What I observed, learnt and thought about tertiary education at The University of Sydney: Comparing, thinking, and planning in science teaching and learning

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Abstract

From June 19 to October 28, 2006, I attended a collaborative project between The University of Sydney (USyd) and the China Scholarship Council, which included a series of professional development courses, seminars, and observations for Chinese university science teachers at USyd. In the following sections, I am going to summarise briefly what I observed, learnt, and thought about tertiary education during the project in terms of the following four aspects:

1. science education and its significance and effects on society;
2. current trends in educational ideas and pedagogical theories;
3. components of education systems and a comparison between them; and
4. problems or difficulties in the process of education evolution.

I should declare here first, that the education I am talking about will focus mainly on science education, and in particular on Chemistry and its related educational issues.

Science education and its significance and effects on society

Science education is extremely important since it is relevant to educating future generations, and to science and technology that have very real effects on the whole of our society, economy, and military defence of our country. The past wars, especially World War II, the Gulf War, and the Iraq War, well demonstrate that science and technology are extremely crucial for our military endeavours. With the development of the economy, globalisation, science and technology (especially high technology such as information technology (IT), biotechnology, and nanotechnology), continually show that they have had very real effects on national commercial endeavours. As a result, some science educators believe that science should be taught in general, practical, real-world terms so that everyone in the whole of society could understand and appreciate how science and technology affect society [1].

It is not questionable that science education is extremely important, however, the process of science education is complicated. We need to build an education system to educate future generations. Secondly, to make it work well, educators should continually research the cognition process and the associated psychological process of human beings, which is a complicated research area. Education research is scientific research that can be done well or not so well. Unfortunately in China it is not usually done well due to the lack of focus within the higher education system. The other important reason why the science education process is complicated is that the teaching and learning process or behaviour is 'chaotic' [2,3]. There is no 'one-way' that people teach or learn science, all educators and learners are different. Therefore, there is no 'one right way' to teach and learn science. However, this does not mean that educators should not do something in the area of science teaching and learning. Since it is an open-ended scientific problem with extreme importance for society, educators have a responsibility to carry out education research to constantly improve the quality of the science education process. The ultimate goal for educators is to construct the best and most efficient public tertiary education system (PTES), whose principal purpose is to enhance the scientific and cultural quality and generic capabilities of a whole nation. A better and more efficient PTES should not only maintain common characteristics in science teaching and learning, but also be compatible with, and supportive of, individual speciality development in terms of contemporary education ideas and theories coming out of educational research.

To construct such a PTES is of special and realistic significance for the development of China. As is well known, the GDP of China has kept increasing at a speed of over 10% per annum in the past decade, which is miraculous in the context of the worldwide economy. China has been currently called ‘the worlds’ manufactory’, however, due to lack of a own core technology, especially a core high technology, the sacrifice to this development in China is tremendous, especially in the field of environmental conservation. How to maintain a continuing and harmonious (scientific and environment-friendly) development of our economy and society in China is a big challenge and realistic problem. One, most likely unique, solution to the problem is a science and education-based strategy.

The national scientific and technology conference of China held in 2006 called for the creative capability of science and technology as it is crucial to the future continuing and harmonious development of China. Where does the creative capability come from? It only comes from the next generation with an ability to think creatively about different issues and associated skills such as independent and interdependent problem solving skills and lifelong learning skills. These capabilities and skills are just what PTES should deliver and achieve.

Current trends of educational ideas and pedagogical theories

Educational ideas belong to ideologies which instruct educators to build and reform the systematic engineering of tertiary education. After World War II, there were two different ideologies in the USA [1]. Some science educators believed that science should be taught in general, practical, real-world terms so that everyone in the whole of society could understand and appreciate how science affects them. Other science educators believed that science should be taught in ways that would increase the number of scientifically trained workers because there were extreme shortages of qualified scientific, technical, and industrial workers after the War [4]. After the launch of Sputnik by the Soviet Union on October 4, 1957, science education in the USA experienced a crisis which shifted science education away from the rigorous study of the sciences as disciplines toward the study of sciences in terms of personal and social relevance [1].

Education ideas and education theories are usually correlated with each other. The recent trends within education are of ideas and developments in pedagogical theories affecting Western universities over the past decade. These are briefly summarised as the following [5]:

1. a move from a behaviourist view of teaching and learning toward a more constructivist and developmental view of teaching and learning;
2. a move from teaching students concrete discipline concepts and knowledge toward delivering students generic skills, especially problem solving skill, lifelong learning skill, teamwork capability and ability in written and oral communication;
3. a move from a strongly teacher-centred approach in teaching and learning toward a more student-centred approach in teaching and learning; and
4. the recognition of the idea that students must be more active participants in the learning process wherever possible, in order to promote a deeper level processing of knowledge and encourage them to take greater responsibility for their own learning.

In addition to stressing the delivery of the generic skills mentioned earlier, I personally hold that discipline knowledge and capability is indispensable because it is an inevitable pathway for students by which they acquire the various generic skills training. For example, in the major or degree of chemistry education, experimental skills such as synthesis, instrumental analysis, molecular modelling, and integration skill, as well as a broader knowledge of chemistry, life science, materials science should be delivered to the students. Simultaneously, philosophy of science and associated ethics should be delivered to the students to help them to build their own attitude to the universe and life.

Behaviourist, developmentalist, and constructivist are three essential contents of the main stream of education theories in Western countries. The behavioural theorists see the learner as an empty vessel, needing to be efficiently filled up with correct scientific knowledge, learned in discrete and small stages, using a process of structured and sequenced learning stages, with each stage being positively reinforced once mastery of it has been demonstrated [5]. The developmental theorists see the learner as developing through a series of inherent stages associated with intellectual and cognitive growth process. They need to assimilate significant ideas and fit them together into an intellectual schema. Their conceptual understanding tends to occur in leaps when coherent schema are formed [5]. The constructivists see the learner as coming to any learning situation with an existing set of beliefs, values and understandings (correct, partially correct or incorrect) and that the teaching and learning experience they have with you only makes sense in terms of what they already know [5].

Teachers should be very careful when they choose pedagogical methods in their teaching process. In my personal opinion, there is no unique education method which can work universally. A sensible mix of pedagogical methods and teaching styles to educate students is popular.

In my personal understanding, there exist two fundamental but extremely important loops or circles in higher education (especially science) teaching and learning: one is the learning loop in which learner is the main player, the other is a teaching loop in which teacher is the main player. These two loops are correlated and interacted closely with each other. Otherwise, the education system cannot work well. In the constructivist theory, the learning loop has already been well described and focused, which is called a constructivist learning circle [5]. Herein I am going to stress the teaching loop a little further. In the teaching loop, the responsibility and task of the teacher is to constantly acquire the teaching skills and knowledge, to become an accomplished teacher (See USA National Board of Teaching Standards in Higher Education (2000) for details [5]). From the point of view of teaching-skill-acquisition, teachers themselves are learners in the teaching loop, doing problem-based learning. Accomplished teachers should gradually achieve understandings and capabilities in the teaching loop.

They must:

- be capable of having a rich understanding of the subject knowledge they teach and appreciate how knowledge of their subject is created, organised, linked to other disciplines and to realworld settings;
- develop critical, analytical, problem solving and lifelong learning capacities in their students;
- be capable of commanding specialised knowledge of how to convey and reveal subject matter to their students;
- have pedagogical content knowledge;
- be capable of commanding a wide range of teaching strategies that enable them to organise, adapt and present the curriculum in ways that take account of the specific context in which they teach and of the way students learn;
- be capable of knowing the preconceptions and background knowledge that students typically bring with them to each discipline, and of teaching strategies and instructional materials that can be of assistance;
- be capable of understanding where difficulties are likely to arise and modify their practice accordingly; and
- be capable of employing their instructional repertoire to create multiple paths to the subjects they teach and they will be adept at teaching students to pose and solve problems on their own.

In chemistry teaching, accomplished teachers should be further capable of showing students the magic of chemistry, showing them the giant contributions of chemistry to the reality of society and the economy, including industrial, agricultural, medicinal, and material applications, etc.; showing them that chemistry is central pillar of human culture [6].

Components of education system (university) and their comparison

There is a viewpoint that argues 'top teacher' plus 'top student' plus 'top instruments and facilities' is equal to 'top university'. Maybe the statement is incomplete, however, from it one can see that the three essential constituents of universities are teachers, students and academic equipments. A sophisticated educational idea of a university is also very important, which is most likely responsible for the characteristics of any university. In addition to them, curricula, syllabus, teaching service, feedback and assessment system, and IT-based teaching and learning systems are also important components of a university education system. In the following part, the concrete settings of degrees, curricula, syllabus, lectures, practices, and teaching staffs are compared between USyd [7,8] and Central China Normal University (CCNU), mainly focusing on science and chemistry education, followed by a brief analysis of data tables, discussion of the strengths and weakness, and identification of 'take home messages'.

Table 1. Comparison of science degree settings

Science at USyd	**Science at CCNU**
BSc and BSc (Advanced) BSc (Advanced Mathematics, Bioinfomatics, Molecular Biology & Genetics, Environmental, Marine Science, Mole Biotech, Nutrition & Dietetics) **Combined Science Degrees**: Bachelor of Science & Technology, Bachelor of Computer Science & Technology, Bachelor of Information Technology, Bachelor of Medical Science, Bachelor of Psychology The choice of 29 specialist majors in one degree	BSc Mathematics BSc Physics BSc Chemistry BSc Biology BSc Computer Science BSc Environmental Science

It is clear from Tables 1 and 2 that degree settings at USyd are flexible and cross-disciplinary. USyd sets up a priority for life science, computer science and IT, reflecting the trends of contemporary science developments. Degree settings at CCNU are relatively fixed and less inter-disciplinary. We have realised the weakness of this kind of settings and are starting to make changes. For example, attempts to teach undergraduates at the interface of chemistry and biology is a collaborative project between the School of Chemistry and the School of Life Science. Tables 1, 2 and 3 show that Chinese students at CCNU experience a greater workload for attending lectures and therefore which reflects a typical behaviourist teaching style.

Table 2. Comparison of degree structure: BSc (Advanced)

USyd	CCNU
1st year: Mathematics, Science Elective 1 and 2, Elective	Mathematics, Physics, English, Major Fundamental
2nd year: Major 1 and 2 Intermediate*, Elective	Physics, English, Major Fundamental
3rd year: Major 1 and Senior*, Elective*	Major Senior, Elective
4th year: Honours and Graduate Diploma Projects	Major Elective, Practice,* BSc Degree Thesis

Table 4 shows that the number of students studying in the School of Chemistry at USyd is not fixed. They have to do their best to attract students to continue to study in the School of Chemistry in the first and second year, which is a challenge as well as an opportunity. From my own observation it seems they have done well. The Faculty of Science at USyd is considered by many people to be the leading science faculty in Australasia. They have top local students and a lot of overseas students. For the really talented students, they have a talented students program. From Tables 5 and 6 it can be seen that a series of interdisciplinary curricula and intradisciplinary syllabus have been put forward for students at different levels and coming from different science degrees. Impressively, most parts of knowledge and concepts of chemistry discipline have been integrated into two courses (CHEM1101/1901 and CHEM1102/1902, see Table 6 for detail) for the first year chemistry study. We still educate students in terms of a second order classification of chemistry (inorganic chemistry, organic chemistry, analytic chemistry, physical chemistry and structural chemistry).

Table 3. Comparison of credit points (cps) for BSc degree

BSc & BSc (Adv) at USyd	BSc of CHEM at CCNU
At least 12 credit points of Mathematics required 6 credit points/unit 48 credit points (~8 units of study)/year Totally 144 credit points need for BSc Degree	Advanced Mathematics, 143 hrs 8 credit points; Linear Algebra, 34 hrs, 2 cps; Probability & Statistics, 34 hrs, 2 cps; General Physics, 120 hrs, 8 cps College English 64*4=256 hrs, 16 cps 1 cp/16~18 hrs Totally 154 cps need for CHEM Degree

Practice is the most important teaching and learning sub-loop for chemistry students to deliver their various skills and capabilities, including pre-laboratory work, experimental records and reports and experimental performance. Due to the size constraints of this paper, I can not compare practice between the two universities in detail, however, the following issues deserve to be pointed out. They often collect practices from the papers published in the recent academic journals instead of from experimental textbook. They strongly stress safety and ethical education in practice teaching. They use a demonstrator strategy in the laboratories. All these actions are valuable for reference in our practice in teaching and learning.

Table 4. Comparison of student resources for the School of Chemistry

CHEM as a major at USyd	BSc of CHEM at CCNU
No. of student is not fixed, Attracting students	Pre-occupied and fixed (150/y)
Top local students + a lots overseas	A few top + most over average
Full time and part time	Full time
Living in home	Living on Campus
Talented Students Program	Special Program (Chemical Biology) for Talented Students (30/year)

Table 5. Comparison of curricula settings of Chemistry

School of Chemistry at USyd	School of Chemistry at CCNU
First year	**First year**
Fundamentals of Chemistry 1A/1B (CHEM1001/2): Chemistry background is weak Chemistry 1A/1B (CHEM1101/2): Junior Chemistry unit of study Chemistry (Veterinary Science) (CHEM1405) Chemistry A/B (Pharmacy) (CHEM1611/2) Chemistry 1A/1B (Advanced) (CHEM1901/2): Advanced units of study, very good background Chemistry 1A/1B (Special Studies Program) (CHEM1903/4): truly exceptional student Chemistry 1 Life Science. A/B (Advanced) (CHEM1908/9)	Inorganic and Analytical Chemistry (S2, 54hous, 3 cps) for BSc BiologyFor BSc ChemistryGeneral Chemistry (S1, 50 hours, 3 cps) Inorganic Chemistry (S2, 48 hours, 3cps) Analytical Chemistry (S2, 54 hours, 3cps)
Second year	**Second year**
Core unit Molecular Relativity and Spectroscopy (S1) 3 levels: Normal, Advanced, SSP (CHEM2401/2911/2915) Chemistry Structure and Stability (S2) 3 levels: Normal, Advanced, SSP (CHEM2402/2912/2916) **Elective Unit** Forensic and Environmental Chemistry (S1, CHEM2404) Chemistry for Biological Molecules (S2) 2 levels: Normal, Advanced (CHEM2403/2913)	Organic CHEM (S1, 54hours, 3cps) for BSc BiologyFor BSc ChemistryOrganic Chemistry (S1/2, 100hours, 6cps) Physical Chemistry (S2, 72hours, 4cps) Instrumental Analysis (S2,48hours, 3cps)
Third year	**Third and Fourth years**
Biomolecules: Properties and Reactions (S1, CHEM3110/3910): Normal and Advanced Organic Structure and Reactivity (S1, CHEM3111/3911): Normal and Advanced Materials Chemistry (S1, CHEM3112/3912): Normal and Advanced Catalysis and Sustainable Processes (S1, CHEM3113/3913): Normal and Advanced Metal Complexes: Medicine and Materials (S1, CHEM3114/3914): Normal and Advanced Synthetic Medicinal Chemistry (S1, CHEM3115/3915): Normal and Advanced Membranes, Self Assembly and Surfaces (S1, CHEM3116/ 3916): Normal and Advanced Molecular Spectroscopy and Quantum Theory (S1, CHEM3117/3917): Normal and Advanced	Structural Chemistry (S1, 54hours, 3 cps) Biological Chemistry (S1, 54hours, 3cps) Fundamental Chemical Engineering (S1, 48hours, 3 cps) Chemical Informatics (S1, 36hours, 2 cps) **Elective Courses** (S1/2, 36hours, 2cps) Advanced Organic Chemistry Synthetic Chemistry Coordination Chemistry Molecular Modelling Material Chemistry Pesticide ChemistryPolymer Chemistry Contemporary Physical Chemistry Environmental Chemistry Green Chemistry Medicinal Chemistry

Table 6. Syllabus of CHEM1101/1901 and CHEM1102/1902 courses in the School of Chemistry at USyd

CHEM1101/1901		**CHEM1102/1902**	
W1.	Introduction, Nuclear and Radiation Chemistry	W1.	Representations of Molecular Structure
W2.	Nuclear and Radiation Chemistry (continued)	W1.	Alkanes
W2.	Periodic Table and the Periodic Trends	W2.	Alkenes
W2.	Wave Theory of Electrons and Resulting Atomic Energy Levels W3. Shape of Atomic Orbitals and Quantum Numbers W3: Filling Energy Levels in Atoms Larger than Hydrogen	W2.	Alkynes
W3.	Atomic Electronic Spectroscopy	W2.	Aromatic Compounds
W4.	Material Properties (Polymers, Liquid Crystals, Metals, Ceramics)	W2:	Organic Mechanisms and Molecular Orbitals
W4.	Bonding in H_2 – MO theory	W3.	Structural Determination
W4.	Bonding in O_2, N_2, $C_2H_2$and C_2H_4W5. Band Theory – MO in Solids	W4.	Alcohols
W5.	Polar Bonds	W4.	Amines, Introduction to Synthetic Strategies W4. Stereochemistry
W5.	Ionic Bonding	W5.	Stereochemistry continued
W6.	Lewis Structures	W5.	Organic Halogen Compounds
W6.	VSEPR	W6.	Aldehydes and Ketones
W7.	Liquid Crystals	W6.	Carboxylic Acids and Derivatives
W7.	Gas Laws	W7.	Carboxylic Acids and Derivatives continued
W8.	Thermochemistry	W7.	Synthetic Strategies
W8.	Enthalpy and Entropy	W8.	Strong Acids and Bases
W9.	Enthalpy and Entropy Continued	W8.	Weak Acids and Bases
W9.	Oxidation Numbers	W8.	Calculations Involving pK_a
W9.	Nitrogen Chemistry and Compounds	W9.	Periodic Trends in Aqueous Oxides
W9:	Nitrogen in the Atmosphere	W9.	Intermolecular Forces and Phase Behaviour
W10.	Chemical Equilibrium	W9:	Physical States and Phase Diagrams W10. Phase Diagrams (2 Components)
W11.	Equilibrium and Thermochemistry in Industrial Processes	W10.	Crystal Structures
W11.	Introduction to Electrochemistry	W11.	Solubility Equilibrium
W12.	Electrochemistry Continued	W11.	Hydrolysis of Metal Ions
W12.	Electrochemistry (Batteries and Corrosion)	W12.	Metals in Biology
W12.	Electrolytic Cells	W12.	Coordination Chemistry
W13.	Types of Intermolecular Forces	W13.	Kinetics
W13.	Polymers and the Macromolecular, Consequences of Intermolecular Forces	W13.	Kinetics – Influences
		W13.	Kinetics – Catalysis

Table 7. Comparison of practice settings.

School of Chemistry at USyd	School of Chemistry at CCNU
First year Practice (Fundamental Inorganic, Organic Experiments)	**First year**Fundamental Experiments
Second year Practice (Quantitative Analysis, Organic)	**Second year**Intermediate Experiments
Third year Practice (Organic, Physical, Inorganic CHEM) Consisting of Core and additional Experiments, Projects, Workshop *Tuesday~Friday 1:00 – 5:00 pm Laboratories Open	**Third year**Advanced Designed Experiments Pay more attention to the normative manipulate of fundamentally experimental skills.

In section two we discussed that to be accomplished teachers is an extremely important issue in the teaching-loop since teachers are the most important component of a university education system. Most members of academic staff in the School of Chemistry at USyd are gifted teachers, and their teaching is outstanding. They are usually capable of teaching multiple cross-discipline or intra-discipline courses. There is about thirty teaching staff in the School of Chemistry and they are responsible for the teaching of over two thousand students in the Faculty of Science. Therefore, they work in a very highly efficient way. This is attributed to a set of rational academic-staff recruiting procedures. Each new academic staff member has a six months probationary period and three to five years confirmation period. After that, each staff member accepts performance management and development assessment each year. This procedure effectively guarantees the academic staffs working at USyd are well trained and versatile.

Problems or difficulties on the way to education evolution

The context discussed before shows that PTES is a real example of complicated systematic engineering. Many aspects of the education system are responsible for its running efficiency and quality. What universities should deliver and achieve and how universities can achieve them are the recurring themes of education evolution. It is an open-end, real-world problem with extreme significance to the greater society. There are a lot of difficulties endemic in different aspects mentioned in sections 2 and 3 on the way towards education evolution. In the present paper I have only addressed problems or difficulties which existed in aspects of the assessment system. Since assessment criteria are a major driving force in science teaching and learning, it can and does function as a lever.

First of all, how to assess students learning and evaluate academic staff teaching has been a contentious argument for a long time. Of course, each university has its own assessment system. However, does it work correctly or efficiently? It is an area for educators to study carefully? In principle, how to balance the following three categories of assessment is important in assessment settings. (1) How to assess teachers of university in terms of their outcome from doing scientific research and their teaching practice. Actually, how to quantitatively assess teachers' teaching performance is still a problem. Universities in China are still, more or less, perturbed by this category of assessment, in which doing scientific research has a much greater weight in assessment criteria. (2) How to assess students in terms of knowledge-based criteria and skills-based criteria. (3) How to assess students in terms of formative assessment and summative assessment. It is a complicated issue and there is no one assessment system which works and is universally acceptable.

Conclusions

Current trends of education ideas and pedagogical theories in Western universities have been discussed. The concrete science degree settings, curricula settings, syllabus settings, practices settings, and quality of teaching staffs have been compared between USyd and CCNU. Through the above observations, discussions and comparisons, we start to think about science education and education research in a deeper and more systematic way. The more important point is that we should keep going on thinking and trying to:

- do something in accordance with what we have observed, learned and thought about here;
- instruct students to shift away from rigorous study of the sciences as disciplines, toward the study of sciences in terms of personal and social relevance;
- use a sensible mix of contemporary education theories, to develop in students more generic skills through science teaching and learning;
- improve our curricula and syllabus to set up more sophisticated interdisciplinary curricula and intra-disciplinary syllabus;
- update theoretical and experimental content and context;
- be an accomplished teacher; and
- introduce a rational academic staff-recruiting procedure into our education system.

Acknowledgements

First of all, I wish to express my sincere acknowledgements to USyd, China Scholarship Council, Centre for English Teaching, and the School of Chemistry at USyd. I am very grateful to Associate Professor Michael King, Associate Professor Anthony Masters, Dr Siegbert Schmid, Dr Tom Hubble, Associate Professor Mary Peat, Mr Tony Sperring, Professor John Hearn for their interesting lectures, seminars and constructive talks and suggestions. All the teachers and staffs in Centre for English Teaching for China visiting scholar program at USyd, and all the teachers whose lectures I have audited at USyd, especially in the School of Chemistry, are much appreciated. I sincerely thank all 'mates' of The China Visiting Scholar Program at The University of Sydney. Finally, all officials of Education Office, Consulate-General of the Peoples' Republic of China in Sydney are appreciated for their kind help and support.

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