Using Problem Based Learning and Cooperative Group Learning in Teaching Instrumental Analysis

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Problem Based Learning (PBL) is one of the most exciting and powerful teaching/learning methods that have appeared in the last 40 years. In general, PBL is a method of instruction that uses problems as a context for students to acquire problem solving skills and basic knowledge. Unlike traditional instruction, which is often conducted in lecture format, teaching in PBL normally occurs within small discussion groups of students facilitated by a faculty tutor (Aspy et al. 1993). Rather than focusing on facts, PBL encourages active learning and self-directed learning; allowing students to define their own learning tasks; facilitating group learning, research and communication skills; ensuring knowledge of a specified subject domain; and transferring knowledge to novel situations. Many studies show that PBL teaching method not only enhances students' knowledge of the basic principles, but also has the potential to develop students' self-directed life-long learning skills, communication skills, to increase students' ability to solve real world problems, and to increase students' motivation for learning (Nendaz and Tekian 1999). PBL is now increasingly entering the repertoire of instructors in many universities. In fact, over 80% of medical schools are using PBL to teach students about clinic cases (Vernon and Blake 1993).

PBL in analytical chemistry is not a new concept. As early as 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, Ken Hughes at Kennesaw State University has developed an introductory analytical course in which gravimetry, titrimetry, spectrophotometry, and potentiometric methods are used to analyze the chemical constituents of a marine aquarium (Hughes 1993). Thomas J. Wenzel at Bates College has used PBL successfully in undergraduate analytical chemistry and its laboratory experiments (Wenzel 1995, 1998). These examples show that with PBL, students are more fully engaged in the learning process and their understanding of the process of chemical analysis is increased. The successful application of PBL in these examples also shows that it is possible to design courses that can simultaneously develop the foundation, content and problem solving nature of analytical chemistry (Wenzel 1999).

Usually cooperative group learning (CGL) is employed in classes taught by PBL. Many studies serve to document the advantages of CGL methods, which include engaging the students more fully than a lecture, leading to improvements in understanding and retaining the material (Wenzel 1998; Cottell and Millis 1994; Nelson 1994; Johnson et al. 1991). It is also reported that group learning creates a support network among students working on the same problems and facilitates out-of-class learning, thereby increasing the time students spend working on course material and improving the quality of their understanding (Wenzel 1998). Students' skills such as cooperation, communication, problem defining and solving, which are valued by employers and often are not emphasized in traditional methods of teaching chemistry, are also developed.

In China, teaching and learning of analytical chemistry is usually carried out in a didactic approach: teachers deliver formal lectures to transmit knowledge; students receive it passively and then reproduce accurately in examinations. This teacher-centred teaching/learning approach may be easy for teachers, but it does not provide an active learning environment for students, therefore sometimes the learning outcomes and the feedback from the students are not satisfactory. In order to improve students learning activities, I will try to modify the teaching/learning approaches used in the course of Instrumental Analysis, which is a very important course in the subject of analytical chemistry. The major goal of this trial is to have students learn the theory of instrumental analysis by lectures combined with problem solving projects in cooperative groups rather than just get information from lectures.

Course description

Instrumental Analysis is a course for 3rd year undergraduate students majoring in applied chemistry, marine chemistry, environment science and material science in Ocean University of China. It builds on the analytical knowledge and experiences gained in the course of analytical chemistry (or quantitative analysis) in second year. Usually it involves 54 hours lectures and 54 hours laboratory work. The main course objectives are to let students:

1. gain an in-depth understanding of the principles, instrumentations and applications of the most frequently used analytical techniques, including the chromatography, molecular and atomic spectroscopy and electrochemical methods;
2. gain an overview to help students choose 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
3. learn to use basic scientific theory to solve real-world chemical problems and develop critical thinking skills.

Course format

Since PBL is a relatively new concept in our university, it's difficult to use this approach thoroughly in the whole course. So this course will be taught mainly in the format of lectures, but there will be many group works related to PBL, including a one semester long problem solving project and several small problem solving projects. The lectures will generally provide part of the information or idea students needed to deal with the problems, so students must go beyond their textbooks to pursue more knowledge in other resources. Cooperative group learning will be employed in this course. The class will be divided into groups of about four and most of the in-class discussion and out-class problem solving works will be performed by the group. Since I will start trying PBL alone in this course, it's difficult to provide a tutor for each group. I will employ the method described by D. R. Woods: empower the groups to run without a tutor and thus the students learn skills in facilitating the group task, problem solving and learning process; or be a wandering tutor to wander among the groups and upon invitation become a temporary group member to facilitate the process (Woods 1994).

Selected problems at the end of the chapters in the textbook will be assigned. Solutions to the problems will not be required for grading; however, the final examination questions will be adapted, to some degree, from these assigned problems, so the students are encouraged to work them in conjunction with the lectures and discuss them in the group out of classroom.

For the students who have extra efforts and interests, some academic articles related to the topics taught in class or the development of some new analytical techniques would be assigned as supplemental reading materials. The articles will be selected from the scientific journals such as *Analytical Chemistry*, *Applied Spectroscopy*, *Journal of Electrochemical Analysis* and the *Journal of Gas Chromatography*. Usually this kind of supplemental reading is mandatory, it just provides more chance to help the students not only to improve their academic English but also intrigue their interests in research work.

Why did the fish die? The big problem solving project

An important consideration in problem based learning is the formulation of the key questions that need to be answered. They must be related to real world and open-ended. In my course, a one semester long problem will be posed to each group: Why did fish die?

At the fishpond named Lucky at the downstream side of the Dagu River, dead fish were observed. The owner of the fishpond went to the local insurance company to claim his compensation. The pre-inspection showed that these fish were not diseased but suspected to be poisoned by certain toxic substances from one of the factories on the upstream side of Dagu River. The map of the fishpond will be provided, and it shows that there are three factories on the upstream side of the river and the wastewater of the factories will be emitted directly into the river. The students, now a group of specialists in analytical chemistry, are employed by the local insurance company to inspect this accident and are asked to develop a proposal of analysis to show why fish died and who is responsible for this accident. The proposal will include:

1. What are the waste emissions of each factory and which are toxic to the fish?
2. Which analytical approaches can be used to determine these waste emissions?
3. List the most appropriate method for each toxic substance and give the detailed information for it (including how to collect and store the water samples, sample preparation, assay validation, as well as the estimated cost of materials, equipment use, and labour).

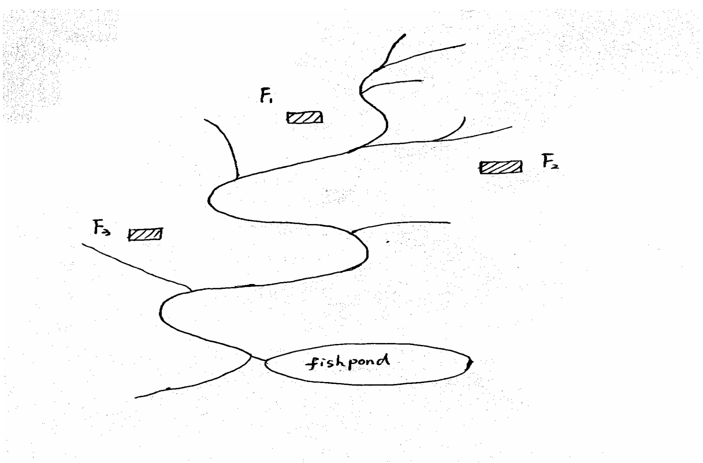

Figure 1. Map of Lucky Fishpond near Dagu River (F1, F2, F3 are factories, whose waste water are emitted directly into Dagu River)

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 this problem solving project, the class will be divided into teams of four students. At the end of the second class, each team will receive a detailed description of the same problem but the factories will be different, for example, they may be a fertiliser factory, a paper mill and a pesticide factory, or a paint factory, an electric coating factory and a fine chemicals factory. I also will provide a timetable to help the students manage their time.

At the first month, the groups will devote to defining the problem and identifying the possible waste emission of each factory. They can find part of the information needed from given references, but I would rather encourage them to find more information from other resources including other faculty in the university, students in other groups, books in the library, and the Internet. They will be asked to present a report on the possible waste emission from each factory at the end of the first month. After looking at all these reports, I will discuss with each group separately to choose several substances for further study.

At the second month, the groups will be directed to find possible analytical approaches for each toxic substance. Usually there will be alternatives and the groups will be asked to provide a review on these methods including their principles and the comparison of the advantages and disadvantages of them. During this period, part of the information needed by the students may have been introduced by the lectures, but they still need to find more information by themselves.

At the third month, the group will be asked to choose the most appropriate method for each toxic substance and present a report on the detailed information for them, including how to collect and store the water samples, sample preparation, assay validation, as well as the estimated cost of materials, equipment use, and labours.

The last month will be devoted to oral presentations. Each group will be given 20 minutes to make an oral presentation on their proposal to all classes. There will be class discussions after the presentations so even the groups 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 teams will be graded on how well the oral presentation supports the position, and how prepared the team members are to participate in the subsequent group discussion.

By proper designing, this problem solving project will cover most of the analytical techniques taught in this course and it will drive students learning the subject throughout the whole semester. Students are asked to engage in self-directed learning, collaborative learning and problem based learning during this period. This problem solving project will involve team-based 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 problem. Therefore, the students will have a better opportunity to understand all aspects of solving an analytical problem, and develop their self-learning, cooperative working and problem solving skills.

Small problem solving projects

Several small problem solving projects will be assigned during the course of the semester and discussed in class. These projects will also focus on solving "real world" chemical problems associated with certain topics discussed in the class, but they are different from the big one. They are often one-dimensional and fairly simple, will focus on one or two basic concepts or theories in certain chapter, and need less time for students to prepare them, so they are good for drills in learning these concepts and theories.

Whether the problem solving projects are big or small, the main objective is to enable students to apply the theories learnt from both self-directed learning and lectures to real problems. All these problem solving projects are group activities, and each group member is expected to participate equally. Efforts are made to ensure that all of the group members frequently have an opportunity to contribute and demonstrate their job skills during the project. Within each part of the project, work must be divided up because there is far too much work to be done by one person and the results can be pooled. One important key to success is for someone to be in charge and know what everyone is supposed to be doing. I will ask each group to designate a group leader for each part of the project. The leadership should rotate with each new phase of the project. Everyone should have a chance to be the leader. The leader should designate what each person's responsibilities are and ensure that each group member is doing their fair share of the work. The leader can schedule group meetings regularly to discuss and prepare for certain topics or for the periodic progress reports. In this way, I hope to avoid the problem of only several students providing the essential input, while the others simply do what they are told or do nothing.

Assessment

PBL differs from traditional instruction in a variety of ways, and therefore students' knowledge and achievement may be better measured with alternate assessment methods. Usually these methods include written examinations, practical examinations, concept maps, peer assessment, self-assessment, facilitators/tutor assessment, oral presentations, posters and written reports. Although students are increasingly familiar with the Internet, they are not especially proficient at accessing databases and other information useful to chemists, nor have they had much experience in problem solving, working as a member of a team, or communicating orally or in writing (Wilson et al. 1999). Consequently, these activities will form the basis for performance evaluations. In my course, a mixture of assessment methods and grading procedures will be used to evaluate students' achievements.

Course grading

In this course, group learning is encouraged which demands that students attend class, therefore credit is awarded for attendance and active participation. There will be a total of 100 or 10% of the total grade for attendance. A traditional written examination will be conducted as closed-book examination at the end of the semester, which will be worth 400 points or 40% of the total grade. I hope it will encourage the students to review their knowledge systematically. Questions should be designed properly to ensure transference of skills to similar problems but avoid resulting in rote memory. Because so much of work life revolves around presenting ideas and results to peers, development of one's written and oral communication skills are two important aspects of the undergraduate training in chemistry. Therefore three periodic progress written reports will be required at the different stages of the semester-long problem solving project, which will be worth 300 points or 30% of the total grade. A final oral presentation for the semester long problem solving project provides students with an opportunity to practice their oral communication skills, and it will be worth 100 points or 10% of the total grade. There also will be another 100 points or 10% of the total grade awarded to students for the active participant of the small group problem solving projects.

Assessment methods

In this course, assessment will be based equally on individual and group performance. The criteria include demonstration of technical knowledge and its application, ability to function in a team framework, individual contributions to the project, quality of written reports and oral presentations, leadership, and attitude toward work. In order to evaluate the students' performance fairly, peer assessment**,** self-assessment, and instructor assessment will be employed.

Because life outside the classroom usually requires working with others, peer assessment is a viable option to measure students' contribution. In this course, peer assessment will be used to evaluate the oral presentation and written reports. An evaluation rubric will be provided to the students to guide the peer evaluation process. This process emphasizes the cooperative nature of the PBL environment. An important element of problem based learning is to help students identify gaps in their knowledge base in order for more meaningful learning to result. Self-assessment allows students to think more carefully about what they know, what they do not know, and what they need to know to accomplish certain tasks. So self-assessment also will be employed in evaluating problem solving projects. Some studies showed that empowering the students to have some role in the assessment, whether it is self- of peer-assessment, will help improve students' learning (Woods 1994).

Instructor assessment is also very important to give feedback to students. The feedback provided by instructors should encourage the students to explore different ideas. It is important that facilitators not dominate the group, facilitate learning and exploration. Instructor assessment may consist of how successful individuals interacted with their group and their cognitive growth.

I hope students may 'develop the ability to give and receive feedback and to appraise one's own needs' through all these assessments as Nendaz said (Nendaz and Tekian 1999).

Possible problems encountered in using PBL in this course

Although I have read a lot of literature on PBL and CGL and designed the format of this course carefully, I am sure I will still come across many challenges accompanying the use of PBL, particularly for the first time. To think more about these problems and have a good preparation will be very helpful.

Difficult transition

PBL and CGL are new concepts in our university, so the transition is not only difficult for me; it is also a big change for students. PBL and CGL not only require the students more time and to be responsible and independent learners, but also require cooperative ability to work in a group. However, most students in China have spent their previous years assuming their teacher was the main disseminator of knowledge. Many students (and some of my colleagues) may feel that, 'If you don't lecture, you're not teaching'. The students are not used to taking as much responsibility for their own learning and will complain about the extra effort needed and be reluctant to use these learning approaches. Therefore it's very important to make the transition smooth for students (Bridges 1992). Success will depend on effective communication and good orientation, so how to get started is very important. In this course, a significant portion of the first class will be spent describing the problem based learning and cooperative group learning process and my expectations. I will tell the students what PBL and CGL are, why and how I will use them in my teaching, which advantages they have, which assessment methods I will use in this course. This practice will make the students clearly understand how the class operates and why. Occasionally, bright students may resist cooperative learning in the class. If such a problem develops, I will point out that cooperative learning will develop the ability to explain things to others, which is a valuable skill, especially for those who may eventually aspire to a supervisory position in their career. I also will make it clear to the students at the beginning of the semester that their grades will be based equally on individual and group performance. Once the students are clear about what is expected of them, it will not be difficult to engage them any more.

Lack of experience in teamwork

Most students lack experience working in a team with other people in our college, since they are accustomed to learn knowledge by attending lectures. At the early stage, most students will not know how to deal with their group members and how to ensure all members are equal participants. My suggestion is that each group designates a group leader for each part of the project and peer assessment is used to evaluate the contribution of each group member. The reflective information will be given back to students to let them have chances to improve their work.

Academic cheating in written work

In this course, students are encouraged to find information through all possible ways and share it among different groups. In this situation, extra attention should be paid to possible academic cheating. The Internet may cause a frequent problem. The students may download some materials directly from the web and use the tool of cut and paste in the word processor to create a written report. I have met this kind of cheating before in my courses. The best thing to prevent cheating is to make sure students know precisely what my expectations are and what the penalties are once being found. Since search tools are available to detect this type of work, I will tell the students not to even think about doing it. Another problem is how to share information among different groups. Cooperation is encouraged, but it does not mean they can copy each other's work. Work that appears simply to have been copied from another's group will not be accepted from either group involved.

Surely I will come across other problems such as creating the problems without a full understanding of the important components and the time required, lack of support from colleagues who don't understand the method, difficulties in directing each group to run smoothly and so on. However, to do is better than not to do, so I will try to modify my teaching bit by bit and learn from the lessons.

References

Aspy, D. N., Aspy, C. B. and Quimby, P. M. (1993) What doctors can teach teachers about problem-based learning. *Educational Leadership*, **50**(7), 22-24.

Bridges, E. M. (1992) Problem based learning for administrators. Eugene, OR: ERIC.

Cottell, P. G. and Millis, B. J. (1994) Complex Cooperative Learning Structures for College and University Courses. In E. C. Wadsworth (Ed.) *To Improve the Academy: Resources for Student, Faculty, and Institutional Development*, Stillwater, OK: New Forums Press.

Hughes, K. D. (1993) Marine microcosm – using an aquarium to teach undergraduate analytical chemistry. *Analytical Chemistry*, **65**, 883A-889A.

Johnson, D. W., Johnson, R. T. and Smith, K. A. (1991) *Active Learning: Cooperation in the College Classroom,* Edina, MN: Interaction Book Company.

Mayo, P., Donnelly, M. B., Nash, P. P. and Schwartz, R. W. (1993) Student Perceptions of Tutor Effectiveness in problem based surgery clerkship. *Teaching and Learning in Medicine*, **5**(4), 227-233.

Nelson, C. E. (1994) *Critical Thinking and Collaborative Learning In New Directions for Teaching and Learning*, (Series: New Directions for Teaching and Learning, **59**) San Francisco: Jossey-Bass Publishers.

Nendaz, M. R. and Tekian, A. (1999) Assessment in problem-based learning medical schools: A literature review. *Teaching and Learning in Medicine*, **11**(4), 232-243.

Vernon, D. T. and Blake, R. L. (1993) Does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine*, **68**(7), 550-563.

Wenzel, T. J. (1995) A new approach to undergraduate analytical chemistry. *Analytical Chemistry*, **67**, 470A-475A.

Wenzel, T. J. (1998) Cooperative group learning in undergraduate analytical chemistry. *Analytical Chemistry*, **70**(23), 790A-795A.

Wenzel, T. J. (1999) Does problem-based learning sacrifice content and fundamentals? *Analytical Chemistry*, **71**(9), 693A-695A.

Wilson, G. S., Anderson, M. and Lunte, C. E. (1999) Instrumental Analysis at the University of Kansas: An Experiment in Problem-based Learning. *Analytical Chemistry*, **71**, 677A-681A.

Woods, D. R. (1994) *Problem-based Learning: how to gain the most from PBL*, Canada: Waterdown.