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Trainee Science Teachers' Understandings of Evaporation and Boiling - a small-scale study in three countries
Como entrenar la comprensión de los profesores de ciencias con respecto a evaporación y ebullición: Estudio a pequeña escala en tres países

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Abstract

This is a report of a small-scale and informal research study undertaken by the authors at their institutions, each with a small opportunistic sample of students who were nearing the end of their training course to become secondary school science teachers. In view of the small numbers involved there are no claims for high reliability, but the authors believe that significant educational questions are raised. Six scenarios relating to evaporation and boiling were shown to the students on a video and answers sought to questions via a written questionnaire after each scenario.

That the students did not score highly on all the questions is unsurprising, but significant educational issues are raised regarding

a. the students' understandings of evaporation and boiling and the previous teaching/learning they had experienced. There appear to be some interesting differences between the three countries;

b. the researchers' own understandings of the same topic;

c. the value of such research probes for the students' learning process;

d. language issues.

Overall it is clear that this has been a valued learning opportunity for the authors and their students. Hopefully it will encourage others to use opportunities afforded by modern communication techniques to learn together - and share experiences with others.

Key Words. Evaporation and boiling, understanding, science teachers.

Resumen

Este es un reporte de un estudio de investigación informal tomado por los autores en sus instituciones, cada uno con una muestra de estudiantes que se encontraban en la fase final del curso para profesores de ciencia de escuela secundaria. Seis escenarios relacionados con los conceptos de evaporación y calentamiento fueron mostrados a los estudiantes en un video, y las respuestas fueron entregadas de manera escrita después de cada escenario.

El que los estudiantes no hayan logrado altas calificaciones en todas las preguntas no es sorprendente, pero surgen temas interesantes al respecto:

a. el entendimiento de los estudiantes sobre evaporación y ebullición y sus experiencias previas de enseñanza / aprendizaje. Parecen existir algunas diferencias interesantes entre los tres países;

b. el propio entendimiento de los investigadores del mismo tema;

c. el valor de tal investigación profundiza en el proceso de aprendizaje de los estudiantes;

d. Problemas de lenguaje.

Después de todo es claro que esto ha sido una valiosa oportunidad de aprendizaje para los autores y sus estudiantes. Se espera que esto estimule a otros a usar las oportunidades proporcionadas por las modernas técnicas de comunicación para aprender juntos – y compartir experiencias.

Palabras clave. Evaporación y ebullición, compresión, profesores de ciencias.

Introduction

This research programme happened by accident. Indeed, the key resource, a video showing various scenarios involving evaporation, boiling and bubbles in liquids was not primarily a research tool. It was made in Manchester for the purpose of focussing a discussion between education tutors who were exploring the use of video conferencing. Because the video existed and seemed to be a useful way of focussing the attention of groups of people on a range of related phenomena, it was used as an educational aid to probe the understandings of students in science teacher education classes. The initial co-operation between UK and Colombia began with chance discussions at the ECRICE (European Conference on Research In Chemistry Education) held in Lublin, Poland, in 1995 and the link with Finland established at the ECRICE in Ioannina, Greece, in 1999. In each country the students answered a brief written questionnaire immediately after watching each scenario on the video, and it is on these data that this paper is mainly based. However, subsequent discussions were found to be particularly valuable learning experiences by the students. Some of the answers were surprisingly controversial even among the authors and, in one or two cases, the 'right answer' changed during the process.

A short paper reporting some of the findings of the UK/Colombian study was published in this journal (REC Vol.1 (2) 118-123) (Goodwin and Orlik, 2000).

<u>The instrument</u>

The scenarios of the six video-sequences are listed below.

1. **Evaporation**: Equal volumes of hexane (light petroleum) and water are left exposed in open beakers in a fume cupboard under the same conditions for about three hours.

2. **'Forced' evaporation**: Air is blown through hexane in a small beaker that is standing on a piece of wet wood. The beaker becomes frozen to the wood.

3. **Boiling water**: Water is heated in an open beaker with a Bunsen burner until it boils.

4. **Reducing the pressure over water at room temperature**: Air is extracted from a flask of water until it 'boils'.

5. **Water in a syringe**: A small amount of warm water is sealed in a plastic syringe and the plunger pulled upwards until bubbles are seen. (In the video sequence a small bubble of air had been inadvertently left in the syringe.)

6. **Opening cans of cola**: Two cans of cola are opened, identical except for the fact that one had been shaken immediately before, and the other had not. The effect of shaking is clear.

The first scenario seeks to probe understanding as to why hexane (which has larger, and thus slower moving, molecules on average at any given temperature) evaporates more rapidly than water under the same conditions. All of the other scenarios involve bubbles in some form or other, together with evaporation and/or condensation. Bubbles serve to focus on the more specific notion of 'boiling'.

<u>The process</u>

After viewing the video the participants completed a pro-forma, which requested them to answer questions in their own words. The questions are listed in the next section (Table 1) together with the percentage of answers, which were deemed to be consistent with the accepted 'scientific' model from each country. An answer was accepted as correct even if subsequent elaboration indicated the presence of 'alternative conceptions'. For example, in question 24 (6.2b) (see Table 1) the answer 'Yes' was marked correct, even if the reason given demonstrated that the student did not understand or if no explanation was attempted.

TABLE 1 About here

CHART 1 About here

A comparison of the result from UK, Colombia and Finland is shown on Chart 1. Note that the questions here are numbered 1 to 26 as they are in the first column of Table 1. Column 2 of the table gives the actual question number from the questionnaire - the first digit of this number refers to the scenario to which the question relates.

Results

Some indication of the ‘acceptable’ answers is given in Table 1 and from experience we know these will cause comment, if not dissent from the reader.

This discussion will begin with a brief commentary on the results from the six scenarios. This will be followed by a list of the issues we believe should be highlighted.

Scenario 1 (Questions 1 - 5)

As expected, most students are familiar with simple evaporation (Question1), but linking this to energy and a molecular explanation caused some surprises. Language issues also arise.

On the video the two liquids were described as water and ‘petrol’. Unfortunately petrol is called gasoline or ‘gas’ in the US and this causes difficulty. Hence an attempt was made to change the name to ‘hexane’ for this paper. Also question 4 is quite a difficult construction linguistically and demonstrates an interesting issue in interpreting the answers given. In Finland it seems that the words ‘should escape faster’ were interpreted as meaning ‘what you know will happen in practice’, whereas the intention of the question was to ask ‘what they would expect given the different sizes of the molecules’.

Perhaps the most surprising finding was that most students from all three countries were not convinced that liquids cool when they evaporate (Question 5). (The more energetic molecules are the ones that escape and thus the average kinetic energy of the molecules remaining in the bulk of the liquid falls.)

Scenario 2 (Questions 6 - 9)

Except in Colombia the students seem to be clear that blowing air in increases the rate of evaporation of the petrol. (It increases the surface area from which evaporation can occur and also blows away the petrol molecules, making re-condensation much less likely.) And UNIVERSALLY the students (Question 7) agree that the petrol is not boiling under these conditions.

Most students (except in Colombia) explain the freezing in terms of a lowering of temperature caused by the evaporation of the petrol, which is an endothermic process. This is in contrast with the result for Question 5 where most do not expect the temperature to fall!

Again except in Colombia, most students seem happy that the condensation is water vapour from the air and its appearance is *not* dependent upon the water on the wood.

Scenario 3 (Questions 10 - 15)

One would expect familiarity with the scenario that involves water being heated until it boils. Almost all students were able to give an accurate picture of the expected temperature changes (Question 10).

Dissolved gas or air or oxygen or nitrogen were all acceptable answers to Question 12. Again the majority (except in Colombia) seemed happy about this. (The bubbles also will contain water vapour, although it was counted as correct if this was not included.)

Overall only about 50% expected the big bubbles to contain only water vapour (Question 13). This item relates closely to other published results (Osborne and Cosgrove, 1983) whose results are reproduced in Table 2.

Generally the students seem to understand that the condensation comes from water vapour in the air (Question 14). If this is accepted as the right answer a majority gets it right. However, the condensation does not appear until the Bunsen flame is put under the beaker - many fewer students see the condensation as coming from the water vapour formed by the combustion of gas in the flame. This seems to be a general issue.

Only UK students seem to be familiar with the idea of an imperfection in the glass acting as a nucleation site for the facilitation of bubbles of vapour (Question 15). A number of them referred to the similarity to 'boiling grains' used to promote steady boiling. It seems that this is something usually taught in UK that is not emphasised in Colombia or Finland?

<u>Scenario 4 (Questions 16 – 19)</u>

The vast majority of students accept that the water in the flask is 'not hot' (Question 16) and, except in Colombia, they also believe that it is 'correct' to refer to *this* bubbling process as boiling (Question 17). Question 18 relates to the composition of the bubbles and is equivalent to question 13 in the context of water boiling at normal atmospheric pressure. Except in Finland, where there in no change even fewer students accept that the bubbles contain only water (vapour).

With regard to an expected change in temperature (Question 19) one might expect comparable results in question 5. However, we can see no pattern here.

Scenario 5 (Questions 20 –21)

This scenario does not really differ significantly from the previous one. The use of the plastic syringe is a less complex way of reducing the pressure over the surface of the water.

The bubble of air inadvertently left in the syringe (Question 20) proved more of a challenge in U.K. It seems that many students believe that unless the bubble is present then it will not be possible to pull sufficiently hard to move the plunger up the syringe.

The expected temperature change (Question 21) might have been expected to be as in questions 5 and 19 but there seems to be no pattern and many students do not seem to make a connection between the three scenarios.

Scenario 6 (Questions 22-26)

This scenario, although it is the one closest to every-day experience, turned out to be the most problematic in practice. Indeed, there is still no consensus as to what are the 'correct' answers to questions 25 and 26. The answers given in Table 1 are those used to allocate marks and it is clear that most of the students disagreed. On question 26 there is still no agreement between the authors although we do *now* mostly believe that fizzing drinks *are* boiling solutions. (Goodwin, 2001) Had we been asked this question five years ago we would have been unanimous in agreeing that they *are not* boiling.

All students, except those in Colombia, were clear that the main gas involved in fizzing drinks is carbon dioxide (Question 22). Everyone agrees (Question 23) that the pressure in the two cans is the same *before* one was shaken. We *assume* they expect both cans to be at equilibrium although most of the students did not make this explicit. Question 24 begins the debate since most (almost all) think that shaking the can increases the pressure inside. Similarly all of the students give who give a clear explanation of the effect of shaking the can in terms of a pressure rise following an input of energy rather than an explanation in kinetic terms. (See discussion section below.) Only one (Finnish) student hinted that 'shaking made the escape of gas easier' and was given the mark. Students were unanimous that the fizzing drinks were not boiling – and were thus given no marks (since the examiners had changed their minds!)

Discussion

It is very important to realise that the students involved in this research were not expecting to be tested on their understandings of evaporation and boiling and there had been no specific preparation within their programme. Most of them would have been taught about this topic in previous courses or in earlier stages of their current courses. Thus we were probing their adult understanding rather than their recollection of planned teaching events.

Another significant issue for us is that we are keen that our paper is *not* interpreted merely as demonstrating the lack of knowledge of students or teachers. Hopefully the fact that the authors are prepared to expose their own learning during the research is evidence that we privilege learning over knowledge. *Moreover, a number of the students indicated that they had valued the opportunity to explore their understandings in this (unthreatening) research context and found it helpful to their own learning.*

In this discussion we wish to raise the following issues:

1. Issues relating to the results of the questionnaires outlined above:
    a. <u>Evaporation causes cooling:</u> This was a surprising finding that across all three countries the majority of students did not think this was the fact. (We would have expected most of them to know this *before* the entered secondary school.) It seems from their answers that many of them have learned (been taught) that the temperature and state of a substance cannot both change at the same time. Others seem to imply that the evaporation takes place at the boiling point, which is constant. There seems to be evidence here that the science they have been taught has over-ruled a basic fact that they probably knew earlier. (Caution for teachers.)
    b. <u>What is in bubbles in boiling water</u>: Results for pupils at different ages are given in Table 2 for comparison.

<u>Table 2 about here.</u>

It can be seen that there is some development towards the expected answer, but there many science graduates still do not immediately think of the bubbles in boiling water as containing *only* water.

   c. <u>Small bubbles from the side of the beaker:</u> There is a clear indication of a curriculum effect here since it seems that this is something that is highlighted in many UK schools (in the context of promoting smooth boiling using sharp anti-bumping granules) and not stressed in Colombia or Finland.

d. Fizzing drinks and boiling: This is not the place to go into long discussions (see Goodwin, 2001 and the 'Information Box'), but to stress that we are learning. The answer is still being debated. It is likely that in many places – even in national tests that answers would be marked correct if students were to explain the effect of shaking on cans of Coke as energy added causing an increase of temperature and therefore of pressure. They would almost certainly be marked incorrect if they suggested that fizzing drinks are boiling.

e. Students from Colombia generally seem to get lower scores: There could be many explanations for this but this is probably due to the severe lack of resources and to a lower standard of teaching (and teacher preparation) in this country.

2. The educational value of the instrument for engaging (teacher education) students in learning. (Students seem to value it, but we have no evidence that it helps gain higher grades (we have not sought this.) However, large-scale adoption of such discussion as a teaching methodology would impact on assessment procedures?
3. Language and cultural issues: We appreciate that language has probably affected the results although the questionnaires were translated and the students answered in their own language. Such discursive approaches that problematise science and that expect students to contend with ideas – rather than just to know the answers - are not evenly accepted across different countries or different schools or even different teachers.

We are dealing here with only very small samples of students so the results are only indicative. Statistical analysis is not considered appropriate – and unless the difference in scores for a particular item exceeds 30% we do not consider it to be significant. However, the questionnaire findings have been verified with a much larger group of Graduate Scientists in the UK (Goodwin, 2002).

Conclusion

1. We are all – teachers and pupils - continually constructing and reconstructing our knowledge.
2. Teachers need to beware of teaching (or encouraging learning of) meaningless information.
3. Students need to be critical of their own learning – and to contend knowledge with their teachers. (This may be particularly important as they need to learn independently from less reliable sources such as the inter-net and newspapers.
4. Teachers can also learn together – provided they are not afraid of learning themselves.

We would welcome comment and further discussion with readers.

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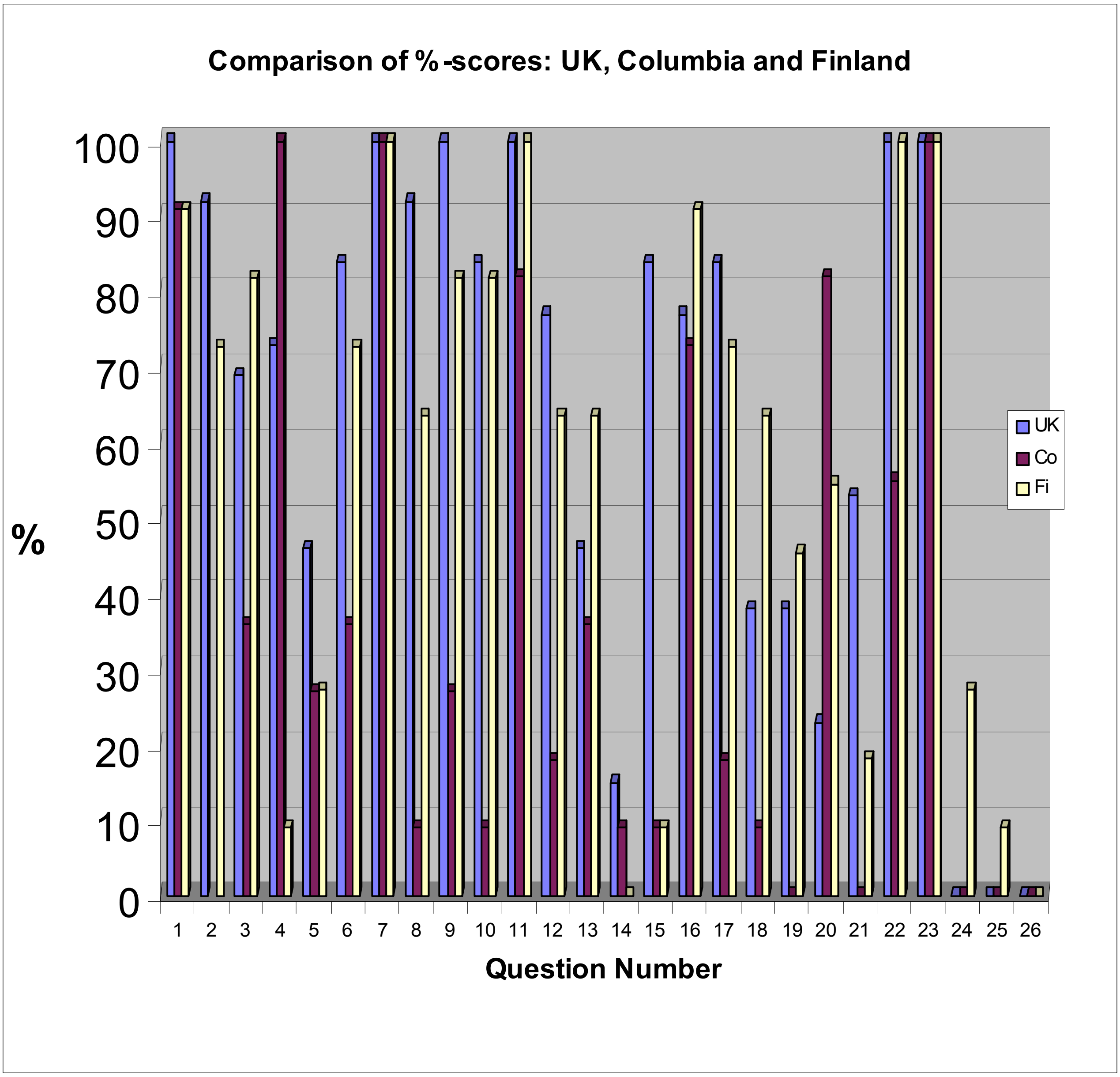

Chart 1: Comparison of scores between the three countries.

Table 1: Questionnaire results from the three countries. (An indication of the 'correct' answer is given in brackets after the question.)

		Question	UK	Co	Fi
		Sample size	13	11	11
1	1.1	Where have the liquids gone? ('evaporated', 'vaporised' and/or 'into the air' were accepted)	100%	91%	91%
2	1.2	Explain why more hexane evaporated than water. ('More volatile' or 'lower boiling-point' accepted - many included a brief kinetic explanation.)	92		73
3	1.3a	Which molecules are larger? (Hexane.)	69	36	82
4	1.3b	Which do you think *should* escape faster? (Water. Hexane was accepted if there was an explanation in terms of H-bonding between water molecules.)	73	100	9
5	1.4	How does the temperature of a liquid change when evaporation takes place? (Temperature falls / liquid cools.)	46	27	27

6	2.1	What effects do the bubbles of air have on the evaporation of hexane? (Increase rate of evaporation – due to increase of surface area / prevention of re-condensation.)	84	36	73
7	2.2	Is the hexane boiling? (No.)	100	100	100
8	2.3	Why does the water freeze? (Because of cooling to below its freezing point caused by evaporation of hexane.)	92	9	64
9	2.4	Where does the condensation on the outside of the beaker come from? (From the condensation of water vapour from the air.)	100	27	82
10	2.5	Would it still appear if there were no water on the wood? (Yes.)	84	9	82
11	3.1	Sketch a graph of the way the temperature changes. (A steady rise with time followed by a plateau – probably marked 100ºC.)	100	82	100
12	3.2	What do you think is in the very small bubbles you see at first? (Air / Oxygen: Nitrogen with	77	18	64

		water vapour.)			
13	3.3	What is in the big bubbles you see when the water is boiling? (Water vapour / steam. Air NOT acceptable.)	46	36	64
14	3.4	Where does the condensation on the outside of the beaker come from? (Water vapour formed by combustion of hydrocarbon gas in the flame.)	15	9	0
15	3.5	What do you think is the cause of bubbles from the side of the beaker? (An imperfection in the glass acting as a nucleation site for bubbles.)	84	9	9
16	4.1a	Is the water hot? (No.)	77	73	91
17	4.1b	Is it boiling? (Yes.)	84	18	73
18	4.2	What is in the large bubbles? (Water vapour / steam. Air NOT acceptable.)	38	9	64
19	4.3	How does the temperature of the water change? (Cools as boiling proceeds.)	38	0	45
20	5.1	Would this still work if a small bubble of air were not left in the syringe? (Yes.)	23	82	55
21	5.2	What change of temperature – if any –would you expect as the plunger moves up/down? (Cools as plunger moves up.)	53	0	18

22	6.1	What gas is mainly involved? (Carbon dioxide.)	100	55	100
23	6.2a	Is pressure the same before shaking? (Yes.)	100	100	100
24	6.2b	Is pressure the same after shaking (one of the cans.)? (Yes.) (The contents of the can are at equilibrium and shaking will not disturb this. There is a minuscule rise in temperature as energy is dissipated within the liquid but this is insufficient to cause an appreciable change in pressure.)	0	0	27
25	6.3	Why does shaking make so much difference to the result when opening? (Small bubbles are distributed in the liquid by shaking. These act as nuclei and allow many bubbles to grow within the body of the liquid when the can is opened, thus ejecting much some of the contents.)	0	0	9
26	6.4	Is the fizzing cola boiling? (Yes.)	0	0	0

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

Table 2. *What is in the big bubbles you see when water is boiling? Osborne and Cosgrove 1983, 829.)*

Information box:

Fizzing drinks: Boiling?

Fizzing drinks can be considered to be a solution of carbon dioxide in water (soda water) with a few added flavors. Bubbles are formed when the pressure is released and the solution is poured into the glass. These bubbles mostly contain carbon dioxide but are also saturated with water vapor.

The condition that scientists require for ‘boiling’ to occur is that bubbles of vapor can be formed within the liquid. That is, that the saturated vapor pressure of the liquid is equal to or greater than the external pressure on the surface of the liquid. For a pure liquid this is fairly straightforward but if there are two components of a solution that are able to form a vapor then they *both* contribute to the total vapor pressure of the solution. In the case of soda water dissolving carbon dioxide in the water *reduces* the vapor pressure of liquid water and dissolving water in the carbon dioxide reduces the vapor pressure of the liquid carbon dioxide. Soda water fizzes (boils?) when the saturated vapor pressure of the carbon dioxide ***plus*** the saturated vapor pressure of water is equal to that of the atmosphere at the time. This happens at a temperature well below room temperature and so the liquid ‘boils’ (the fact that it ‘boils’ for a long time is due to the fact that there are few small particles or sharp edges present to act as nuclei to aid the formation of bubbles. If a spoonful of sugar or salt or fine sand is added the soda water will ‘boil’ more vigorously for a short time.