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RESEARCH REPORT
Methods and issues of teaching and learning

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THE TEACHING OF CHEMISTRY: WHO IS THE LEARNER?

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ABSTRACT: Research undertaken with graduate trainee science teachers into their conceptions relating to the evaporation and boiling of liquids and the escape of gases from solution. It is clear that, even after many years of science study, conventional scientific views are not always strongly in evidence and, as with pupils, alternative conceptions abound. This raises serious questions about the current (UK) government strategy of assessing subject knowledge standards which it is expected that all trainee teachers must meet before being allowed entry to the profession. Such findings raise important issues regarding: science teachers' knowledge of, and need for continuing learning in, science - indeed, it may be that it is the teachers' valuing of learning and enthusiastic engagement *with* their students, which is their major contribution to students' education; the *critical* stance which students should take in relation to teaching and other sources of 'authoritative' information; the importance of *negotiating* meaning. This paper challenges any simplistic view of the roles of teachers and learners and stresses the belief that although teachers must know about their subjects, they need not know everything. The *fact* that many graduate scientists do not immediately have 'the right answers' to some basic scientific questions need not be perceived as a problem, nor should it undermine their confidence as teachers. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 51-60]

KEYWORDS: *chemistry; teacher training; alternative conceptions; evaporation; boiling*

INTRODUCTION

The context of this paper is important. The research has its roots in work by the author with graduate scientists training to become secondary school science teachers. This began some six years ago (Goodwin, 1995), well before the current UK Government initiative to publish 'standards' for beginning teachers' knowledge and understanding in the 'core' subjects of English, mathematics and science (DfEE, 1998).

The following statements are taken from the science standards for primary teachers and serve to illustrate the nature of the requirements for *all teachers* whatever their subject background. In all, these science knowledge standards for primary teachers occupy ten A4 pages.

- most materials can exist as solid, liquid and gas, depending on conditions:
- changes of state can be brought about by transferring energy:

- finely divided substances still contain many atoms and molecules:
- the movement of particles explains the properties of solids, liquids and changes such as dissolving, melting and evaporating. (Taken from Circular 4/98 p. 82)

The thesis of this paper is *not* that these statements are inappropriate or wrong, rather that 'knowing and understanding' them are complex and problematic. Attempting to test comprehensively the intending teachers across the whole range of statements seems likely to be counter-productive. Attempting to 'know' everything *before* qualifying as a teacher seems an impossible task. The science subject criteria for intending secondary science teachers are more stringent. Much more important than personal subject knowledge are professional motivation and confidence to engage in learning before, during and after teaching a particular topic with pupils. It is this confidence to engage in learning, which the testing may put at risk.

Realistically, during any course of initial teacher training, it is unlikely that a student teacher would *actually teach* more than a small proportion of the subject matter covered in 4/98. (Few teachers would address it all during a career!) The value of the statements in providing an overview of the subject, *some* of which they will need to contend during training is not disputed. This, however, is *not* the explicit purpose of Circular 4/98.)

METHODOLOGY

The study was undertaken with a cohort of 52 post-graduate science students who were undertaking a one-year course of initial teacher training for secondary schools. Almost 70% of the sample held 2(i) honours degrees in science or higher. (32 were biologists, 15 chemists and 5 physicists.)

In order to provide a consistent stimulus and framework to the questions a short video was made of situations involving the evaporation and boiling of liquids and the escape of gases from solution. These are met with in a wide variety of everyday contexts such as the drying up of puddles, the boiling of water (and other liquids) and opening of cans or bottles of fizzy drinks. They are also covered in the context of formal science learning at a fairly elementary level. Since they are so 'commonplace' it might be assumed that graduate scientists would have complete familiarity with the processes and a secure qualitative understanding of the models - in terms of randomly moving atoms and molecules - which would explain them 'scientifically'. Earlier studies (Bodner, 1991; Goodwin, 1995) have indicated that graduate scientists do indeed struggle.

After viewing the video the trainees answered a series of questions in writing. Each answer was then judged right or wrong. Where appropriate, the trainees were encouraged to explain or to comment on their answers.

In the context of *this* paper focus will be restricted to three 'simple' questions, which were included in the questionnaire (A brief description of all scenarios, a copy of the video, the questions and the success rates on the questions are available from the author on request):

A. How does the temperature of a liquid change, if at all, when evaporation takes place?

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

C. Why does shaking a can of 'Pepsi' make so much difference to the result when the can is opened? Is the 'Pepsi' boiling?

The responses to each of these questions are considered in turn.

RESULTS

How does the temperature of a liquid change when evaporation takes place?

Just less than *one third* of the respondents gave the expected answer - that the temperature would fall. This was somewhat surprising, especially given the numerous examples of cooling by evaporation which abound e.g. evaporation of 'sweat', wind chill factor and its use in refrigeration.

The majority 'getting it wrong' seems to have a clear belief that the temperature does not change when the 'state' changes. In relation to *boiling* liquids, statements can often be found in textbooks that changes in state and of temperature cannot occur at the same time. As a teacher I certainly used these words. Perhaps respondents learned their science too early! (All quotations given in italics are taken directly from the written responses.)

- *"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 these 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 little difference between biologists and physical scientists except that, where given, the latter produced much longer explanations.

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 & Cosgrove, 1983). A table of results interpreted from their paper and extended to include the results of this study is given below.

TABLE. *What is in the big bubbles you see when water is boiling? (Interpreted from Osborne and Cosgrove 1982, p.829.)*

Bubbles made of	13 years	15 years	17 years	Post graduate
Steam/Water or Water-vapour	8	10	36	50
Oxygen/Hydrogen	38	48	38	25
Air	26	25	23	21
Heat	28	17	3	2

One further option was also given:

> *"There is a vacuum inside the large bubbles. Since the air has been evacuated from above the water, the force on the water upward is greater than that downward, and so the surface becomes disturbed, creating bubbles."* (Phys.)

The model explicit in this final response was applied consistently in a subsequent answer relating to water 'boiling' under reduced pressure.

Opening cans of 'Pepsi' before and after shaking

There is almost total agreement among respondents 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 also seems clear that energy was transferred to the can by shaking and that this 'must be' the basis of the explanation. Putting in energy leads to an increase of temperature and thus an increase of pressure. This is, however, *not* the case.

> 'Unfortunately' the amount of energy transferred to the system is infinitesimal compared with that which would be required to produce a significant increase in temperature/pressure. Thus, the 'correct' explanation must be based on the rate 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 of its own. However, it is clear that almost all 'scientists' certainly tend towards the obvious, but 'wrong', explanation. Even more controversial is the use of the term 'boil' in the previous paragraph. Few people - even graduate scientists and professors of chemistry - really believe it to be appropriate. This author is convinced that fizzing drinks are examples of *boiling solutions***.**

DISCUSSION AND EDUCATIONAL IMPLICATIONS

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 qualification scientists and most have now demonstrated 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. This, hopefully, is effective in promoting learning by the trainee teacher.

If graduate scientists have such a struggle, like the author, with evaporation, boiling (even boiling lemonade) then convincing beginning primary school teachers that they know all about such things seems to be futile. I would contend that the answer is that we should be celebrating teachers' learning rather than over-stressing what they know or do *not* know.

There are a number of important dimensions that seem pertinent to 'lifelong learning' and 'teaching' which are explored in more detail below. These are:

1. Science Teachers' Learning (and engagement with Science)
2. Being Critical
3. Negotiating Meaning

Science Teachers' Learning and engagement with science

It would be silly to suggest that any teacher should know nothing about the subject s/he is teaching. Indeed it would be unprofessional to attempt to teach any subject formally without considerable and appropriate preparation. Teachers *do* need to know and understand lots of things. However, it is contended here that the process of teaching changes the teacher's understanding of the science s/he is teaching. This assumes that the teacher is intellectually involved with the subject and is not simply reading from a script. Some of the very powerful forces which can act to shape the teacher's (our) understanding include:

- personal reflection on questions which students might ask and to which we know we have no satisfactory answer;
- signals from students, more astute than we are, that our understandings are partial, do not make logical sense or are confounded by something they know that we do not. (Many students are reluctant to pass on these perceptions and perhaps teachers could, with benefit, seek them more actively.)
- insights gained from the errors and misunderstandings of those students struggling to make sense of what we are talking about;
- reflection on personal learning experiences.

It is the science understanding developed by these processes that seems to constitute pedagogic science understanding {see Shulman, 1986. P. 9). In many cases it is difficult to see how such pedagogic science understanding differs from the teacher's personal understanding of science. To some extent it is possible for a teacher to prepare to meet these pedagogical complexities by becoming familiar with, and possibly learning from, studies of students' developing conceptions of science. [A thorough review focusing on chemistry has recently been published: Garnett *et al.* (1995).] For the teacher at the start of his/her career too much of this could make teaching seem so complex that it becomes an impossible task. Perhaps the *priority* for the beginning teacher is to provide for him/herself convincing 'stories of science' appropriate to the pupils involved (and consistent with the syllabus). This can be defended and shared with the students - and refined by interactions listed above as well as by using the experiences of colleagues and researchers. [This theme of science stories is picked up in Millar and Osborne (1998).]

It is interesting to note that the literature bristles with studies of student alternative conceptions and it generally seems to be assumed that scientists and science teachers have entirely 'correct' conceptions. In fact, the evidence seems to be that particularly outside our immediate (and narrow) area of interest and expertise, we all have much to learn. Any expectation that a teacher, especially one at the beginning of her/his career, will be fully competent to explain and explore ideas across the whole of science is unreal. A teacher's continuous learning is necessary and should be encouraged and celebrated. Current attitudes and expectations tend to make teachers hide their learning from colleagues and from students. In no way are these comments intended to argue against, or detract from, the high value ascribed to 'teachers' knowledge and understanding of the subject' which is found in school inspection schedules and in competence criteria for initial teacher education. However, they are significant for the way in which the criteria of competence should be used and interpreted. Rather than 'mere' factual accuracy it is an approach to knowledge, which continuously and critically seeks for meaningful, consistent and relevant links between *theory* and *application.* It is the encouragement of this *intellectually involved* approach to learning that is crucial and is central to the thesis in this paper.

Being critical (teachers *and* students)

This requires teacher *confidence* and a learning relationship between pupils and teachers. Classroom based studies (e.g. Carlson, 1993) have shown that teachers who are personally competent in the subject they are teaching are more prepared to ask open and challenging questions of their students (rather than questions requiring answers based simply on recall of taught material). Clearly the teacher who is a subject ‘expert’ is less likely to be caught unawares within the much wider spectrum of answers which open questions inevitably generate. The intellectual involvement of the students requires more than a readiness by the teacher to ask more open questions. This may, however, be a first step. A *relationship* between the teacher and student which both legitimises and encourages the asking of questions *by* the student is necessary.

It is important that students do not learn meaningless material by rote - all the more important for trainee teachers! The following extract from Novak (1990, p. 942) is pertinent:

> “In our studies of the learning patterns of Cornell University students we have found that the large majority engages 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.”

One way of avoiding these sorts of problem is by very skilful questioning and examining of students. Another, and arguably more effective, way is the legitimisation and encouragement of the student checking again (and again) with the teacher, or with others, if the ideas are not making sense. Indeed, this ‘sense making’ by the student is a prerequisite for her/his intellectual involvement. (Ausubel, 1968).

Other situations in which there is need to encourage a critical stance from students are when the teacher makes an error, or when the student actually has relevant information or experience, which is not accessible to the teacher. There are few teachers who never make mistakes. Indeed, there are also few who do not have a number of students in their classes who are more able, or even more experienced in some respects, than themselves.

There are certainly situations in which the students *should be expected* to be considerably more expert in a particular field than the teacher is. I would contend, for example, that a Ph.D. student who, by the end of the programme, did not know more about the topic than did his supervisor had either been given inappropriate supervision or was failing. Even under more usual classroom conditions it is likely that a student who is carefully trying to make sense of the teacher will find some aspects unconvincing and may even be able to contribute insights previously not available to the teacher. (Imagine trying to explain to a group of bright 16-year-old students why the temperature falls well below $0^{o}C$ when salt is added to a quantity of melting ice.) As Mason (1982) p.106, suggests in the context of mathematics education “the first step is to convince yourself. Unfortunately that is all too easy! The next step is to convince a friend or colleague and the third to convince an enemy.” (He also usefully adds “Learning to play the role of enemy to yourself is an extremely important skill, if only because other suitable enemies may be hard to find.")

Thus it seems that teachers and their students should all be engaged in lifelong learning. Where do we find the *motivation* to keep doing it? This promotes a brief digression.

There are all manner of reasons why students wish to learn science and these affect motivation. Some students merely *suffer* it as a compulsory core subject at school (and would have cheerfully given it up had they been allowed). Others are passionately keen to learn (what turned them on?) Yet others study science because they need a qualification to support other ambitions. In many respects it is this last group who are most at risk of attempting to learn science which is meaningless to them - a process which I believe is all too common. It is not possible, nor even desirable, to engender the same motivation levels in all students about the learning of science, although we should aspire to have all students passionately keen to learn *something.*

It seems to be generally accepted that a key feature in the motivation of students is the ability and enthusiasm of the teacher. Informal research on students being interviewed for places on teacher training courses indicates that they almost universally include 'enthusiasm for, and knowledge of, the subject' as a feature of 'the good teacher'.

Clearly there are other dimensions including the values ascribed to education in general, and science education in particular, by family, peer-group and school. Also in various economic, social and cultural contexts there are significant differences in the priorities afforded to education. However, since it appears that *Homo sapiens*, as a species, are uniquely able to 'wonder' (Goodwin 1994) about their place in the universe and 'how things are', surely science education should contribute to this dimension. In part this provides motivation for students and teachers.

Negotiating meaning

When a teacher uses words or symbols to communicate with a student, it is the *students'* interpretation of meaning, which the student receives. Similarly, if the student replies to the teacher using the *teacher's* words, the teacher may believe this to be evidence that the student understands. A student learning responses verbatim and regurgitating them to order can mislead teachers and examiners. This can seriously undermine the educational process. (This is why understanding is most appropriately demonstrated by requiring an idea to be used successfully in a context different from the one(s) in which they were learned.) The consequences for the educational process are frightening if the *teacher* learned the words only to satisfy an examiner.

Unless the subject under discussion makes sense to the student then intellectual involvement is impossible. Under these circumstances either the student gives up study or learns nonsense by rote. The latter is the path of least resistance and is taken by too many students since it frequently satisfies the teacher and can even lead to examination success. Indeed, the more important are the extrinsic motivations to learn such as examination success, social or parental pressure or fear of the teacher, the more likely is the student to learn uncritically by rote.

Time must be taken to explore and negotiate meaning - ideally, if motivation is there, this need not involve the teacher excessively. Students become *independent* learners and learn from other sources and each other too. After all, independence and lifelong learning are probably the major aims of formal education.

CONCLUSION

The above discussion, in the context of science learning, is hopefully applicable in all areas of learning. Key issues (adapted from Goodwin, 1994) include:

- the subject must make sense;
- if we expect students to be enquirers, then teachers must demonstrate a spirit of enquiry;
- teachers do not need to know and understand everything about their subject (but they should continuously explore what they don't know - and re-examine what they (think they) know;
- enthusiasm (for learning) is caught rather than taught;
- intellectual involvement of student and teacher are essential;
- balance is important.

Who is the learner? Ideally everyone involved in the process should be. Certainly, *teachers must be learners* and learning should be valued beyond knowing.

NOTE: An earlier draft of this paper was presented at a Conference on 'Lifelong learning' at the University of Bremen in February 1999.

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