Using problem-based learning in teaching *Analytical Chemistry*

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Abstract

This paper describes a comprehensive problem-based learning approach to the third year of an *Analytical Chemistry* course at Hunan University of China. The activities involved cover the area of analytical chemistry and students must use their judgement in order to come to an acceptable conclusion. It is possible to compare this course with a conventional parallel course and to monitor the longer-term effects of students' approaches to studying.

Introduction

Problem-based learning (PBL) is a curriculum design and a teaching/learning strategy that was developed in the west over the last 40 years. It is also a learning environment that embodies most of the principles that we know to improve learning, i.e. being active and cooperative learners, receiving prompt feedback, teaching which is tailored to students' learning preferences and promoting student empowerment and accountability. It aims to help students develop higher order thinking skills and a substantial disciplinary knowledge base by placing students in the active role of practitioners (or problem solvers) confronted with a situation (ill-structured problem) that reflects the real world. Rather than focusing on facts, PBL encourages active learning and self-directed learning, is context-based using 'real life' situations; focuses on thinking skills (problem solving, analysis, decision making, critical thinking), requires integration of interdisciplinary knowledge or skills or behaviours and develops lifelong learning skills.

Many studies have argued that PBL makes students more engaged in learning because they are hard wired to respond to dissonance and because they feel they are empowered to have an impact on the outcome of the investigation (i.e. assume more responsibility for learning); PBL offers students an obvious answer to the questions 'why do we need to learn this?' and 'what does what I am doing in school have to do with anything in the real world?'.

PBL promotes higher order thinking because the ill-structured problem scenario calls forth critical and creative thinking by suspending the guessing game of 'what's the right answer the teacher wants me to find?'. PBL promotes meta-cognition and self-regulated learning by asking students to generate their own strategies for problem definition, information gathering, data-analysis, hypothesis-building and testing, comparing these strategies against, and sharing them with other students' and mentors' strategies.

PBL engages students in learning information in ways that are similar to the ways in which it will be recalled and employed in future situations and assesses learning in ways which demonstrate understanding and not mere acquisition. Many studies also show that PBL method not only enhances students' knowledge of the basic principles, but also has the potential to increase students' ability to solve real world problems and to increase students' motivation for learning (Nendaz and Tekian 1999). Many disciplines have used problem-based learning (PBL) to achieve the balance of knowledge, qualities and skills (Savin-Baden 2000). Many universities use PBL to teach students (Vernon and Blake 1993).

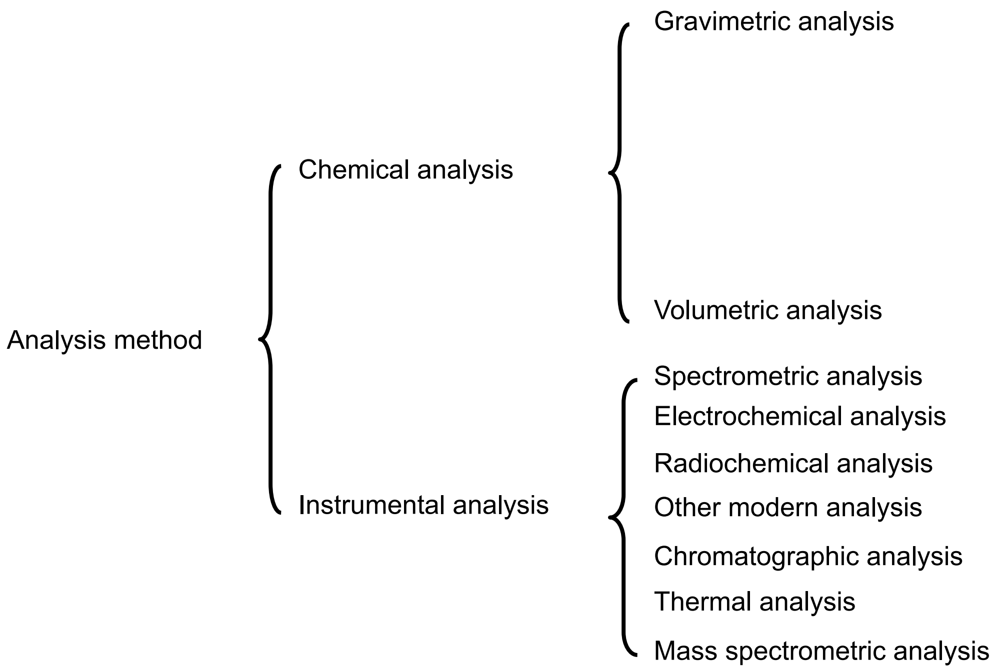
PBL in analytical chemistry is also not a new concept. In the mid-1960s, Herbert Laitinen began to focus undergraduate analytical chemistry curriculum development at the university of Illinois on problem solving (Wilson et al. 1999). In recent years, PBL has been successfully applied in analytical chemistry in the west. For example, Simon Belt at the University of Plymouth has developed problem solving case studies as an approach in analytical chemistry (Simon 2002). Thomas Wenzel at Bates College has used PBL successfully in undergraduate analytical chemistry and associated laboratory experiments (Wenzel 1995, 1998). Ken Hughes at Kennesaw State University has developed an introductory analytical course in which gravimetry, titrimetry, spectrophotometry and potentiometric methods are used to analyse the chemical constituents of a marine aquarium (Hughes 1993). These examples show that using PBL, students are more fully engaged in the learning process and their understanding of the process of chemical analysis is increased. A report (Kuwana 1997) from the USA has recommended that PBL methods should be used to teach all analytical science.

Course description

Course structure

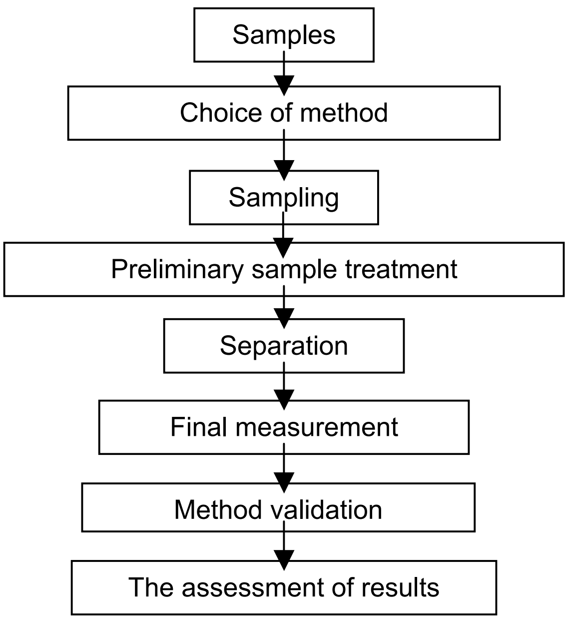
Analytical Chemistry is a subject which is broad in its scope whilst requiring a specialist and disciplined approach. It includes: qualitative analysis (what is it?); quantitative analysis (how much is it?); and structural analysis (which structure is it?).

An overview of the approach to analytical procedures is set out below:



Analytical problems and their solution

Analytical samples may come from any part of the environment and the significant stages on the analytical process are:



Our current teaching system

Analytical Chemistry is a course for 3rd year (5th semester) undergraduate students majoring in chemistry, chemical engineering, applied chemistry, biotechnology, environmental science and material science at Hunan University of China. It usually involves 72 hours of lectures and 56 hours of laboratory work as well as occasional tutorials. At the end, there is a final assessment that is carried out by written examination.

The main course objectives are to:

1. provide a basic understanding of the principles, instrumentation and applications of chemical analysis as it is currently practiced;
2. demonstrate that analytical chemistry has bounds which are amongst the widest of any technological discipline;
3. enable students to design, carry out, and interpret measurements within the context of the fundamental technological problem with which they are presented;
4. give students an overview such that they can choose and utilise suitable chemical procedures or an appropriate analytical technique for a specific problem including defining the problem, determining any constraints, choosing the best method, identifying alternatives and

comparing the advantages and disadvantages of each; and
5. help students learn to use basic scientific theory to solve real world chemical problems and develop critical thinking skills.

Teaching method at present

Traditionally, teaching and learning of analytical chemistry in China is carried out using a didactic approach. Teachers deliver formal lectures to transmit knowledge; students receive it passively and are then expected to reproduce it accurately in examinations. I have also used this method in my teaching so far. The duration of each lecture is about 2 hours (with a short break in the middle) during which students listen and take notes. Within lectures, in order to force students to think more, I insert some interesting questions relating to the content and ask students to think about answers to them. But even so, this kind of teaching strategy still mostly leads to a surface level approach to learning and an over-dependence on the lecturer in learning. It is also unsatisfactory with respect to the learning outcomes and the feedback received from students.

Modification assumption

In order to: overcome the deficiencies in the above teaching strategy; help my students to take a deep level approach to their learning; and make students become more independent, lifelong and active learners, I will attempt to use some approaches that I have studied at the University of Sydney. I will certainly consider making changes to my own teaching strategies and try to modify the problem-based learning approaches used in the course on analytical chemistry on my return to China. The major goal of this trial is to have students learn the theory of analytical chemistry by lectures combined with problem solving projects rather than by just getting information from my lectures.

A typical model of PBL

Since PBL is a relatively new concept in our University, it's difficult to use this approach throughout the whole course. I think this course will continue to be taught mainly in the format of lectures, but I plan that there will be other exercises related to PBL, including a semester long problem solving project and several smaller problem solving projects, as well as laboratory based experiment phases. My lectures will generally provide only part of the information or ideas that students need to deal with the problems, so requiring students to go to other resources to pursue more knowledge rather than just reading their textbooks.

I will assign some supplementary reading materials related to the problems (*Journal of Electrochemical Analysis* and the *Journal of Gas Chromatography*) or the development of some new analytical techniques to the students, such as environmental chemistry, environmental monitor, applied spectroscopy. This kind of supplementary reading provides more opportunities to help the students not only to improve their academic English but also stimulate their interests in research work.

The big problem solving project (needing one semester)

One month ago, the water which flowed from Yuelou mountain could be drunk safely. Now, the people who drink the water become sick with stomach aches. Why? What do you have to do to make it safe to drink?

Our University is located at the bottom of Yuelou mountain in Chang Sha, Hunan province of China. Usually, the water flowing from the mountain can be drunk by the local people, and the water is full of a rich micro-amount of elements which are needed for human health. Many people like to drink it and indeed it is considered healthy to do so. But, sometimes this water cannot be drunk because it is contaminated due to the bird garden that is located at the top of the mountain or by some other source of pollution.

The students, now a group of specialists in analytical chemistry, are employed by the local people and are asked to develop a proposal to analyse the water in order to show why the it cannot be drunk and how to make it safe to drink. The solution to this big problem will include the students gaining an understanding of:

1. what is 'clean' water? what is 'contaminated' water? what is the standard for drinking water?;
2. what is in the water (ions, bacteria, pH value, toxic substances, colour degree, etc.)? how to measure them using the best methods? what amounts are present?; and
3. how to make the water clean (water purification)? what methods to use (distillation, extraction, ion-exchange, other chemical reactions)?

Since the use of PBL is relatively new to both the students and me, I must focus not only on the problem itself but also on the process. In terms of the arrangement of my lectures in this course, I will provide a timetable and advice to help students manage their time.

In the first 4 weeks, the students will devote themselves to defining the problem and finding out the answers to the first question. They can find the information needed from given references, but I would also encourage them to find more information from other resources including other faculties in our University such as the Department of Environmental Science, books in the library, and so on.

In the period of the fifth to twelfth weeks, the students will be directed to find possible analytical approaches for each substance in the water and answer the second question. During this period, part of the information needed by the students may have been introduced in my lectures, but they will still need to find more information for themselves. At the end of this period, the students will be asked to provide a review of these methods including their principles and the comparison of the advantages and disadvantages of them.

In the thirteenth to fourteenth weeks, the students will be asked to answer the third question. With respect to this question, most of the information needed by the students may have been introduced by my lecture in a 'separate analysis' section.

The fifteenth week will be devoted to writing the report and the sixteenth and seventeenth weeks are the period for oral presentations. There will be class discussions after the presentations so even the students not actually making presentations are expected to have investigated the topic and thus be able to contribute to the discussions and learn something from them. The students will be graded on the written report and the oral presentation as well as how prepared they are to participate in the subsequent group discussion.

This problem solving project will cover most of the analytical techniques taught in this course and it will drive students learning of the subject throughout the whole semester. It will also involve approaches to problem identification, the proposed application of multiple methods of analysis to solve a problem, comparison of different analytical approaches, development of the ability to learn new techniques and concepts and effective cooperation to solve a real world problem. Therefore, the students will have a better opportunity to understand all aspects of solving an analytical problem and develop their own problem solving skills.

Small problem solving projects

In order to drive students learning towards some important and central concepts, theories and analytical methods, several small problem solving projects will be developed and assigned. These problems will scaffold their learning. A few examples of these more directed and specific problem-based learning tasks are as follows:

1. how can we obtain a quantitative profile of the ionic constituents in a water supply?
2. how do you determine how much fluoride is in a water supply?
3. how do you determine how much calcium and magnesium is in a water supply?
4. how do you determine how much iron is in a water supply?
5. how do you determine the total alkalinity in a water supply?
6. how do you determine the concentration of total dissolved solids in a water supply?
7. which precipitating reagent will remove the most contaminant? and
8. how much precipitating reagent is required for effective water treatment?

These projects are different from the main project. They are often one-dimensional and fairly simple, will focus on one or two basic concepts or theories in a certain chapter, and need less time for students to prepare them. But I will design and set them in conjunction with the main project in order to help and guide the students to complete the main project well, thus scaffolding their learning.

Laboratory experiment phases

Students who acquire scientific knowledge in the context in which it will be used are more likely to retain what they learn, and apply that knowledge appropriately (Albanese and Mitchell 1993; Boud and Felletti 1991). Problems should strive to induce students to learn at the higher levels (Bloom 1956), where they analyse, synthesise, and evaluate rather than simply define and explain.

Practical ability is very important for chemistry students both at the level of individual skills and group skills. To avoid 'cookbook recipe' results, the experimental investigations conducted by the students will be open-ended. Students will be asked to design an experiment which will: answer the questions posed to them; identify sources of uncertainty in the data to be gathered; plan ways to minimize that uncertainty; and solve a real world problem. The experiment can be divided into several sections and students will need will be about 24 hours of laboratory time. After the experiment is conducted, students will be asked to report their results and make a formal presentation to the local people.

Course grading (assessment)

Firstly, because this course will be taught mainly in the format of lectures, a traditional written examination will be conducted as a closed-book examination at the end of the semester which will be worth 50% of the total grade. I hope it will encourage the students to review their knowledge systematically.

Secondly, in my trial of problem-based learning strategy, I plan that the solutions to the problems and the experimental phase will be required for grading. The solutions will be worth 40% and the experiment will be worth 10% of the total grade.

The assessment criteria relating to PBL will be as follows:

1. effectiveness of the work;
2. responsibility and independence;
3. information processing skills;
4. problem solving skills; and
5. interpersonal communication skills.

Furthermore, the final examination questions will be adapted 'to some degree' from the assigned problems, so the students are encouraged to work on them in conjunction with the lectures and to discuss them in their groups outside the classroom.

Comparison of traditional and PBL methods of teaching

The traditional lecture-based method is intrinsically not conducive to learning unless augmented by activities which involve students directly, and which give them opportunity to acquire the necessary knowledge by other means besides passive listening. This active learning is, to a large extent, what students do in a PBL environment.

Furthermore, the summative assessment method used in the lecture-based approach of teaching encouraged surface learning due to the significant importance given to students' performance in the final examination. In this environment, most students tend to waste their time during the semester and cram the material of the entire syllabus into a single night's study just before the final examination. Obviously, this study style does not allow for any fruitful thinking. It tends to force students to try to memorise the material and rely on their ability to recall the information quickly when required. It is therefore not surprising that 3rd year students may not remember the prerequisite material covered in the 2nd year, and so on.

Problem-based learning begins with the introduction of an ill-structured problem on which all learning centres. Teachers assume the role of cognitive and meta-cognitive coach rather than knowledge-holder and disseminator. Students assume the role of active problem solvers, decision makers, and meaning makers rather than passive listeners.

Problem-based learning causes a shift in roles

Teacher as a coach:	**Student as active problem solver:**	**Problem as initial challenge and motivation to attention:**
• asking about thinking; • monitoring learning; • probing and challenging students' thinking; • keeping students involved; • monitoring and adjusting levels of challenge; • managing group dynamics; and • keeping the process moving.	• active participant; • engaged in the process; • constructing meanings; and • learning how to learn as well as what to learn.	• ill-structured; • appeals to human desire for resolution, stasis or harmony; and • sets up need for and context of learning which follows.

Anticipated problems

Students' attitude

PBL is a new concept in our University, so the transition is not only difficult for me, it is also a big change for students. PBL requires that students give more time to study and to be more responsible and independent learners. Because the students are over-dependent on teachers for direction as previously passive learners, some of them will not be used to taking as much responsibility for their self-directed learning and will complain about the extra effort needed and be reluctant to use these learning approaches. So good orientation is very important.

Academic cheating

It is possible that some passive students will copy other talented students' results. I have met this kind of cheating before in my course. In order to prevent such cheating, I will tell the students not to even think about doing it, and I will make sure students know precisely what my expectations are and what the penalties are once they are found out.

Time limitation

PBL needs to take more time for both teachers and students. Nowadays, everyone is very busy. The teachers have many varied tasks to perform, and the students have many things and courses to learn. It is possible that some students cannot endure the high load and cannot finish on time. I will constantly urge the students in the process to prevent this problem. In case some students cannot finish at the end of the semester, I will allow them to finish it at the beginning of the next semester.

Certainly, I will come across other problems in the process, but, doing it is better than not doing it. I will try to modify my teaching step by step and make more and more improvement in the future.

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