Revista de Educación en Ciencias (Journal of Science Education), Vol 1, N2, pp 118 -123, 2000

An Investigation of Graduate Scientists' Understandings of Evaporation and Boiling

INVESTIGACIÓN SOBRE COMPRENSION DE LOS CONCEPTOS DE EVAPORACIÓN Y EBULLICIÓN QUE POSEEN LOS PROFESORES DE CIENCIAS

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Abstract

The research undertaken both in Manchester and Bogotá used a video presentation of six situations relating to the evaporation and boiling of liquids and the escape of dissolved gases from solution. Understandings were probed using a brief written questionnaire. All of the participants in the study are already graduates in science. Despite some obvious, and currently unexplained, differences in the responses from Colombia and UK it is very clear that even after many years of science study conventional scientific views are not always strongly in evidence and alternative conceptions abound. This, we believe, has significant implications for the chemical education of students at all levels and especially for any who are, or aspire to become, teachers of chemistry, and these are explored in some detail. We would, however, strongly dispute the suggestion that expression of these alternate conceptions are simply indicative of a cognitive deficit in the sample who 'should have learned (or should have been taught) their basic science much 'better''.

Keywords: understanding, evaporation , boiling, graduates, teaching, learning

Resumen

Esta investigación se efectuó en Manchester y Bogotá y se realizó una presentación con video de seis situaciones que se relacionan con la evaporación y ebullición de líquidos. La comprensión se sondeó utilizando un cuestionario. Todos los participantes en el estudio eran graduados en ciencias. A pesar de las diferencias en las respuestas en Colombia e Inglaterra, es claro que aun después de muchos años de su ejercicio profesional en ciencias, los profesores no son siempre fuertes en la explicación científica de los conceptos y poseen varias concepciones alternativas . Esto tiene implicaciones importantes para la educación de ciencias de estudiantes en todos los niveles y especialmente para quienes son, o aspiran llegar a ser profesores de ciencias. Estas concepciones alternativas son simplemente indicadores de los defectos de los conocimientos de los participantes en el experimento, quienes deberían aprender (y enseñar) su ciencia básica mucho mejor.

Palabras clave: evaporación, ebullición, graduados, enseñanza , aprendizaje

Introduction

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Evaporation and boiling of liquids and the escape of dissolved gases from solution are met frequently in a wide variety of everyday contexts. The drying up of puddles, the boiling of water and the opening of a bottle of lemonade are simple examples. They are also met frequently in the context of science teaching and learning at all levels, but rarely form the major focus of thinking: rather they are more likely to be a part of a process which is being discussed. However, since they are so 'commonplace' it would generally be assumed that graduate scientists would have a complete familiarity with the processes and a secure qualitative understanding of the models which underpin a 'scientific explanation' of the phenomena.

An earlier study (Goodwin, 1995) indicated the difficulty which beginning teachers who are graduate scientists and authors of school science text books have in providing a simple, consistent and coherent explanation of basic phenomena in terms of random molecular (particle) movement. The current study focuses upon a much narrower range of phenomena and attempts to explore the 'facts' known and explanations offered by the beginning science teachers rather more closely.

Studies of children's conceptions (Osborne and Cosgrove, 1983) provide interesting evidence of the way in which their ideas change over time. For example, Table 1 below indicates the approximate percentages of the age group studied which believed the 'substance' inside the bubbles of boiling water was steam (water vapour); oxygen/hydrogen; air or heat.

Bubbles made of	13 years	15 years	17 years
Steam	8	10	36
Oxygen/Hydrogen	38	48	38
Air	26	25	23
Heat	28	17	3

Table 1 (Interpreted from Osborne and Cosgrove 1983, p.829)

Similarly detailed phenomenographical study of “Students’ Conceptions of Matter” (Renstrom, Andersson & Marton, 1990) reports similar findings from earlier work.

“more than half the students (13-16 years old) participating in the investigation thought that boiling means that air leaves the water (in the form of bubbles) rather than that water in liquid form turns to water in gaseous form” (and escapes as bubbles). (p.119)

It is clear that even at age 17 only a minority believed that the bubbles consisted (entirely) of steam, although there seems to have been considerable progress towards this ‘correct’ ‘scientific’ view. It is also relevant to note that the second answer (Table 2) also seems reasonable (although incorrect in terms of the substances present) if one considers that “Water is a compound of hydrogen and oxygen - H_2O” Thus, whilst the learner is contending with the differences between elements, mixtures and compounds it is hardly surprising that this confusion exists. However worrying it is that so high a proportion of pupils at 17 still have this confusion, presumably this will not be a problem with those who have graduated in science? One of the authors has developed the analysis separately and with a different educational perspective (Goodwin, 2000).

The Investigation

The Instrument

In order to provide a consistent stimulus to the explanations from the participants, a short video was made. The scenarios of the six video sequences are listed below.

1. Evaporation Equal volumes of petrol and water are left exposed in open beakers under the same conditions for about three hours.

2. ‘Forced’ Evaporation Air is blown through petrol in a small in a small beaker which is standing on a piece of wet wood. The beaker becomes frozen to the wood.

3. Boiling Water Water is heated in a beaker until it boils.

4. <u>Reducing the pressure over cold water</u> Air is extracted from a flask of water - at room temperature.

5. <u>Water in a syringe</u> Water (warm) is sealed in a plastic syringe and the plunger pulled upwards until bubbles are seen.

6. <u>Opening cans of cola</u> Two cans of cola, identical except for the fact that one had been shaken and the other not, are opened. The results are compared.

2.2 <u>The Participants</u>

All are <u>science</u> graduates. The samples sizes Colombia N = 14 and UK N = 52. Their distribution between the major science categories is given in Table 2. The participants from Colombia are already practising secondary (high) school science teachers; those in the UK are in the process of a one year postgraduate course of initial teacher training for secondary schools.

	Biology	Chemistry	Physics	Total
Colombia	4	6	4	14
UK	32	15	5	52

Table 2 Subject Specialists within sample

2.3 <u>The questions</u>

1.1 Where have the liquids gone?

1.2 Explain why more petrol evaporated than water.

1.3a Which molecules are larger, petrol or water?

1.3b Which do you think <u>should</u> escape faster?

1.4 How does the temperature of a liquid change (if at all) when evaporation takes place?

2.1 What effects do bubbles of air have on the evaporation of petrol?

2.2 Is the petrol boiling?

2.3 Why does the water under the beaker freeze?

2.4 Where does the condensation on the outside of the beaker come from?

2.5 Would it still appear if there were no water on the wood?

3.1 Sketch a graph of the way the temperature changes.

3.2 What do you think is in the very small bubbles you see at first?

3.3 What is in the big bubbles you see when the water is boiling?

3.4 Where does the condensation on the outside of the beaker come from?

3.5 What do you think is the cause of bubbles from the side of the beaker?

4.1a Is the water hot?

4.1b Is it boiling?

4.2 What is in the large bubbles? Explain.

4.3 How does the temperature of the water change during the experiment?

5.1 Would this still work if a small bubble of air were not left in the syringe?

5.2 What change of temperature - if any - would you expect as the plunger moves upwards?

6.1 What gas is mainly involved?

6.2a Is pressure the same before shaking?

6.2b Is pressure the same after shaking one of them?

6.3 Why do you think shaking makes so much difference to the result?

6.5 When the cans are opened, is the cola ‘boiling’? (Not asked in Colombia.)

Results

The comparative results for the various items above are given in the Chart 1. At this stage detailed comparisons would not be valid because of the differences in background of participants and discrepancy in sample size

In view of the limited space this is restricted to items 1.4, 3.3 and 6.1-4.

3.1 Item 1.4 "How does the temperature of a liquid change, if at all, when evaporation takes place?"

Reference to Appendix 1 will show that just less than one third of respondents indicated that the temperature would fall.

The authors were very surprised at this low value and had seen the question as 'unproblematic' and probably too easy, particularly since we believed that all would be familiar with everyday applications of 'cooling by evaporation' e.g. in refrigerators, wind chill factors, evaporation of 'sweat' to reduce body temperature. Although an explanation was not required to 'get the mark', respondents were encouraged to explain their answers.

The majority 'getting it wrong' seems to have a clear belief that the temperature does not change when the 'state' changes. (Confusion with boiling point.)

- *"There is a temperature at which a liquid evaporates. It stays at that temperature until it all evaporates."* (Biol.)
- *"Liquids reach their boiling point and then get no hotter so they begin to evaporate."* (Biol.)
- *"Temperature remains the same when changing state i.e. liquid to gas."* (Chem.)
- *"No change in temperature at the point where it changes state."* (Chem.)
- *"Energy goes into evaporation rather than increasing temperature until it has changed state."* (Phys.)

Some are struggling with competing ideas.

- *"Not at all - though this assumes thermodynamic equilibrium (process allowed to proceed infinitesimally slowly). If evaporation takes place there will be temperature gradients within* *the liquid."* (Phys.)

- *It doesn't actually change, but it occurs at the surface - those molecules with energy are released at the surface."* (Biol.)
- *"It doesn't - surface molecules do get extra KE so they can leave."* (Biol.)

A small number believes in a temperature increase, although rarely is any explanation offered.

- *"Heats slightly giving energy for further bonds to break and vapour or gases produced."* (Biol.)

There were also some very sophisticated <u>and</u> 'correct' explanations, although they could still stimulate discussion.

- *"The temperature of the liquid falls when evaporation takes place because energy is required for evaporation ."* (Biol.)
- *"The temperature of the liquid lowers due to the removal of particles with higher energy (with evaporation)."* (Chem.)
- *"If the liquid is thermally isolated from its environment then heat will be lost from it as vapour is formed. The temperature will drop. If heat from the environment is allowed to enter the liquid, then it will stay at the same temperature as the environment."* (Chem.)
- *"The heat energy required to make surface particles evaporate comes from the body of the liquid or the container. This causes the body of the liquid to lose heat energy and cool."* (Chem.)

It is also worth noting that there appeared to be no significant difference between biologists and physical scientists except that, where given, the latter produced much longer explanations. There is also evidence of inconsistency with Situation 2. Here a much higher proportion explained the freezing of water in terms of evaporation being an endothermic process.

3.2 <u>Item 3.3</u> "What is in the big bubbles you see when water is boiling?"

This connects very closely with the reported results of children's conceptions (Osborne and Cosgrove, 1983) referred to in Section 1.

The breakdown of responses from the 52 UK graduates is: Water/water vapour/steam 26; water and air 4; air 7; oxygen and/or hydrogen 13; heat 1; a vacuum 1. Progress from age 17 - just?

Few answers included comment, but the following are of interest:

- “*The heat rising up through the water.*” (Biol.)
- “*Air - hydrogen + oxygen.*” (Biol.)
- “*Air - trapped - almost enough energy to escape but trapped by water molecules.*” (Chem.)
- “*When the water is boiling the large bubbles contain nothing, i.e. they are a vacuum.*” (Phys.)

It is pertinent to note that the model implicit in this final response was applied consistently into situation 4 (Item 4.2) when water was ‘boiling’ under reduced pressure.

- “*There is a vacuum inside the large bubbles. Since the air has been evacuated from above the water, the force on the water upwards is greater than that downwards, and so the surface becomes disturbed, creating bubbles.*”

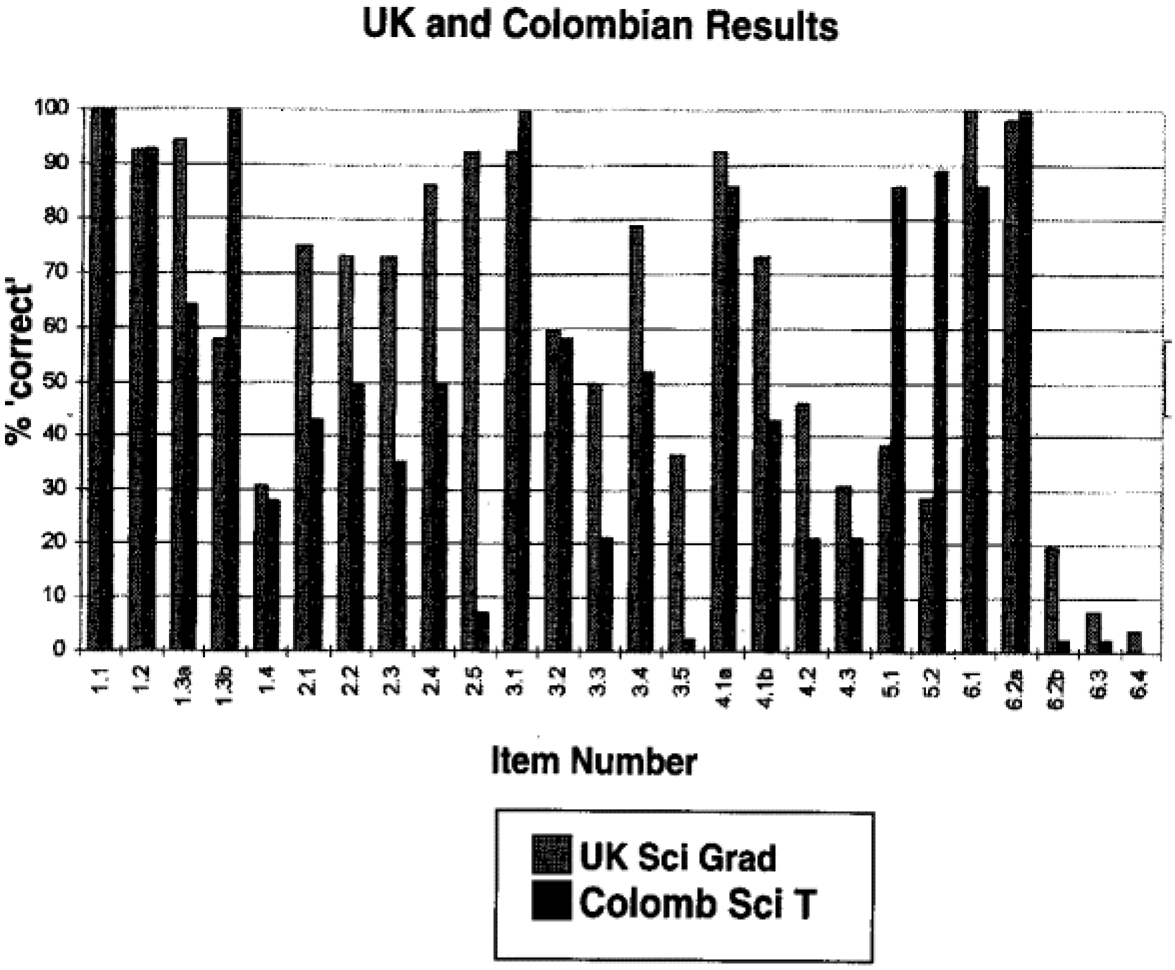
3.3 <u>Situation 6</u> “Opening cans of ‘Pepsi’ before and after shaking”.

(Items 6.1 - 6.4) There is almost total agreement that the major gas involved in this situation is carbon dioxide and the pressure in the two cans is identical before shaking. So clearly does the shaking of a can of coke prior to opening it lead to an almost explosive result when the ring is pulled that there is no need for persuasion that the pressure has increased. It is also clear that energy was transferred to the can by shaking that this ‘must be’ the basis of the explanation. Putting energy into the system leads to an increase of temperature and thus to an increase of pressure. (NB: This is the ‘wrong’ answer.)

In fact, the amount of energy transferred to the system by shaking is infinitesimal compared with that which would be required to produce a significant increase in temperature/pressure. The ‘correct’ explanation must be based on the <u>rate</u> at which gas is enabled to escape from solution by allowing the solution to ‘boil’ vigorously by virtue of the very small bubbles which are distributed throughout the liquid and which act as nuclei for the formation of larger bubbles. (See Deamer and Selinger, 1988).

A full exploration of the responses given and ‘deep water’ entered by some of the participants is worthy of a paper on its own. However, it is clear that almost all ‘scientists’ certainly tend towards the obvious ‘wrong’ explanation.

Chart 1



Discussion

First it must be stressed that there is no intention in this study to denigrate the subject knowledge of science graduates or of scientists. All participants are by virtue of their qualifications scientists and most are, or are demonstrating their potential to become, good, thinking secondary school science teachers.

The value of such experiences as presented by this task was recognised by one of the participants who wrote on the answer paper:

"This is 'An illustration of needing to continue learning and that science 'out of context' can be easier than science 'in context', i.e. in the real world. Thanks. 'Only the fool thinks he's a wise man.' " (Chem.)

It is unlikely that any of the participants will have considered qualitative explanations of these 'everyday situations' since they themselves were at school (if then?). The situations presented a substantial intellectual challenge to participants that we hope is effective in promoting learning <u>by the teacher</u>. This is a continuous process that requires constant and critical review of explanations offered by both learners and teachers. The development of a consistent explanatory framework is one of the goals of science, but, by whatever means, each individual has to construct a meaningful framework for him/herself including those aspects that are significant to him/her. This is neither a trivial process nor an easy one for a beginning teacher to have to cope with. Outside particular (and fairly narrow) fields of expertise we all have experiences and know of phenomena which, although explicable, have yet to be fitted into our framework. Thus, it is not surprising that science teachers exhibit the same range of conceptions as pupils or other adults who are prepared to articulate explanations.

What seems a major problem is that we do not seem to apply at all levels of education what we know to be true, e.g.

- that we learn best only things which make sense and are significant;

- that learners *construct* understanding and build upon what they already (think they) understand;

- that transmission of what the teachers know (or think they know) to students is <u>a very complex</u> process.

This 'constructivist's'' view is well summarised by Bodner (1986). Some of the key issues have been identified (Goodwin, 1994).

- Science must make sense
- It we expect students to develop enquiring minds, then teachers need to demonstrate these, too.
- Teachers should not know or understand everything about science (but they should continuously explore what they don't know, and re-examine what they (think they) know).
- Enthusiasm tends to be caught rather than taught (and early experiences can be vital).
- Students need to be actively and intellectually involved.
- Balance is very important.

Teachers MUST be learners - we should all 'wonder' much more. It is salutary to reflect on two extracts from the seminal paper by Novak (1990)

"*In our studies of the learning patterns of Cornell University students we have found that the large majority engage in essentially rote learning most of the time.....The same patterns have been observed* *in students preparing to teach. If prospective teachers are to adopt practices that encourage meaningful learning, it seems evident that they must also seek to learn subject matter meaningfully."* p.942

"*......MOST pre-service and in-service teachers we have worked with still see science as a large body of information to be mastered.......it remains an enormous challenge to help teachers and their teachers to see science as an evolving framework of concepts and concept relationships and a methodology for constructing (not discovering) new concepts..........Solving these problems will not be easy."* p.944

Conclusions

We believe that the above findings and brief discussion provide pointers to some important educational issues. Although these are not new, they often seem to be forgotten by politicians and those responsible for setting standards for education:

1. Learning is a complex and continuing process – even graduate scientists find basic science difficult (and show misconceptions) when they are unexpectedly asked questions or are asked to give explanations of things learned (rather than understood) at an early stage. It is never complete and is always intellectually challenging.

2. Attempting to score highly in examinations is an important aim for students and their teachers. However, this is NOT why science is studied. Overvaluing scores in standard tests and examinations distorts the learning and teaching processes. Students only want to learn right answers and teachers stop being concerned about students' understanding providing that they pass the test.

3. The fundamental interest, meaningfulness, utility, joy and wonder of trying to understand ourselves, our world and our universe should be nurtured in science teachers and students. This is why humans do science.

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