

Building a bridge to a student-centred learning environment in *Instrumental Analysis*

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Introduction

Nowadays, the keywords of analytical science have changed from the classical chemical analysis period to the modern instrumental analysis period. Instrumental analysis is a metrological science that develops, optimizes and applies strategic, methodological and instrumental tools intended to derive chemical information and solve real-world problems (Valcárcel Cases 2001). In other words, it is actually a 'self-contained' interdisciplinary which develops from a wide array of 'feeders' in science and technology, including mathematics, physics, biology, engineering, computer science and other chemistry, then provides information about the objects and systems in these social precincts via research, education and real problem-solving. Obviously, the research and development of analytical tools, processes and methods are the primary sources of the teaching materials used by this discipline. As a consequence, education in an instrumental analysis course should establish effective links with the social and economic areas that generate analytical problems in order to accurately identify the information required, and give students an opportunity to become competent in their professional careers with the techniques and instrumentation used in contemporary analytical chemistry.

Instrumental Analysis is an honours compulsory course available for third year undergraduate students majoring in chemistry, biochemistry and environment science in Fuzhou University of China. Students entering the course should have background knowledge from prerequisite courses in mathematics, physics, inorganic chemistry, organic chemistry and quantitative analysis. The overall goal of this course is to provide students with sufficient understanding of the principles and theories of analytical chemistry to enable them to gain problem-solving abilities by accurately analysing samples provided, using selected instrumental methods (Figure 1). Through the teaching process, it is anticipated that students gain some of the basic skills of analytical chemists, for example, a deep understanding of the principles, teamwork ability, practical analytical skills, information retrieval, and real-world problem-solving skills.

Conventional teaching and learning environment

In general, the conventional instrumental analysis course involves 45 hours of lectures and 36 hours of laboratory work in one semester and has a maximum enrollment of 40 students. It is carried out mostly with a teacher-centred model that the teaching process places its emphasis on the integration of academic knowledge. The class meets two times per week in two lectures over the whole semester and one 4-hour laboratory session from mid-term. Lectures include the theory of instrumental analysis (spectroscopy, electrochemistry, mass spectrometry and separation techniques) and criteria for choosing different instrumentation, and form the centre of the education process. Laboratory work, which includes nine basic individual instrumentation skills for students in groups of four, serves as support for knowledge construction and emphasises hands-on experience with spectrophotometers, gas-chromatographs and High Performance Liquid Chromatography (HPLC), fluorometry, atomic emission or absorption spectrometry and some electrochemical instrumentation (potentiometer and polarograph). Thus, the summative assessment, which is composed of an examination (75%), assignments (10%) and experimental reports (15%), is mostly reliant on short-term memorising. This sort of syllabus is designed for the conventional teaching and learning environment to make students master important theories by lectures, to understand basic skills by laboratory practices and gain some elementary analytical abilities suitable for an analytical chemistry career.

Indeed, the teacher-centred teaching model is a low cost and feasible method for organising course content. However, in most cases, instruction occurs as the transmission of abstract knowledge rather than a process of interaction and construction of knowledge. Conventional teaching usually presents basic models and concepts essentially as established facts, so that students are typically trained to memorise and apply these models, rather than to analyse and understand them. As a result, creative students are inclined to feel that Chemistry is dull and uninteresting. The students sit quietly without talking before, during, or after class. They take notes but ask very few questions, even when the professor invites questions (Williamson and Rowe 2002). At this point, they will memorise superficial knowledge for an examination, then forget, fail to apply or integrate knowledge, and resist further learning. Analytical science is uniquely positioned to serve needs in the community, so laboratory skills training plays an important role in linking with the real world. But in the traditional teaching environment, although instructors have guided students through the process of experimentation in standard laboratories by providing background information, defining the experiments, and optimising the procedures, the process was apparently not obvious to students. Often students only pay attention to the defined procedure and certain results. They are not challenged to cooperative problem-solving and thinking independently. Therefore, students who saw only the basic laboratory procedures and not the overall experimentation process often encounter difficulty when they try to use their learning outcomes to solve a real world problem. In these situations, students frequently complain that the lectures and laboratory experiments do not have real-life applications or are not derived from 'real' situations, so that the students lack ability and confidence when they encounter a complex real-world problem.

According to Savery and Duffy (1995), constructivism assumes that 'knowledge' is not an absolute, but is 'constructed' by the learner based on previous knowledge and overall views of the world, namely, understanding comes from our interactions with our environment, while cognitive conflict stimulates learning. In the constructivist viewpoints of knowledge, education occurs only when the students are willing to actively engage in their learning experiences. Students' attitudes greatly impact the degree to which learning can occur. A survey showed that the most desirable characteristics in chemistry candidates of major companies are communication skills, computer skills, self-motivation, problem-solving skills, and being a team player. Each characteristic relates to the life long learning and working ability of a person (Jackson and Walters 2000). In order to make instruction more meaningful for students, a shift of teaching processes from teacher-centred to student-centred pedagogy is needed, since honors students generally tend to be highly motivated and goal-oriented. In these cases, instructors must give students explicit learning purposes and develop a bridge between text-based knowledge and the real world. That mean, we must place more emphasis on interactive and cooperative learning strategies, relate more to social events and everyday life experiences, pay more attention to process skills and problem solving. In this paper, some modification to the instrumental analysis course are made to develop a

student-centred 'bridge' to link the previous knowledge and the real world.

Building a bridge to a student-centred learning environment

There was a strong consensus that students do not need to learn about every single analytical technique. Instead, they are better served by cutting back the curriculum to add more depth and to place analytical techniques in a relevant context (van Bramer 2001). The underlying thread throughout the session on teaching *Instrumental Analysis* in the new century is how to provide more depth and more real-world related activity to the curriculum. Derived from research launched by the American Institute of Higher Education in the 1970s, the concepts of student-centred learning (SCL) strategies are widely accepted since they put more emphasis on students' activity in teaching and learning, put more responsibility on the students for their own learning, and focuses on improving learners' skills for lifelong learning. From this point of view, many prior works (van Bramer 2001) have elucidated the strategies of how to encourage greater participation of students in the process of learning science and have brought real world problems into the classroom or laboratory to help students develop critical thinking and problem solving abilities. Students are engaged in more active decision-making processes and learn by doing rather than passively listening to the teacher, so the learning becomes more memorable, personalised, and relevant to the real world. The effective application of these SCL strategies, such as problem based learning, case studies, project based learning, interactive learning, workshop/laboratory/tutorial, web-based learning, cooperative learning and self-directed study, etc., mostly depends on the characteristic of the course and the students' situation.

Modification of the curriculum syllabus

Since each curriculum has specific objectives and a particular knowledge base, it requires a unique teaching approach and syllabus design. Instrumental analysis uses a wide array of tools in science and technology, and integrates the advancements in these fields and their impact in the formulation of chemical principles and their applications. An optical, electroanalytical, magnetic or mass technique can be used in an offline or online coupled mode. In the case of online coupling, gas and liquid chromatographs and capillary electrophoretic systems can be considered as powerful separate and analytical instruments. Chemical information provided by instrumental analysis always arises from social-economic problems and the innovative approaches in this discipline are related to the incorporation of developments from scientific and technical areas. These characteristic provide a specific foundation for the use of contemporary SCL strategies in teaching and learning.

In order to encourage students' actively deep learning and build a bridge between text-based knowledge and real-situation, I will modify the course syllabus and incorporate some SCL strategies into the teaching process. The new curriculum (Table 1) is divided into three follow-up

teaching sessions to complete key topics and train problem-solving skills and cooperative skills. In each session a

series of modules including lectures, tutorials, laboratory exercises, real-problems learning is included.

Table 1. The syllabus of *Instrumental Analysis*

Sessions		Week	Teaching Style	SCL Strategies
Lectures	Optical Spectroscopy	1-5	Lecture, tutorial	Problem based case study, online learning, mini-seminar
	Electroanalytical Chemistry	6-10	Lecture, tutorial	Problem based case study, online learning, mini-seminar
	Fundamental magnetic, mass technique, and chromatography	11-14	Lecture, tutorial	Online learning, mini-seminar
Laboratory exercises		7-14 (3 hours/week)	Hands-on teaching, demonstration	Group work, laboratory written report, Online learning
Project (Separation science)		15-18 (3 hours/week)	Mini-lectures and laboratory work	PBL, cooperative learning, online learning, self-directed learning, peer-assessment, report and presentation

In the first and second session (weeks 1-14), students are exposed to lectures focused on the principles of instrumental analytical methods and the more common techniques of sampling, spectroscopy, electrochemistry, mass or magnetic techniques and fundamental chromatography. Problem based case studies in environmental and clinical science will be applied in the lectures and tutorials to enact the active problem-solving role. The case under study will be presented at the beginning of semester and extended until week 10. During the whole process of teaching, other SCL strategies, such as mini-seminars, concept mapping and online learning will be incorporated to enhance deep understanding by students, and the browsing of web-available animations can be considered as homework. From mid-term, the laboratory exercises (weeks 7-14) that accompany the first session will focus on what are basically text-based laboratory skills and teamwork training. The class in this session has one 3-hour laboratory session per week with 4 students in each group. Students will work in their group with the instructor to learn how to correctly and safely operate the designated instrument, to practise their procedure with known materials or with standards, and perform calculations and evaluate results so that the experiment can be repeated. The third session (weeks 15-18) focuses on more sophisticated separation methods of instrumental analysis with an emphasis on project based laboratory work and mini-lectures. The teaching purpose for this session is to create a real-world learning environment for students and develop lifelong learning skills (problem-solving, critical-thinking, decision-making, self-assessment and teamwork).

Using problem based case studies in the teaching process

The problem based case study method of teaching has been employed successfully for many years in the humanities, business, educational and medical fields (Challen and Brazdil 1996). Many students would find it more efficient to be set assignments that require them to find answers, demonstrate their understanding or learn from each other. In a case study, students learn to think about the problems they encounter in the course, rather than memorizing solutions, and willingly seek assistance when their thinking does not lead to the solution of the problem. Each case

study begins with the description of an initial 'foundation' of assumed knowledge, followed by a statement of questions/problems which arise from the foundation. By analyzing these cases through critical reasoning, students will gain a deep understanding of a significant concept. Then, the reasoning will enhance students' development of critical thinking, a skill which is most important to success in professional life. Furthermore, a very good way for self-assessment in the case study is to study in a group in which students can take turns explaining the development of the model. Taught by this student-centred, active-learning approach, students become more motivated and effective when they participate actively as learners in the classroom. Although case studies have been used in chemistry courses to examine societal, environmental, and ethical issues, their use in the teaching of *Instrumental Analysis* is not common. In *Instrumental Analysis*, a case study about screening for lead poisoning and its diagnosis is presented as follows.

Case study: Diagnosis of lead poisoning in children

Lead's toxicity was recognized and recorded as early as 2000 BC. It may enter the environment at any point during mining, smelting, processing, use, recycling or disposal, and finally reach humans through the food chain and in drinking water. Lead poisoning is known to cause a series of health disorders in human beings. In developing countries, lead in gasoline and household paints is a major cause of lead poisoning. In Australia, childhood lead poisoning was firstly described by eminent physician A. J. Turner in 1892. Modern epidemiological studies shows that young children's mental and behavioral development are adversely affected by exposure to very low levels (silent doses) of lead. Children six years old and under are most at risk, because their brain and nervous system are still developing (von Schirnding 2004). Persistent neurological impairment can follow even mild episodes of lead poisoning. In the United States, lead poisoning is the No.1 environmental disease of children and affects nearly one million children under the age of six.

While primary prevention of lead hazards remains the essential public health goal, the only way to identify individual lead-poisoned children is by screening for blood lead. Mass public screening programs were enacted to

monitor the lead exposure of young children, and mandatory testing programs were established to enable early identification of lead problems. The blood lead level (BL) is still the best and most sensitive biomarker. The Centers for Disease Control and Prevention (CDC) currently advocates that children with a BLL exceeding 10 µg/dL are considered to be at potential risk. Venous blood lead level testing is the most useful screening and diagnostic tool for evaluating recent or ongoing lead exposure. The advancements in instrumental analysis have made it possible to research lead exposure down to very low levels approaching the limits of detection. To determine the status of lead pollution in the environment and human exposure in China, a nationwide blood lead screening program has been conducted since 1983, the goal of which is to improve screening strategies and relevant background information for health-care providers, health officials, and the parents.

The case study project

At the beginning of course lecture (week 1), the case background material will be given to the students for independent study and to simulate their interest. At the same time, a series of questions raised by instructors can help students to focus their attention on a topic concerned with the course.

Questions in the case study

1. What are the major exposure sources of lead poisoning?
2. Describe briefly the chemical process by which lead poisoning damages children's health.
3. Why has childhood lead poisoning in small doses become an issue in recent years? Explain the role that instrumental analysis plays in this issue.
4. What is the quantitative criterion in the diagnosis and evaluation of lead poisoning and human exposure?
5. How is blood lead level screening conducted?
6. How many instrumental analytical methods can be applied in blood lead level testing?

This case will be used as an educative way to introduce students to instrumental analytical techniques. The instructors' guides include an overview of the case, tips for self-study, an assessment guide and typical session plans. Based on self-study and information collection via the Web or print resources, students can select the topics (all the topics must be selected in each group of 5-6 students) and discuss them in a group, then they will give a group seminar in week 3. The study and discussion can be used as a brief introduction on *Instrumental Analysis*. Working in groups or teams is not only an effective way for students to learn and get feedback from peers, but also develops one of the generic skills highly sought by employers. The mini-seminar will direct the students to search for related materials on the various aspects and understand some basic concepts in the course, such as sampling, toxicity, configuration of sample limits of determination, contamination, interference, diagnosis and screening. The most important thing is they can link the testing techniques used in the case study (atomic absorption spectroscopy (AAS), atomic emission spectroscopy (AES), anodic stripping voltammetry (ASV), potentiometric stripping analysis (PSA), ICP-MS and X-ray emission) with the real-

world diagnosis problem. The teacher can make both a formative and a summative assessment by observing the mini-seminar and frequent quizzes on the assignments and on classroom activities, then adjust the focus of lecture as required. After giving students the general background of the principles of instrumental analysis (weeks 8-10), the instructor will give another assignment to students and guide them to the problem-based learning project in the following lecture session.

Comparative problem based learning project

Problem based learning (PBL) in medical education began with the Faculty of Medicine at McMasters University (Giancarlo and Slunt 2004) in Canada in the mid 1960s. The use of PBL in science teaching incorporated goals for students that are much broader than the acquisition and application of content, and is expected to influence several aspects of the students' lifelong learning experience. In this project, a problem will be given to a group of 5-6 students, and they have to solve the problem in a group in an informal and interactive way and finish the assignment within 4-6 weeks (weeks 6-12).

PBL Assignment

A hospital is tendering for a new contract for the childhood blood-lead level (BLL) testing program. For this purpose, the management decide to establish a quick, easy, effective and economic blood-lead poisoning testing laboratory. The students (in their group) act as part of the analytical technicians team whose task is to ensure that the hospital can deliver a high quality service with a suitable profit margin if they secure the contract. The result of the project and their findings will be sent to the manager (instructor) and used as the basis for establishing the laboratory.

The time is limited to 4-6 weeks and so students will split up into several groups, each of which must focus on a specific testing method and procedures by learning in a SCL method (Figure 2). At the first seminar, each group should elect one member to report the groups' finding to the class, then get feedback from peer groups' discussion for further research. At the second seminar, each group should take a comparison of each technique and choose their final project. The assessment of learning will involve a mini-seminar (2 times), written-report, group oral-presentation (10 minutes) and peer-assessment. In PBL, students are confronted with a scenario to act as a group of analysts to solve a problem and make decisions.

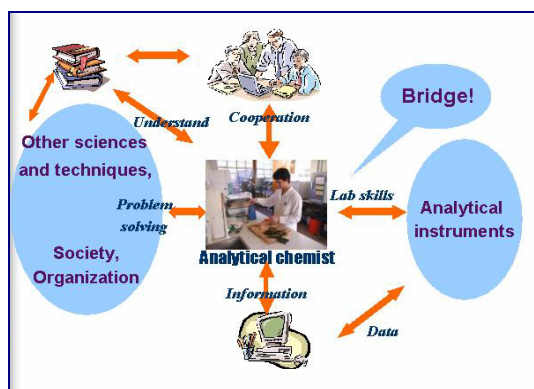


Figure 1. The description of the *Instrumental Analysis* course

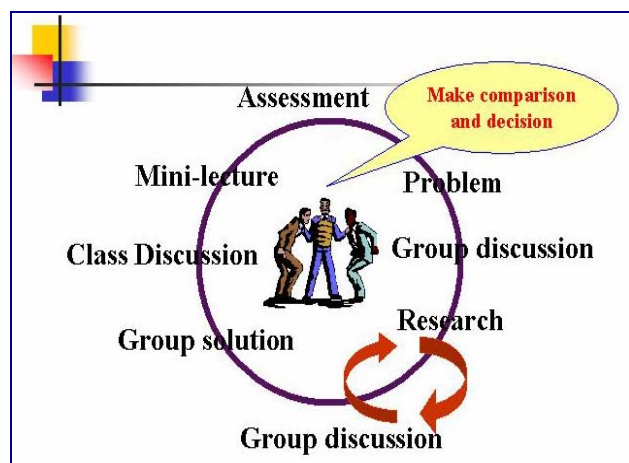


Figure 2. A scheme of comparative problem based learning strategies

As a supplement to lectures, this problem-based *comparison* learning (Edmiston 2002) uses many instrumental techniques to measure a single analyte, and serves to deepen student knowledge of instrumental analytical methods and concepts, including sampling and sample treatment, AAS, AES, ASV, PSA, and MS. Students are afforded an opportunity to compare the results obtained with different methods and discover that an instrumental technique can only be used effectively with certain types of chemistries. It also helps to foster student ability in linking the interdependent topics and allows students to apply their knowledge to real situations. This division of students into group, models, on a simple level, the division of labor found in analytical laboratories. A key aspect is that students meet as a class after the project, so that the strengths and weaknesses of each instrument can be compared as a starting point for the rest of the course. They can discuss the advantages and disadvantages of different analytical or instrumental techniques and gain better insights into the possibilities and the accuracies of these methods. Students are more self-assured when they have more opportunities to verbalize their understandings to peers. The feelings of comradeship will enable students to overcome the feelings of isolation and competition, and reduce their reluctance to ask questions in class. Since the atmosphere in PBL is more casual, the students understand more by working problems, and will have better feelings toward the whole educational experience. Owing to the rapport between instructor and students, the discussion and communication in teaching and learning will lead to a positive modification in both lecture and laboratory exercise session.

To measure content knowledge, quizzes, observation notes, the open-response comments and individual interview will be used for assessment. Observations are made of the group interactions during the class, and group members will be interviewed individually during the lecture session. Notes about the groups includes dialogue and interaction of group members.

Project-based laboratory

The theory of constructivism proposes that knowledge is constructed by the learner through his personal interaction with objects and events (Cruikshank and Olander 2002).

For years, instructors have realized the importance of stimulating high-order thinking in the chemistry laboratory, so instrumental analysis courses are gradually turning toward project based approaches (Breslin and Sañudo-Wilhelmy 2001; Arnold 2003). In the last session, an application project will be incorporated into the teaching and learning. The objectives of such projects are to perfect students' laboratory techniques, to stimulate their high-order thinking in research and development, to foster their problem solving and decision making skills, and some generic skills.

As the main section of *Instrumental Analysis*, separation techniques embed online optical and electroanalytical detection knowledge and have been successfully applied in a wide range of social-related problems, mostly in the life sciences and environment science. The project based learning will focus on this technique and be scheduled in the last four weeks of semester. In this case, some real-world related hot topics in life science or environment science will be selected for the project, such as pesticides residue analysis in food, herb medicine separation or sports drugs assay. In the project studying (Figure 2), students will conduct a literature search, select the possible methods of assay, define the preliminary laboratory procedure, give the instructor a design or project for experiment, and have it approved by the supervisor. Tutors will encourage students to discuss their projects both in and outside the laboratory. Students in a group explain their projects to each other and offer suggestions on how to overcome specific problems before the laboratory work. After all the groups have finished planning, a member of the group will be randomly selected to begin the solution on the board, or to direct the tutor through the steps to solve the problem. Tutors conduct mini-lectures, demonstrations and additional questions to encourage exploration of overlooked problems and help students perfect their design. When students perform the experiments, they will check their design and modify the laboratory project according to the finding in the experiments. Having finished the laboratory work, each group will deal with the experimental data, phenomena and write the laboratory reports and give a 20 minute oral presentation. If abnormal results are obtained, students will be forced to think about the possible reasons for such results. Because of the former lectures and laboratory training session, students are expected to perform the mechanics of the experiment with technical correctness, so failures are in the planning and thinking, not in the technical performance.

In a sense, students will be more involved and challenged when they working on a problem, reflecting on their learning, designing their own experiment, dealing with a project and generating their own questions about it rather than instructors doing it for them. The project based learning provides time for students to think through and discuss improvements in a non-rushed, non-graded environment, provides the opportunity for students to share ideas with their peers and develop communication skills necessary for the workplace, and also allows them to revise their approach and critique their projects with less emotional attachment (Marine 2003), which is necessary to critically evaluate and perfect their work. The

experimentation process demands involvement in the original question and thus can become a powerful means of active learning and can help them foster the problem-solving skills. On the other hand, training for technical

correctness will help students perfect laboratory techniques and practice thinking critically.

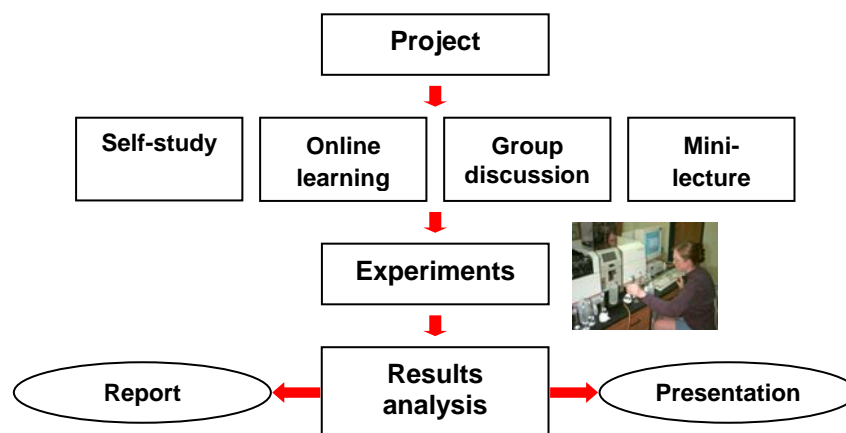


Figure 3. A scheme of a project-based learning strategy

By utilising real-world problems and using SCL strategies in the teaching and learning process, such as case studies, PBL, project based laboratory, this study tries to modify the *Instrumental Analysis* curriculum to some extent, and makes the course teaching focus not only on text-based knowledge and technical skills, but also on students' life-long learning skills, such as communication and collaboration. However, some important factors must be considered in the process of implementing these SCL strategies. In the opinion of the students and the other instructors, the project and PBL may have benefits in increased instructor–student interaction and active learning, but it places greatly increased demands on the teacher for instruction and guidance during teaching, a factor that may be both challenging and time consuming. Moreover, none of the students believed the SCL strategies to be easier than the traditional approaches in which they were previously enrolled. From this point of view, students and other instructors may resist new methods, as a result, positive evaluation and evidence need to be provided for colleagues who may be hesitant to change or critical of the new methods and for the students.

Of all the challenges facing *Instrumental Analysis* education, it is the assessment of SCL that is hardest to overcome. How does one measure the learning outcomes of students? Assessment drives learning more than anything else. We need to be constantly aware of any discrepancies between the assignment and the learning outcome. Curriculum evaluation will enable the teacher to see how effective the course has been. With a combination of outcome evaluation and process evaluation in the PBL and the project, instructors can get feedback on how well students are understanding the key concepts, consider what happens during the SCL process and tailor future lectures or tutorials in response.

Since all assessment methods require that students present evidence of their learning, I will consider the use of formative assessment and criterion-referenced assessment

to ensure that the assessment practices reflect, encourage, and reward the SCL pedagogy. It is based on a combination of group-based assignments (15%), management interviews and observation notes (5%), individual assignments and reports (15%) and exams (65%). To create an SCL environment that presents the professional aspects of *Instrumental Analysis* in a comprehensive fashion is an attractive but long-term blueprint, it does need considerable effort from the instructor to link the students with the real-world problem, and help them to take a large step towards lifelong learning.

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