Applying student-centred teaching strategies to enhance the teaching quality of an *Inorganic Chemistry* course

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Abstract

This paper reflects the current teaching and reform progress on inorganic chemistry course in China, and introduces the future teaching reform project. It includes the following four themes: (1) a brief description of the current teaching outline of the *Inorganic Chemistry* course in China; (2) a brief description of current approaches to teaching and learning on inorganic chemistry; (3) some considerations on modifications to the course which would make it more student active, more interactive, and more suited to promote the skills of students; and (4) some possible problems in implementing these modifications

Introduction

Inorganic Chemistry in our university is a compulsory course available for the students majoring in chemical engineering. The course, in conjunction with other chemistry courses (Organic Chemistry, Physical Chemistry, etc.), is designed as the foundation of a petroleum processing course. The objective to learning is requiring students to understand the basic chemical principles and basic theories and to apply this knowledge to analyse and solve chemistry-related problems in oil processing. The students graduating from middle school are accustomed to being spoon-fed in their learning. In middle school in China, the goal for most students is passing the entrance examination for university; after they enter university they face the transition from secondary school to university. They need to foster learning skills, communicative skills, self-reliance, lifelong learning abilities etc.

In recent years, in order to improve our teaching; we have been striving to make it more active and interactive for the students and more conducive to promoting the skills of the students. Since March this year, as a visiting scholar, I have participated in the project of 'Teaching Science in English'. The program has been very beneficial in presenting many new ideas about teaching and learning. These ideas have stimulated reflection on my own teaching in recent years.

Student-centred teaching theories and strategies are new concepts to me. These concepts put more emphasis on students' activity in teaching and learning, and focus on improving learners' skills for lifelong learning. Science teachers (Wilson et al. 1999; Entwistle 1998) are increasingly applying these strategies to improve the teaching quality and their report received positive results. Because of the motivation of these new educational ideas and the incentive to substantially reform my teaching, I would like to apply these new teaching strategies to my teaching and try to improve my teaching quality in *Inorganic Chemistry* after I return to my university.

I think it will be difficult for first year students in China to adapt immediately to the student-centred teaching strategies. So I would like to divide my teaching process into two steps. Firstly, I propose to keep the lecture-style teaching format, but I will organize the teaching according to a conceptual change teaching strategy. Before and after each chapter lectures, I will require my students to reflect and compare their concept maps. Then, I will arrange some chemistry-related problems relevant to the students' majors and their future profession and organize my teaching by way of case studies and problem-based learning teaching strategies. I also would like to design a course web site to support the modifications to my teaching strategies.

The reflection on current course teaching

Course objectives for future modification

The course is a compulsory foundational course available for first year students majoring in chemical engineering (including environmental engineering). The students majoring in chemical engineering will expect to get their professional opportunity in oil processing (such as oil refinery operation and/or management) and the students majoring in environmental engineering will seek jobs as environmental inspectors and managers. In China, when students enter university, they must choose their specialty and study the related course program designed by the university. It is difficult for them to change their specialties during their time at university. So, the teaching and learning should develop students' interest and skills for their future profession(s). The *Inorganic Chemistry* course syllabus is summarized below. This syllabus is also the result of teaching reform during previous years.

Understanding chemistry principles and theories and applying these principles and theories to understanding the chemistry of the elements. Chemistry principles related to chemical reactions and chemical equilibria; chemistry theories include atomic structure, molecular structure and crystal structure and complex compound structure theories. Element chemistry is the content related to the properties and applications of elements and their compounds

Applying chemistry principles to analyse and solve some problems in the areas of environmental, and oil processing industry. We have incorporated some chemistry-related topics in petroleum industry, especially oil processing, into the teaching. Through learning these relevant topics, we hope to develop students' interests and to encourage a deep approach to chemistry learning, and make students relate the basic chemistry knowledge to complex problem in oil processing.

Developing learners' skills for learning in university and lifelong learning. For first year students, it is important for them to develop necessary learning skills in university. It not only encourages them to apply a deep level learning approach to chemistry, but also to any future courses they may undertake.

The course current formats

The course consists of 76 hours of lectures, 54 hours of laboratory work and a 2-week laboratory workshop. These are typical traditional Chinese teaching formats; there are no seminars and tutorials. In these teaching formats, there is a laboratory workshop session; I would like to specify the teaching process. This format is a result of my own teaching reforms in recent years.

We encourage students to discover the problem related to chemistry in their laboratory work or social investigation work and plan the problem solving projects. After the course is finished, we will open the laboratory to these students and instruct them in the conduct of their laboratory projects. For the excellent students, we require and provide the opportunity to present their work to their peers. I think this is a good teaching practice; it promotes a deep level learning approach in the students towards a study of chemistry. I would categorize it as a student-centred teaching strategy.

Motivations for modification to my current teaching

Recently, although we have been striving to focus our teaching more on the students' activity; the teaching strategies used in our current teaching are mainly teacher-centred. After reflection on my current teaching process, the following motivations for modification to my current teaching can be identified:

- some teaching areas are less relevant to the students' majors;
- the current course formats are less focused on student activities, and on developing skills for learning in university and lifelong learning;
- tutorials and seminars provide less emphasis on students' analytical and problem solving skills;
- the lectures focus on the subject knowledge transportation and emphasize less students' reflection;
- the students learn independently and are not encouraged to learn collaboratively; and
- the students' learning interests are focused on the assessment and lack a deep approach to learning in the chemistry course.

Based on these considerations, I would like to modify my teaching strategies and hope to achieve the following objectives:

- modifying the course content to provide more relevance to the learner's majors and future occupations;
- changing course formats to include greater emphasis on involving the students in the process of learning, for example, by adding tutorials, seminars etc.;
- applying the new teaching strategies (case study, PBL, concept mapping) to develop new learning skills ; and
- designing a course web site to support the modification to the course (due to fewer hours in lectures).

Future modification to shift the quality of teaching

Currently, the emphasis of educational theories has moved from teacher-centred to student-centred learning. This development of educational theory represents a move from a dependence on behaviourist theory to one of constructivist theory. The behaviourist educational theory emphasizes that the behaviour of the teacher can change the behaviour of students. This theory assumes that the teachers can construct the schema of students' knowledge. The constructivist theory emphasizes the recognition of the idea that students must be active participants in the process of learning in order to deeply master the knowledge and to construct their own knowledge schema; it encourages the adoption of teaching strategies which promote the active participation of learners in the process of learning and involves a change from the recognition of ideas from recollections of content knowledge to an emphasis on the development of 'generic skills' and on developing the skills for 'lifelong learning'.

Some modifications to course content and format

Inorganic Chemistry is a subject based on laboratory experimental science. Its knowledge system spans a great variety of chemistry principles, structures of matter, chemical changes, synthesis and the properties of substances, and application of elements and their compounds. It is difficult for students to understand the total subject area in the 76 hours lecture session. So, I will integrate the course content into three basic and key topics according to the characteristics of inorganic chemistry and the needs of students' future professions. The design includes two follow-up teaching sessions after these lectures to complete these topics. I will try to apply the student-centred teaching strategies and encourage students' deep level approaches to chemistry learning. I will add some teaching areas with relevance to learners, that is, some chemistry-related problems in environmental science; some chemistry-related problems in the oil processing industry. Additionally, I intend to modify the laboratory work to have a more problem-based content focus, more challenge and greater interest. The modified course format is as follows:

- the lectures (64 hours for the three basic topics);
- laboratory work (54 hours);
- laboratory workshops (2 weeks);
- the tutorials (6 hours for assignments and seminars of three topics); and
- the case study or PBL (10 hours for chemistry-related problems in environmental and petroleum industry).

New teaching strategies directed to student-centred learning

Understanding chemistry is difficult for most students. Most of the chemical concepts cannot be taught merely by showing an example. The teacher is not able to demonstrate atoms, molecules, ions, or bonding between these particles. Many factors influence the acquisition of a deep level of understanding approach to learning chemistry. These include preconceptions, life experience, peer knowledge, etc. It is necessary to arrange different teaching strategies in different teaching areas.

Teaching strategy for the lectures – concept mapping

Concept mapping (Jonassen, Beissner and Yacci 1993) is a technique for representing knowledge in graphs. Knowledge graphs are networks of concepts. Networks consist of nodes (points/vertices) and links (arcs/edges). Nodes represent concepts and links represent the relations between concepts. A concept map clearly defines the central idea, by positioning it in the centre of the page. It allows you to indicate clearly the relative importance of each idea. It allows you to establish the links among the key ideas more easily. This is particularly important for creative work such as essay writing. It allows you to see all your basic information on one page. As a result of the above, and because each map will look different, it makes recall and review more efficient. It allows you to add in new information without messy scratching out or squeezing in. It makes it easier for you to see information in different ways, from different viewpoints, because it does not lock it into specific positions. It allows you to see complex relationships among ideas, such as self-perpetuating systems with feedback loops, rather than forcing you to fit non-linear relationships to linear formats, before you have finished thinking about them. It allows you to see contradictions, paradoxes, and gaps in the material – or in your own interpretation of it – more easily, and in this way provides a foundation for questioning, which in turn encourages discovery and creativity.

According to the conceptual change perspective, during the teaching and learning process, students will be asked to construct two concept maps for each topic: one at the beginning of the course and the second when they have completed each topic. This concept mapping excise is designed to help students build a knowledge framework and a mental connection between the main concepts and their relationships and master the knowledge system. By concept mapping, I will try to encourage students to form the concept map in each topic for themselves.

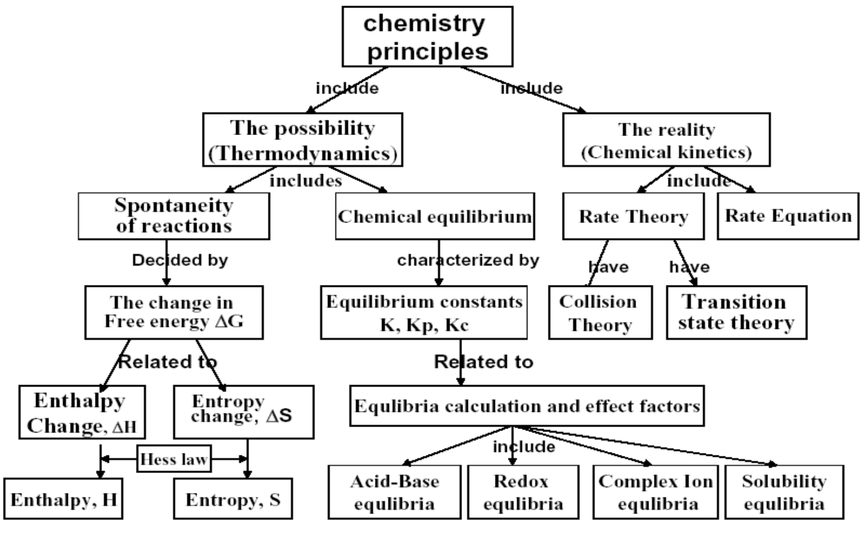

Figure 1. The concept map of the principles of chemical reactions

Above is an example of a concept map of a chemical reaction principle. Figure1 shows an expected concept map after the student accomplishes chemical reaction principle learning. From this concept map, we can see the basic information about chemical reaction principles. We understand a chemical reaction from two perspectives; that is the possibility (the chemical thermodynamic problem) if the reaction can take place and the reality (the chemical kinetic problem) of which chemical reaction takes place, if it can take place under certain conditions. Each aspect is related to a group of basic concepts. The teacher can organize the teaching area according to the concept map and construct students' schema. Students can understand the basic chemical reaction principle by the process of concept mapping.

Teaching strategies for extended content – case study/problem-based learning

Cases are factual or factual-based complex dilemmas written to stimulate classroom discussion and collaborative analysis. In case study teaching a student-centred discussion is the main classroom activity (Challen and Brazdil 1996). Students must collaborate to analyse the full dilemma and the data provided and decide upon a course of action. Case studies enable students to understand how chemistry applies to real problems, show how principles affect real-life decision making, trace commercial innovations of well known products from conception of the idea in the research laboratory to commercialization, look at the impact of chemistry on our environment, and highlight how important chemical principles are used in practice to make critical decisions.

There are many cases or problems related to chemistry in the real world. We can use these cases or problems to help students' deep learning in chemistry. For instance (Hermes and Peterson 2000), we put a compound, tetraethyl lead, in gasoline to make our automobiles run smoothly. Our power plants and engines exhaust nitrogen/sulfur oxides as products of high temperature processes. The ChemCases study shows us how to remove the lead compounds and catalyze the reduction of nitrogen/sulfur oxides without disrupting the transportation systems of the country. In order to stimulate students' deep approaches to chemistry learning, I am going to design this ChemCase study to integrate with the teaching material provided in the lecture classes. By this case study I hope to develop each learner's learning skills and promote each student's deep thinking.

Case background materials: Reducing the smog, removing the lead

Sometimes the sky over a big city is crystal clear. At other times, visibility is reduced to very short distances because of the smog. Smog is the brownish haze we see over our cities. It consists of pollutants, along with dust, aerosols and acid-containing water droplets. Our smog is a penetrating factor of modern urban life. Electric power generation and fuel burning for locomotion and heat distribute pollutants worldwide. We have had airborne pollutants for a long, long time. Smoke from the heating fires of the 18th century blackened the skies over London. In the 19th century, chemical ash from the manufacture of zinc filtered across Palmerton, Pennsylvania, killing most of the local plants. Wastewater from the essential war metal molybdenum, mined high in the Rockies, trickled throughout the streams of Colorado in the 20th century. We put a compound, tetraethyllead in gasoline to make our automobiles run smoothly. Our power plants and engines exhaust nitrogen oxides as products of high temperature processes Chemists know the impact of lead in the environment, and they know the harmful chemistry of the airborne compounds from oxidizing fuels such as coal, oil and gasoline. 'Reducing the smog, removing the lead' has become a worldwide problem since 19th century.

The case study project

Firstly, the students will be given the case background material to read and given a mini-lecture on background materials. The case material or mini-lecture directs students to get the following information and form the concept map relevant to the case study. The mini-lecture will deliver the orientation on the case study, direct the students to search the related materials on the following aspects. Using the background materials and mini-lecture, students understand the generation of the problem, know the solution to solve the case, and future alternatives and advanced research opportunities to solve finally the real world problem. Topics such as:

1. based on an understanding of the thermochemistry of fuel combustion, gasoline oil was invented as automobiles developed;
2. in order to make engines run smoothly, chemists developed tetraethyl lead as an antiknock agent;
3. pollution problems from nitrogen oxides and atmospheric chemistry related to equilibria and rates of reaction between N_2 and O_2;
4. health effects from lead in the atmosphere aroused worldwide health concerns;
5. the need to produce fuels containing no tetraethyl lead resulted in the development of the catalytic converter and new oil processing methods to produce lead-free gasoline (new catalysts discovery); and
6. in order to meet the stricter environmental regulations, what are the future research opportunities to produce new reformulated gasoline oil?

Students will be required to work in three groups to brainstorm the case and build a pre-concept map. After a week of work, they will share their views by oral presentations and finally write a summary report on the case study and reflect on the following aspects.

Attained or reviewed knowledge what they have learned in lecture hours

The case study shows how knowledge of the tools of chemistry is employed in the workplace. What have we done to our environment? Can we do anything about the smog, about the pollution? You will know the impact of lead on our bodies on the plants, of the acrid pollution on our lungs.

Comprehend the process based on chemistry principles

From the case study a learner should understand the maze of conflicting information necessary to translate an idea from the laboratory to the marketplace. What steps have we taken to protect ourselves from the results of the industrial age? As a result of our understanding of chemical equilibria and of chemical kinetics and catalysis, we have removed toxic lead compounds from our gasoline and reduced the production of polluting nitrogen oxides from our fuels.

Applying this information to show how chemical principles are used to make decisions. Chemist John Sinfelt at Exxon research centre applied knowledge and observations to make catalysts for better gasoline with no lead. Corning scientists converted ceramics to catalysts to remove oxides of nitrogen and sulfur.

Asking the student to evaluate the data and synthesize their own solutions to technical and nontechnical challenges
Their opinions are required to give out and evaluate the social impact of making major changes to the entire fleet of the nation's automobiles, to the entire system of fuel delivery. What if all this expense that your government must bear, does not reduce pollution?

Problem-based laboratory design for laboratory work

Many of the traditional laboratory sessions we perform as instructors can be altered slightly to make them more problem-based. Why problem-based laboratory-work? During past laboratory sessions I have seen many students perform experiments without a clue of why they are using the apparatus given to them or understanding of many of the steps. Planning, or problem laboratory sessions, is a definite help in overcoming this weakness.

By designing a problem-based laboratory session I hope that modified laboratory tasks place more emphasis on active learning and extra skills development. The problem-based laboratory will be more focused on research work and designing laboratory activities and require more collaboration between students (teamwork). It will require more imagination, more planning and be more challenging. For example, when I set 'problem laboratories' I want to see evidence of the students' planning and evaluation of their chosen methods of approach. The problem should be a clearly defined goal: 'Obtain 2.5g of Pb'. Here are some problem-based laboratory work examples.

1. Plan and perform electrolysis of lead bromide to obtain 2.5g of lead.
2. Make a solution of 'rust remover' by use of a redox table and evaluate its effectiveness.
3. Determine if the reaction between iron and copper sulfate solution produces iron (II) or iron (III) sulfate and copper.

Before students perform these laboratory experiments, they must plan and design the detailed laboratory steps. When they perform the experiments, they will check their pre-planning and design and revise the laboratory project. After they have finished in the laboratory, they will analyse the data and experimental phenomena and write the laboratory reports. The problem-based laboratory is full of challenge and imagination. It encourages the student to become deeply involved in the laboratory work and to develop their skills.

Some possible problems in implementing these modifications

The modification requires not only adapting the teacher's approach to teaching but also adapting the students' approaches to learning, especially the development of skills such as self-study, teamwork, deep thinking et cetera. The process requires more time and energy. So, it is difficult for students to adjust to these modifications; because they are more accustomed to lecture teaching (spoon-fed teaching) during their studies in middle school. On the other hand, due to less familiarity with the Case Study/PBL approach, the modification is difficult for the leader or other teachers to approve or accept (e.g. proposals such as reducing the number of hours of lectures hours, reforming the course syllabus)

Considering these possible problems, I plan to design a course web site to provide support for these modifications. The website will include the lecture notes, pre-laboratory work, reading materials and useful/relevant web sites and Internet networks, etc. Students will be easily able to access the web sites and obtain more information on course learning; students will be able to easily communicate with me by email or other means. In addition I hope to hold a seminar on modern education theories and share some ideas about what I have learned at The University of Sydney with my colleagues after I return to my university and get their understanding and collaboration.

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