Breaking the Vicious Cycle in Chemistry Education

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1. Introduction:

I have been involved in and have observed chemical education – the teaching and learning of chemistry – at both second level and third level for over 40 years. During that time there has been an increasing awareness of problem areas in the teaching and learning of chemistry, and this has resulted in a considerable research effort in chemical education, and science education in general. We now know more about the problems in teaching and learning science and about successful strategies to combat them, but it does not seem to have much effect on the classroom and lecture hall [1], [2], [3]. The old adage, that teachers teach how they were taught and not how they were taught to teach, still seems to hold true. The actual practice of teaching chemistry in school seems to be little influenced by the research evidence. There is a failure to translate and implement what we do know into effective practice. An Institute for Effective Education [4] was set up at the University of York in the UK in 2009 to encourage this process. The book *Visible Learning* by John Hattie [5] is a report of a meta-analysis of education research to identify the most effective methods for raising student performance.

The problem appears to be that we are locked into a vicious cycle (Figure 1). Teachers are trained (usually at universities) and enter the teaching profession. Whatever they have been taught in their initial training, they have to adapt to the reality in schools and the constraints of the curriculum, resources and examinations. They have to conform to these constraints and the school ethos and often find themselves teaching in a traditional way, much like the way they were taught. Even if exposed to the latest research findings and ideas in their teacher training, they may find it impossible to implement them in practice, for a variety of reasons.

For example, a student doing science for the first time may have alternative explanations (also known as misconceptions) for scientific phenomena. If these, are not challenged and dealt with by an informed teacher, they remain dormant under the surface as default positions, despite what they are taught. Students rapidly learn to give the right answers and how to pass examinations, but may not understand the basic ideas at a deep level and retain their own explanations. These wrong ideas then survive and persist into upper secondary and on into tertiary education, because they are not challenged and the assessment questions are not designed to test basic understanding, as distinct from recall. The students continue to pass examinations and add extra layers of knowledge, but underneath the old ideas remain, like rust under many coats of paint. Under stress these ideas come to the surface, much as rust leaks through the paint coatings. Teacher training may not address and correct these misconceptions, or may do so inadequately due to lack of time, and so the new teacher returns to the classroom still holding their original wrong ideas. They are then not able to recognise or correct these misconceptions in their students, because of their own blindness, and may even teach incorrect ideas, and so the vicious cycle continues for another generation. The problem is not recognised because examination results may hold up and even get better. An interesting study in the UK by Shayer [6] retested a similar batch of students 20 years after their initial study [7] to check on their reasoning ability, using standardised tests. Against a backdrop of improving examination results in the UK, year after year, this new study found an anti-Flynn effect: on the reasoning tests the contemporary students had dis-improved by one grade level. Diagnostic testing in Ireland of undergraduates [8], secondary school students [9] and pre-service science teachers [10] in Ireland reveal very poor understanding of basic chemical ideas at all levels, despite students having taken courses in chemistry and passed examinations, even up to degree level. It would appear possible to study chemistry and pass examinations, and to gain high grades, without understanding the basics in any deep way, and without developing higher cognitive skills. This is almost certainly true of the other sciences as well. The question raised in this paper is whether it is possible to break this vicious cycle.

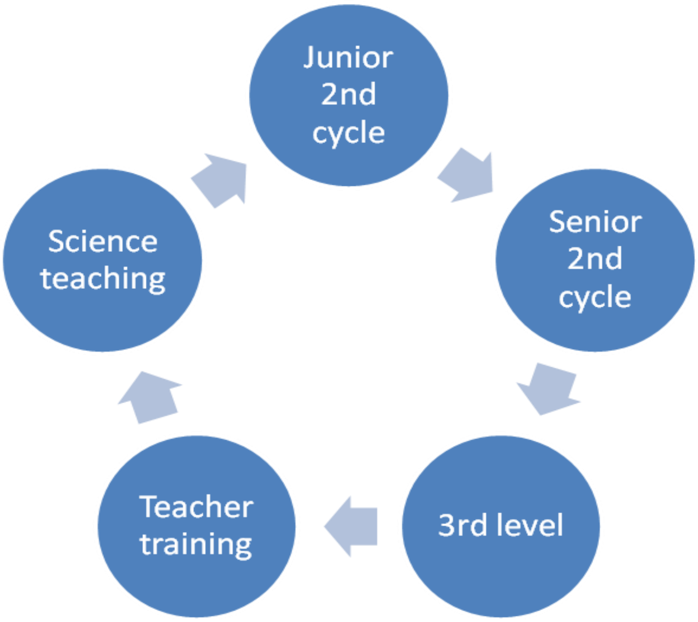

Figure 1 The vicious cycle of chemistry education

2. The vicious cycle

What are the main components of the education system? Figure 2 illustrates the interaction between the three main components: the curriculum (what is taught), the assessment system (how achievement is measured) and the pedagogy (the teaching and learning environment). Each of these aspects is delivered and moderated by the teacher, but two of them are determined externally and are out of the teacher's control: the curriculum and assessment. Each aspect of the system should be informed by the results of science education research (SER), but in practice they are not. [3]

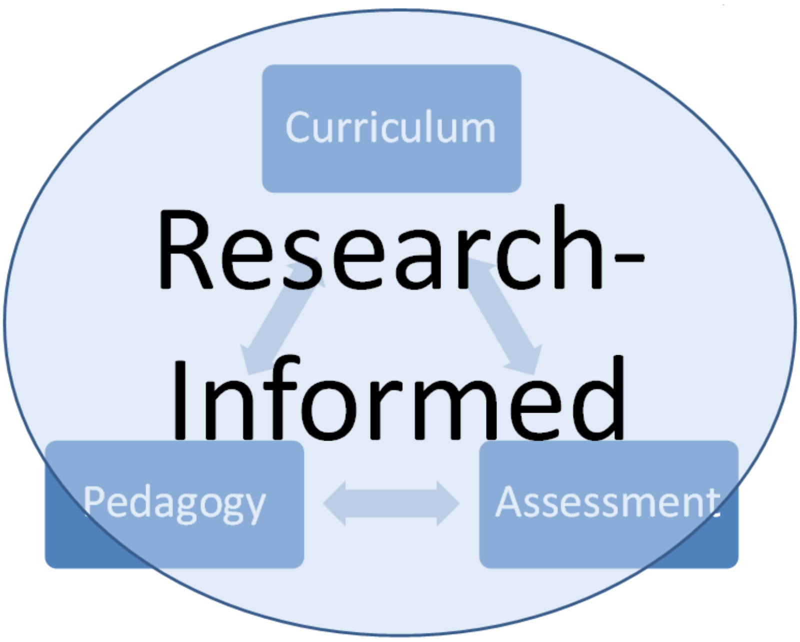

Figure 2 The education system

2.1 The curriculum:

In most countries the curriculum is determined centrally and the content and learning outcomes are specified from outside e.g. by the Department of Education or an examination board. The curriculum may be interpreted within set limits by examination providers in the form of specific syllabi, e.g. in the UK, where several chemistry syllabi are offered by the examination boards, with the same core content but different approaches and emphases. The chemistry teacher has no control over the content of the syllabus or the prescribed learning outcomes.
The curriculum is interpreted and packaged in most countries by science textbooks, produced commercially, which often put their own spin on the syllabus content. Depending on the teacher, the textbook may have a major influence on what is taught and how it is taught and also on what the students learn. Textbook authors are usually experienced teachers but they may not use the results of SER in the way they present material and often the focus is on content knowledge and preparation for examinations.

2.2 Assessment:

Assessment may be formative (usually school-based) or summative (often externally administered). Most school systems have terminal examinations, used for certification and university matriculation. These are centrally organised and administered, by the Departrment of Education or by recognised examination boards, and are linked to the curriculum or specific syllabi. In reality the examinations determine what is taught and how it is taught, and what students are expected to know. Many teachers teach to the examination and prepare students to do well in examinations, rather than developing a love or a deep understanding of the subject. There has been much concern from universities that incoming students are poorly prepared for higher study, both in what they know and understand but also in their attitude to study. There is concern that the quality and preparation of incoming science students has declined over the years, despite good (or improving) examination grades,in both science and mathematics. Employers frequently complain that schools do not develop the skills they want: creativity, individuality, team working, personal organisation etc., in favour of rote learning, examination techniques and conformity. Teachers have no influence on the way their students are examined, except where there are marks for coursework, including practical work, but they do influence the way students learn and prepare for examinations. The pressure for good grades and a good school performance in league tables, can lead to a concentration on examination technique and learning off prepared answers.

2.3 Pedagogy:

The only area where teachers have control is in pedagogy: the teaching and learning environment. They do not control either the curriculum or the examination, but they can determine how the content is taught and the learning experiences of their students. The teacher's ability to teach chemistry effectively will depend on their own in-depth knowledge and understanding of the subject, often assumed to be provided by their own education in the subject (at school and university), and the teaching skills developed during pre-service teacher training (concurrent or consecutive), their in-service experience and continuing professional development (CPD) courses. It is assumed that a good science degree guarantees a good understanding of science and makes a good teacher: neither of these beliefs is supported by research evidence. There is also an assumption that the one or two year's postgraduate course (consecutive model) or a four year concurrent course, together with school-baseds teaching practice, will provide sufficient pedagogical preparation and will equip pre-service science teachers (PSSTs) to utilise science education research (SER) and develop evidence-based practice. Again there is little evidence to support these two beliefs.

3. Breaking the cycle

How can we change this situation in order to embed the results of SER in the practice of science teaching and learning? Simply putting more content into the initial training of PSSTs will not work, even if the time was available. The main problem is that the system as a whole (Figure 2) is not influenced by SER: pedagogy, curriculum and assessment need both to be integrated with each other and informed and directed by SER. The demands of the curriculum and the strait-jacket of examinations restrict the freedom and time available to the teacher to teach science in a way consistent with the ability and age of the students and the nature and demand of the science content.

When PSSTs go into the profession they have to adapt to the reality in schools and jettison much of what they have been taught in their own training. They may also be sent back into schools with their own unrecognised and unchanged misconceptions about science, and incorrect ideas about teaching and learning. So we must start there, by ensuring that PSSTs both understand the basics of their subject, and can recognise and deal with their student's difficulties, and know how to translate the findings of SER into STL. This means that they need to be aware of the findings of SER, they need to have experience of translating these findings into classroom practice, and ideally they need to have personal experience of doing SER. We are in the middle of a project to try and equip PSSTs with sufficient understanding of chemical misconceptions and how to recognise and deal with them, so as to improve their classroom practice. [10]

Teachers have to work with the existing curriculum so we have done two curriculum development projects, which seek to use the results from SER to improve the teaching of the particulate nature of matter and the mole [11] [12] and organic chemistry [13] [14], working within the exisiting chemistry syllabus, but changing the way it is taught. Both projects showed that this was feasible and that students taught in the new way performed better than control groups.

There is also a need for career-long CPD both for new teachers and in-service teachers, to make sure everyone understands the basics, and is kept up-to-date with their subject, and is aware of and is able to access and apply SER in their classrooms. There are many factors that work against this [3] and there is a need to translate the results of SER into a form where teachers can use the ideas in school. We have tried to do this through short, four-page *Research & Resource Guides*, which aim to summarise ideas about research or sources for the practising teacher (see [15]).

We need to adopt a systems approach to the education system (Figure 2), so that the curriculum and assessment are brought into line with the way the subject is taught and all aspects are informed by research and best practice. The assessment, both formative and summative, needs to match the learning outcomes of the curriculum, and actually test the main skills specified in the curriculum. For example, if an aim of the curriculum is scientific literacy, then questions must test skills like comprehension and application. Often a range of skills, at different cognitive levels, are desirable outcomes of the curriculum and there must be a systematic match between these and the things examined. An examination with a high degree of choice makes it difficult to ensure that all candidates are assessed in the same way and favours predictable, standard questions. An examination with no choice, allows the whole syllabus to be covered and allows for a range of question type, assessing different skills, and the various cognitive levels can allowed for in the design of the whole paper and in individual questions. Such an examination would ensure that teachers prepare their students to achieve all the learning outcomes and develop a range of intellectual skills.

4. Conclusions

Breaking the vicious cycle in science education requires a systems approach. Starting with the training of PSSTs is important but can only be a part of an overall solution. All the stakeholders in the education system (teachers, textbook authors, science education researchers, curriculum developers, examiners, CPD providers, science teacher trainers, inspectors, university staff, industrialists etc.) need to collaborate on designing a system, which is fit for purpose and draws on SER as well as science content, in order to deliver an effective science learning environment in school.

One which can deliver scientific literacy for all and also equip science specialists for further study and employment. Although much has been done, especially in SER, much remains to be done to ensure the best science teaching and learning, whatever the level, ability, gender and aspirations of our students.

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