Emmanuel College

THE UNIVERSITY OF QUEENSLAND

Teaching Scientifically

By

Professor Susan Hamilton

President, Academic Board, The University of Queensland

EMMANUEL PAPERS

NUMBER 12 – MAY 2011

Emmanuel College
The University of Queensland
Enriching lives since 1911

Emmanuel College is Australia's ninth, and with St John's College, The University of Queensland's first residential college to gain affiliation. It was founded by the Presbyterian Church of Queensland in 1911 with the first students taking up residence in Wickham Terrace in 1912. As the Presbyterian Church moved towards partnership with other religious denominations during the 1970s, Emmanuel College also came under the auspices of the Uniting Church. Upon its inauguration, Emmanuel College was an all male residence but this changed in 1975 when women were admitted as collegians. Now, the College numbers around 340 students with half our population being female.

Further change was experienced by the College when it moved in 1955 from its original site in Wickham Terrace to its present location on the main university campus in St Lucia.

Since 1911, Emmanuel has stood for excellence in all round education and has had seven Rhodes Scholars during its history. Its graduates have gone on to make a major contribution to Australia in many areas, including as doctors, scientists, teachers, engineers, lawyers and judges, politicians, ambassadors and diplomats, and church leaders.

THE AUTHOR

Professor Susan Hamilton

Professor Susan Hamilton is the President of the Academic Board at The University of Queensland. She is also Professor of Biochemistry with particular interests in the structure, function and engineering of proteins.

Her research has been on enzymes involved in bone resorption and enzymes with commercial application in brewing, sugar refining and meat processing. She has longstanding interests in science education and women in science.

Susan chairs the Education Committee of the International Union of Biochemistry and Molecular Biology and has ALTC funding for two projects on assessment. Susan is also a Fellow and member of the Council of Women's College.

This speech was delivered at the Emmanuel College School Principals' Dinner on Thursday 12 May 2011.

Teaching Scientifically

Just for background – I come from an immediate family made up exclusively of secondary school teachers – and probably would have happily ended up similarly except for the intervention of biochemistry. The impact of a single charismatic teacher of the relatively new discipline of biochemistry in my second year of university led me down the path of biochemistry research, with a special interest in the structure and function of proteins. This in turn led to a variety of fascinating projects doing basic research aimed at determining the three dimensional structure of novel proteins and more applied industry projects with the sugar and beef industries, and drug development related to osteoporosis. However I have maintained a close interest in science education - as director of the Bright Minds project which provided all sorts of professional development for teachers, as a member of the now extinct science advisory committee of QSA and as chair of the committee that developed the curriculum for Science21, the general senior science subject replacement for multistrand science.

Now this may not necessarily recommend me to you highly. I am aware of the many different views that have been expressed about Science21 and some of the difficulties in its implementation. Nevertheless I remain committed to the view that a broad general education in science and its impacts in the modern world is fundamentally important for all students. Whether or not grade 12 is the last formal education in science that an individual is to have, I would place a general course such as Science21 ahead in importance over a specialist course such as chemistry. I would also try to allocate the best teachers and the best resources to the course, and would work to convince universities that it is an entirely suitable course for meeting science entry pre-requisites for any program.

As a result of these interests and as a university teacher I have been forced to ask the question:

What should we be trying to do in science education starting in primary school through secondary school to university and beyond?

It is clear that even we are not trying simply to train the next generation of scientists. We need a **scientifically literate populace** to address the global challenges that only science can explain and possibly mitigate such as global warming, and to thrive in an economy largely based on science and technology we need **technically literate citizens** with **complex problem solving skills**. This is a huge challenge but I think it is achievable – but only if we use the tools that scientists use in research and apply them to our teaching - that is, we "**teach scientifically**".

Which is the topic of this short talk. The title is more or less taken from an article published in the journal *Science* in 2004. The journal is of course one of the most prestigious places in which scientists publish the results of their original research. At the instigation of its editor Bruce Alberts, a distinguished biochemist and previous president of the US National Academy of Science - the journal also takes a leading role in discussing issues around science education, which is very fortunate because it has raised the profile of science education issues immensely in the eyes of research scientists - because while most do not read education journals they do read *Science* (some would rather die in a bog than read an article in an education journal).

The 2004 article posed the question: **Why do outstanding scientists who demand rigorous proof for scientific assertions in their research continue to use and, indeed, to defend on the basis of the intuition alone, teaching methods (and the subtext here is "the didactic lecture") that are not the most effective?**

When I first taught biochemistry in the late 1970s I used the approach to delivering lectures that is still all too common when someone is called on to teach something for the first time. First, I thought hard about the topic till I got it clear in my own mind. Then I explained it to my students in a lecture and if they did not understand I explained it again in a tutorial. They thought I was a pretty good teacher which in turn made me think I was a good teacher. But by any measure I used to find out how much they understood it was clear this did not work - the great majority did not get the concepts, and could not use them in a new context.

What I did not have, and what was still emerging from studies in cognitive science, was any understanding of how people learn. In particular that the prior knowledge of learners determines to a large extent what each individual can learn from a particular situation.

- That it is not productive simply to try and pour facts into their brains.
- That each person must assimilate and make sense of new ideas by connecting them in a logical way to what they already know.

- That such knowledge construction is very hard work, especially when the new information is counter-intuitive and defies everyday experience. Which was exactly the case for most of the big ideas that underpin the biochemistry that I was trying so hard to teach.

Consider this example with which you may already be familiar: in a Harvard/Smithsonian video made some years ago an interviewer shows fourth graders first a seed and then a dry log from a tree. “Where does the weight of the tree come from?” she asks. The fourth graders say, “the sun, the soil, rain, nutrients.” The interviewer presents the same question to students graduating from MIT and Harvard and *gets the same answers from most of them*. Every student has had high school biology. Some have studied biology in college. Some have even majored in biology. Biology professors who have asked this question in their classrooms, even after spending a week or two on photosynthesis, generally find that a large proportion of their students are unable to answer the question correctly. The students memorize details about photosynthesis including the formula, but *they miss the main idea*.

It is gradually discovered when students are questioned more closely that the student believes that air has no weight. How can you take a substance from this weightless, invisible air and create something as massive and heavy as a tree? It does not make sense. Since it makes no sense, students dismiss that part of the formula. At the same time, students attribute the weight of the tree to the soil because soil is known to have weight, even though there is no soil in the formula for photosynthesis.

Misconceptions such as this impact students’ abilities to learn in any science subject. They tend to be shared by a significant proportion of a population, and are remarkably resistant to being “taught away” they persist. Good students can get around it by memorizing correct answers and regurgitating them on tests, but if they have not understood why those responses are correct, the information will quickly fade away and will not be useful in new contexts. So how can a teacher find out about them and do something to address the problem?

In 1992 physics educators in Arizona developed a multiple choice Diagnostic Test to assess student understanding of Newtonian mechanics, based on what they knew of common misconceptions in the area. Each question in this test forces students to make a choice between Newtonian concepts and very attractive, commonsense (but incorrect) alternatives or misconceptions.

Simple everyday scenarios such as car and a truck colliding are the basis of the questions.

When instructors first view the test, they tend to think that it is much too easy and their students will ace it. In most cases, however, instructors are shocked by their students' poor performance. The test reveals that even students who get As and Bs in physics classes often do not understand the most basic physics concepts.

The authors concluded: Every student begins physics with a well-established system of commonsense beliefs about how the world works derived from years of personal experience . . . these beliefs play a dominant role in introductory physics. Instruction that does not take them into account is almost *totally ineffective*, at least for the majority of students.

These tests have now been given in hundreds of college and high school physics classes involving thousands of students. By using the tests as pre and post instruction tools, they have provided compelling evidence for the relative ineffectiveness of didactic lecture instruction in introductory physics and for the much better outcomes obtained with well-designed, hands-on, student-centered lessons and interactive learning strategies.

The important thing is that the test for the first time gives teachers compelling data on their students' learning which was inescapable in its implications for teaching. And it is starting to have a significant impact on university science teaching in physics and beyond.

Supported by the ALTC, my colleagues and I over the past two years have developed a similarly structured diagnostic test that we are using to find out what students understand about key concepts especially around chemistry coming into our introductory biochemistry classes from secondary school and from first year university.

Some of the most common misconceptions we see in biochemistry include the belief (80% of students) that the mass of the food we eat is turned into energy and that a molecule of hemoglobin in the blood "knows" when and how to release oxygen to the tissues. It was indeed a sobering experience to find that the average result for a class on our test was - as in physics - typically no better than 50% and that it is much the same before and after a course of teaching.

On the basis of the data obtained from the test we can and are now doing several things to improve outcomes :

- Give students information on areas of weakness at the start of a course
- Effectively directing attention to those conceptual areas where students are weakest or where there are deeply embedded misconceptions and not wasting time unnecessarily on other areas
- Adopt teaching strategies which are shown to be the most successful in improving conceptual understanding

One of the big challenges is to make the time and space in the curriculum to bring about such changes - and it inevitably means reducing the content of each course. This I think is the biggest challenge ahead at a time where content knowledge in science is growing so fast – and when the use of powerpoint is so pervasive.

The important thing is that we are now for the first time getting tools to provide good data on the efficacy of our teaching which as scientists we cannot ignore.

Which is not the death of the lecture. I think there is another highly attractive misconception out there that lectures are by definition purely didactic and therefore ineffective. The sort of data being generated by the use of these diagnostic tests is causing us to re-think how we teach in large groups as well as small groups for better learning. There is a lively discourse happening and new approaches being tried and for the first time it is backed up by real experiment and real data which is very powerful. The lecture is not dead – it just needs some intelligent re-envisioning.

So to return to the original question: What should we be trying to do in science education?

I believe a successful science education needs to transform novice students so that they can understand and use science as scientists do.

Is this possible?

I think the science education community is beginning to think that it is possible but only if we take a scientific approach to teaching science.

Which means using the approaches that science has used so effectively:

- Developing effective teaching practice based on objective data – not anecdote and tradition
- Using what we now know about how people learn to inform teaching.

Emmanuel College
Sir William MacGregor Drive
St Lucia   QLD   4067

Tel: + 61 7 3871 9100   Fax: + 61 7 3870 7183
enquiries@emmanuel.uq.edu.au   www.emmanuel.uq.edu.au