jar on the candles, bubbles escaping (if any) through the water and may be the condensation of the water vapour. The amount of condensation of water will depend upon the temperature difference between initial and final temperature of the air in the jar. Since air is above water, therefore saturated water vapour pressure is considered in the beginning of the experiment. Increase in temperature, during the candle burning, will make air unsaturated to accommodate additional water vapours especially produced as a product of burning. A decrease in temperature over time after the candle is off to the initial temperature will help water vapour to condense. This condensation will decrease the pressure inside the jar and will help water rise in the jar. The amount of water vapours condensed during a small change of temperature as usually occurs in this experiment may even be small to notice. The amount of CO_2 dissolved in water is minimal in the 30-40 minutes during which experiment is conducted.

Results

The results of the study are reported under following heading (i) summary of responses to individual questions, (ii) comparison of responses to easy and difficult questions, and (iii) interview results. In the following paragraph, CR is correct response, IR is incorrect response and CC is certainly confident. The reported CC data is for the percentage for reported CR or IR.

Summary of responses to questions considered individually

The analysis of respondents' data on the seven questions revealed that teachers knew what reaction is occurring in the jar (CR=98.7%; CC= 51.8%). They confidently believed that all the oxygen is consumed during combustion before the candle is extinguished (IR=75%; CC = 60%) and the water rises in the jar to fill in vacuum created by consumption of oxygen (IR=90%; CC 53.8%). They did not expect the air to escape from the jar as a result of thermal expansion (IR=73.1%; CC= 29.5%). They believed that one candle will burn longer in the jar than three candles (CR=91.1%; CC=57.0%). Most of them reported that the water level in jars with different candles will rise to the same level as the amount of oxygen in the jars is the same that is 20% (IR=78.2%; 50%). These results are supported by interview data. A sample interview is attached in Table 2. The quantitative and qualitative results show that teachers had a limited level of understanding for the experiment.

Table 1

Respondents' Responses to Questions and Confidence in Their Responses to be Correct

Questions		Response		% Confidence			
No	Type	Type	%	CC	TC	TW	CW
1	All	Correct	41.9	19.5	20.8	1.6	0.0
		Wrong	58.1	33.5	21.5	2.7	0.4
2	Easy	Correct	94.9	54.2	39.1	1.6	0.0
		Wrong	5.1	3.2	1.9	0.0	0.0
3	Difficult	Correct	20.7	5.6	13.4	1.7	0.0
		Wrong	79.3	45.7	29.3	3.8	0.5

Comparison of responses to easy and difficult questions

The results in Table 1 (see data for All) show that 41.9% of the responses were correct and the remaining 58.1% incorrect. Of the 41.9%, 19.5% respondents were certainly confident in the accuracy of their responses, whereas 20.8% were doubtful to some extent. On the other hand 33.5 % respondents were certainly confident that their wrong responses were correct and 21.5 % thought that their responses are correct. Even for easy questions, only 54.4% were certain of the accuracy of their response, whereas 39.2% thought their responses were correct. For difficult questions, 45.7% of the respondents were confident that their wrong responses were correct. It is surprising, that despite the large proportion of wrong responses, teachers did not know that they were wrong.

Interview Results

Interviews with 4 trained graduate science teachers were conducted. These teachers were teaching 14-16 years old students. During the interviews, the teachers were asked the reasons for selecting their response to each of the questions in the MCQ questionnaire. They also were asked additional questions dealing with prior knowledge that was believed to be important for answering the questions. The interview data supported the above results. An interview with a Form 4 teacher is reported as a sample in Table 2.

Interview responses to questions on the questionnaire. Interview results to the questions are reported in the following table.

Table 2

Explanation of Questionnaire Answers through Interview

Q. No.	Teachers' answer to MCQ	Interview response
1	b. Oxygen is reacting with hydrocarbon	Air contains oxygen and carbon is present in the wick and in the wax. Carbon reacts with oxygen during the burning.
2	a. Oxygen is finished in the gas jar	It is because for burning or combustion, oxygen is used up. So normally the candle goes out and the percentage of oxygen is exhausted or finished.
3	a. to take up empty space created by finished oxygen	When the combustion is over, oxygen is used up and that creates a space inside the gas jar. And water moves in to take the space. In the gas jar, the oxygen amount is used up.
4	b. You disagree because there was no hot air in the jar	Before lighting the candle, the air inside is normal at atmospheric air with normal temperature. So there is no hot air before lighting. It stays in the gas jar as hot air rises.
5	b. Candle in X will be the last to go out	It is because there is only one candle and oxygen in the available air is used up. In Y, there are 2 candles and in Z there are 3 candles. The more candles, the faster the rate of combustion.
6	d. Equal in all the three	I am certain I am correct because 20% or 1/5 of the air in the gas jar is oxygen. It is the same for all three gas jars so the level is the same in all three; no matter what the number of candles.
7b	The level of oxygen (% of) is same in all the three jars.	The level of oxygen is the same in all three jars.

Interview responses to additional prior knowledge questions. During interviews, some additional questions were asked to explore teachers prior knowledge of the processes that can be used to explain the questions asked in this study. The teachers knew that on heating air expands and increases the pressure in a closed container, whereas in an open container the air escapes from the container, gases respond to heat faster than liquids and solids, hot air rises upwards. They have observed air bubbles escaping from the jar through water. They knew that in a chemical reaction, atoms and molecules combine in fixed whole number ratio and a chemical equation indicates the molar ratio between reactant and products. They also knew that the bigger the fire more the heat and gaseous products are

formed during burning. However, many of them have not imagined that during hydrocarbon burning, the product gaseous molecules will be more than that of the reactants.

Table 3
MCQ and Confidence Scale Responses (%) of Male and Female Respondents in Correct and Wrong Answers

QT	Sex	Correct answer to MCQ					Wrong answer to MCQ				
		MCQ	CC	TC	TW	CW	MCQ	CC	TC	TW	CW
All	M	34.6	17.1	17.5	0.0	0.0	65.4	37.5	25.9	1.5	0.5
	F	45.6	22.8	22.8	0.0	0.0	53.4	30.2	19.3	3.6	0.3
ESY	M	96.3	54.6	41.7	0.0	0.0	3.7	1.9	1.8	0.0	0.0
	F	94.2	52.7	41.5	0.0	0.0	5.8	3.5	2.3	0.0	0.0
DIF	M	10.0	2.1	7.9	0.0	0.0	90.0	50.7	36.6	2.1	0.6
	F	27.1	11.1	15.1	0.9	0.0	72.9	41.5	26.4	5.0	0.0

QT = questions set type; ESY = easy; DIF = difficult; MCQ = multiple choice question; CC = certainly correct TC = think correct; TW = think wrong; CW= certainly wrong

The responses of male and female teachers to easy and difficult question and their confidence in the responses to be correct are reported in Table 3. While discussing the results it was assumed that a 10% difference is educationally valuable. It is clear from the data in Table 3 that female teachers' responses were significantly more correct than that of the male teachers. There was no difference in the responses to easy questions however this difference has appeared in responses to difficult questions. The data also suggest that male teachers were more certainly confident in their wrong responses to be correct by 8 - 9% than female teachers. The male and female teachers were equally unaware of knowing when they were wrong. In general, the degree of certainty in male and female respondents' correct responses to be correct was lower and in their wrong responses to be correct was higher than their actual responses.

Discussion

The teachers are not confident in their correct knowledge and are confident in incorrect responses. These teachers will teach correct knowledge with less confidence and incorrect knowledge with more confidence. Using the theory of constructivism, the interaction between incorrect knowledge of teachers taught confidently and correct prior knowledge of students will produce the construction of incorrect knowledge (Dhindsa & Wimmer, 2003). As discussed in the introduction, there are four types of knowledge of teachers and also of students. Probability of interactions between correct knowledge of teachers and of students is low and it depends upon the extent of correct knowledge of teachers and prior knowledge of students. More interestingly despite teachers giving wrong responses they did not report that they were certain to be wrong. It may mean that we are not trained to know when we are wrong. It is important that future teachers are trained to know when they are and are not wrong.

Teachers during the interview agreed that they have seen air bubbles escaping through the water from the jar. However, they do use this knowledge to explain the rise of water in the jar. It appears that teachers treat this observation as a minor detail of the experiment, therefore they ignore it. It is therefore important that while training teachers or teaching students the observation of micro along with macro processes/points and their use in explaining the major question needs to be encouraged.

The prior knowledge questions asked to teachers during interview revealed that they had sufficient prior knowledge to answer confidently the questions asked, however they did not use this knowledge at all. One of the possibilities is that the knowledge in the teachers' brains is very weakly connected and although it is there, it is not accessible for the solving the simple problems like the one discussed in this study. It is because teachers store various pieces of knowledge in isolation like we store all the apparatus for an experiment in a tray. Any piece of apparatus that is not in tray will not be used. Therefore, they take each piece of knowledge as individual entity. Can we help the teachers improve connectivity in the extant knowledge? Dhindsa and Anderson (2004) proposed that flexibility in thinking and interconnectedness of conceptual knowledge can be increased by conducting short-term in-service training using cognitive strategy instruction programs delivered using a conceptual-change approach.

The major implication of this research is that students at schools as well as at institutions of higher education should be taught for understanding rather than for memorizing. Moreover, techniques for connecting information should be stressed to improve links between different pieces of knowledge. Replacement of teacher guided experiments with project work should help. Teachers should try different experiments to help them improve their conceptions. They should explore multiple sources to confirm the correctness of their knowledge. In this light we have performed some experiments to help our teacher trainees to change their conception. These experiments included studying the solubility rate of CO₂ by inverting a jar full of CO₂ over water and it was found that a jar full of CO₂ inverted in a trough of water did not completely dissolve in number of days. To study the level of water rise when the candle was put out as soon jar touched the water, a floating candle was used and it was made to sink as soon as jar touched the water in the trough. It was found that water did rise to some extent, indicating that some air escaped from the jar because hot air and burning products entered the jar from the candle during the process of placing the jar over the candle. The presence of oxygen in the jar after the candle is put out was studied by using white phosphorus, pyrogallol, iron-wool, mouse and insects. It was found that oxygen in the jar after candle is put out (a) produced rust, (b) reacted with yellow phosphorus to produce white smoke of oxide and (c) supported survival of mouse and insect for long. To test if the presence of CO₂ or lack of oxygen stops candle from burning, the carbon dioxide from the jar was removed by using NaOH solution in the trough in place of water, and, also by spraying cotton with NaOH and attaching it to the bottom of the jar before it is inverted on the candle. The candle burning time was almost doubled in this case indicating that it is the presence of carbon dioxide that puts the candle out. The experiment "A candle burning under a jar inverted over water in a trough" was also repeated using two and three candles. The level of water in the jar increased with an increase in number of candles. This finding was used to emphasize that more oxygen is escaped from the jar before or during the burning of candles. However, a new misconception appeared more the burning candles in a jar more oxygen was consumed. This misconception needs special attention. The students have enjoyed these experiments. They also found these experiments helpful in making them think logically to understand the overall process of burning.

Conclusions

Teachers are unable to access and utilize their stored knowledge to solve simple problems. The inability to do so puts them in a state where they are either not confident in their correct knowledge or they are confident in the incorrect knowledge being correct. They use their incorrect knowledge confidently to teach their students that might result in misconceptions. Teachers should conduct simple experiments to improve upon their confidence in their correct knowledge. More research in ways to improve upon the connectivity of knowledge in teachers' minds is recommended.

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