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# Chemistry Education and Sustainability in the Global Age

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# Preface: Proceedings of the 21st ICCE

*Sustainability.* The dictionary defines this term as “to maintain or endure.” And, following the work of the UN Brundtland Commission, we have learned to think of sustainability in the context of development that “meets the needs of the present without compromising the ability of future generations to meet their own needs.” It is long overdue that we begin to link this vitally important concept with the goals and learning outcomes of science education and think about what it means for chemistry education to be sustainable and contribute to sustainable development.

The 21st conference of the International Conference on Chemistry Education (ICCE) series, held in Taipei from August 8–13, 2010, created just such a linkage, with an overarching conference theme of “*Chemistry Education and Sustainability in the Global Age*.” This theme was developed in recognition of the International Year of Chemistry 2011, which highlights the role for chemistry in meeting Millennium Development Goals and environmental challenges.

This volume of proceedings from the conference provides an opportunity for readers to engage with a selection of refereed papers that were presented during the 21st ICCE conference. Divided into 6 sections, the 31 papers published here pick up on the multiple meanings of the term sustainability. Themes for the sections will be of interest to chemistry educators who care that the learning environments in their classrooms motivate students to learn effectively, so that those learners are equipped to contribute solutions to the serious global challenges our planet faces. Efforts to improve chemistry education must also be sustainable – that is, they must be maintained and endure. And so the reader will sample here reports of research on topics ranging from globalization and chemistry education through a suite of issues related to learning and conceptual change; teaching strategies; curriculum, evaluation and assessment; e-learning and innovative learning; and microscale approaches to chemistry.

One of the unique and valuable dimensions to the ICCE conference series is the way the series brings chemistry educators together from around the world to discuss ways to serve learners better. The reader will discover that both common challenges and creative solutions emerge from very diverse settings – examples include the University of Venda in South Africa (Mammino), Pulau Pinang Matriculation

College in Malaysia (Teh and Yakob), Tokyo Gakugei University (Ogawa and Fujii), the MicroChem Lab in Hong Kong (Chan), and the National Taiwan Normal University (Chen, Lin, and Chiu). I hope you both enjoy and find valuable your engagement with their ideas in sustaining your own professional development in the global world of chemistry education.

Past Chair of Committee on Chemical Education of IUPAC Peter Mahaffy

# Introduction to Proceedings

It was a great honor for the Chemical Society Located in Taipei (CSLT) and National Taiwan Normal University to host the IUPAC's 21st International Conference on Chemical Education (ICCE) from August 8–13, 2010, in Taipei, Taiwan. A different country has hosted this international conference, held every other year, since 1969.

The ICCE, sponsored by the International Union of Pure and Applied Chemistry's (IUPAC) Committee on Chemistry Education (CCE), is one of the most well attended and informative international arenas for furthering chemistry education around the globe. IUPAC was founded in 1919 by chemists from industry and academia. Over the past nine decades, the Union has been successful in fostering worldwide communications in the chemical sciences and uniting the academic, industrial, and public sectors. As an international, non-governmental, non-profit, and independent scientific body, the Union promotes chemistry education via multiple channels, including the CCE, and its emergence as an influential leader in promoting chemistry education around the world.

The theme for the 21st ICCE was "Chemistry Education and Sustainability in the Global Age," which was intended to inspire participants to reflect on global environmental and ethical issues. The CSLT and the Organizing Committee organized ten plenary lectures by well-known international speakers, five workshops, three symposia, one panel discussion with the presidents from chemical education societies of different countries, chemical demonstrations, and a variety of other activities. In terms of the panel discussion, the presidents or chair of science and chemistry associations from countries including Canada, Germany, Korea, Malaysia, the Philippines, Taiwan, and United States came together and discussed issues about chemical education, sustainability in the global age, and objectives and plans for the International Year of Chemistry.

The 21st ICCE had over 300 participants in attendance. Efforts to increase participation by under-represented professionals continued and included, for example, travel scholarships for female scholars provided by the IUPAC and the Asian Chemical Education Network (ACEN) of the Federation of Asian Chemical Societies (FACS). Such efforts encourage attendance at the ICCE and promote the conference's international and diverse focus.

Following the conference, 42 articles were submitted to the Organizing Committee and each article was reviewed by two experts in chemistry education. The articles were submitted from all over the world, and covered a wide range of topics. Twenty-nine articles were finally accepted for publishing. In this compilation we have categorized the articles into six sections. The six sections are: (1) Globalization and Chemical Education, (2) Learning and Conceptual Change in Chemistry, (3) Teaching Chemistry, (4) Curriculum, Evaluation, and Assessment in Chemistry Education, (5) E-learning and Innovational Instruction, and (6) Microscale Laboratory Work in Chemistry. Each section is introduced by a member of our editorial board. These topics were chosen because we, as chemistry educators, are concerned with increasing the quality of chemistry learning and teaching, promoting public understanding of chemistry, highlighting sustainability issues for our global community, and implementing innovative technology in school practice and research. These proceedings aim to further the understanding and focus the attention of the international chemistry education community so our citizens and our planet may benefit. We hope you enjoy reading this book and find effective ways to continuously promote chemistry education research and practice in your own country.

Chairperson, 21st ICCE Organizing Committee

Mei-Hung Chiu
Editor-in-chief
Hsiao-Lin Tuan, Hsin-Kai Wu,
Jing-Wen Lin,
and Chin-Cheng Chou
Editors

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# Part I
# Globalization and Chemical Education

**Mei-Hung Chiu**

Increasing globalization has changed how we live and learn over the past number of years. With exponential advances in technology and information, educational, business, and industrial organizations must be able to adapt quickly to the economic, cultural, and institutional changes that are taking place worldwide. Chemistry, as a discipline, has at its core the goal of educating the population so each generation understands the global needs and global socio-scientific issues of the period. In the twenty first century, we are facing severe issues related to the environment. For the next several generations, these problems will likely become more complex and far-reaching than those we have faced before if we do not pay attention to them now. Therefore, the main theme of the conference, "Chemistry Education and Sustainability in the Global Age," is to allow participants to reflect on global environmental and ethical issues, to provide hard questions yet to be answered, and to suggest possible solutions for the problems we are all facing in the real world. In this section, we offer three chapters that each address issues and concerns related to globalization and the teaching and learning of chemistry around the world.

The first chapter is written by Kolasa and Maciejowska, who reviewed several programs and sources, sponsored by the European Union, that aimed to promote school science practice and lifelong learning from a sustainable perspective. The authors pinpoint the problems and challenges of implementation faced by these projects. The second chapter focuses on the trend in chemistry that extends the discipline from content learning to a focus on humanism in chemistry education. The authors, Yang and He, discuss the importance of cultivating students' humanism in today's globalized society. Finally, Gulinska takes us on a journey to Poland. The author points out that teachers should be aware of the power, possibilities, and limitations of the innovative learning environment in order to stimulate students' motivation and elicit their creativity in learning chemistry.

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# Dissemination of Achievements in Chemical Education (Research) via EU Projects

**Anna Kolasa and Iwona Maciejowska**

## 1 Background and Purpose

Over the last several decades, the European Union has sponsored a variety of projects related to the advancement of chemistry and natural sciences education (European Commission, 2000). Examples of these programs include Tempus, Leonardo da Vinci, Socrates, and framework programs. Because the outcomes of these European projects were often known only by the researchers and participants, the European Commission received the impression that the cost was not proportional to the results obtained. For this reason, greater attention is now being paid to promoting and disseminating outcomes from such projects. In order to reach this goal, a number of innovations have been introduced, such as a common and easily accessible website containing descriptions of European projects, and replacement of the "pilot" projects of the Leonardo da Vinci program with "transfer of innovation" projects. European grant writers are now paying greater attention to their descriptions of the dissemination of results.

## 2 Existing Types of Projects

A variety of recent successful projects have been conducted as part of a collective initiative called the *Education and Culture: Lifelong Learning Programme* (see Fig. 1).

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**Fig. 1** Logo of Education and Culture. Lifelong Learning Programme

**Fig. 2** Logo of ESTABLISH project

*Lifelong Learning Programme* (http://ec.europa.eu/education/lifelong-learning-programme/doc78_en.htm) consists of the following elements:

- The *Comenius* Programme focuses on all levels of school education, from pre-school and primary to secondary schools (e.g., CITIES).
- The *Erasmus* Programme funds co-operation between higher education institutions across Europe (student and teacher exchanges, joint development of study programs, international intensive programs, thematic networks, language courses: EILC, European Credit Transfer System).
- The *Leonardo da Vinci* Programme funds practical projects in the field of vocational education and training (e.g., CHLASTS, FACE, SOLID).
- The *Grundtvig* Programme focuses on the teaching and study needs of learners taking adult education and “alternative” education courses (e.g., TrainAutism On-line).

There is also the *Seventh Framework Programme for Research and Technological Development FP 7* (http://cordis.europa.eu/fp7/home_en.html) with educational component (e.g., ESTABLISH) (see Fig. 2).

For further information on these projects, the websites listed below can be consulted:

- *Socrates* – Database; http://www.isoc.siu.no/
- *TUNING Educational Structures in Europe* – This project has developed an approach to (re-) design, develop, implement, evaluate, and enhance the quality of first-, second-, and third-cycle degree programs; http://tuning.unideusto.org/tuningeu/

- *TEMPUS* – This program supports the modernization of higher education and creates an arena for co-operation in countries surrounding the EU, including those in the Western Balkans, Eastern Europe, Central Asia, North Africa, and the Middle East (e.g., NET, STEP, EXPAND); http://ec.europa.eu/education/external-relation-programmes/doc70_en.htm

## 3 Outcomes

The projects' results can be divided into two groups: hard (easily measurable) and soft (difficult to measure) outcomes.

"Hard" outcomes include:

1. Didactic materials for teachers and students (see Fig. 3):
   - Books, manuals, and other publications
   - Powerpoint/flash presentations
   - Films
   - Games
   - Informative web pages
   - Interactive web pages (e-learning platforms)
   - Classroom scenarios


**Fig. 3** CHLASTS CD-ROM

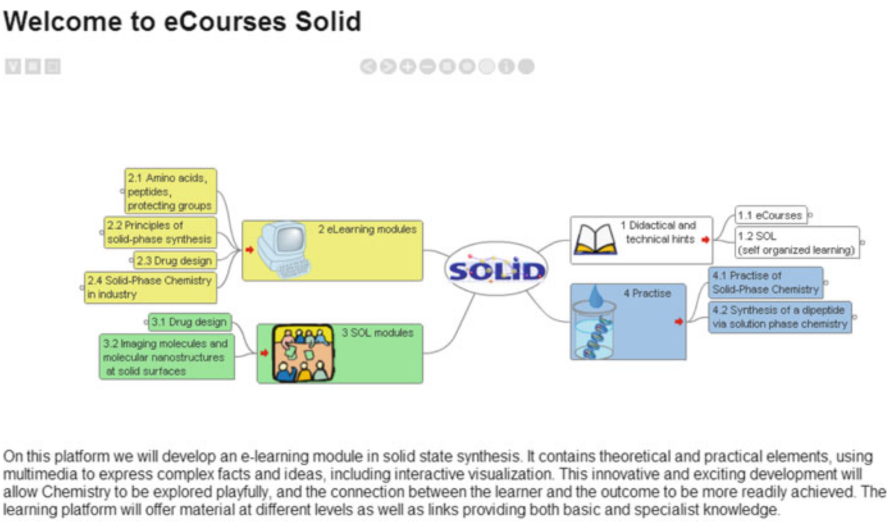


**Fig. 4** Screenshot http://ecourses.solid-info.net/

2. Training programs
3. Case studies, examples of GMP (Good Management Practices) and GLP (Good Laboratory Practices)
4. Reports
5. Expert opinions
6. Databases
7. Trainings and workshops

The screenshots presented in Figures 4, 5, and 6 come from the following two projects. SOLID (Fig. 4) developed e-learning materials concerning solid–phase chemistry, which are included in the structure of Chemgapedia (http://www.chemgapedia.de/vsengine/topics/en/vlu/index.html) and addressed to vocational school students. The CITIES website (Fig. 5) offers class scenarios, descriptions of experiments, and curiosities of the domain that can be used in teaching, in addition to information on career paths for people with a degree in chemistry and about chemical and related industries. The website of another project, FACE (Fig. 6), provides a report on chemical education in Europe.

“Hard” outcomes contribute to the achievement of goals such as improving quality of (teacher) education. Still, they are not a sufficient by themselves. They need to be widely disseminated and efforts should be made in order to also achieve “soft” results, such as:

1. Establishing international contacts
2. Development of attitudes and skills
3. Familiarization with other educational systems
4. Contribution to mutual understanding between various target groups

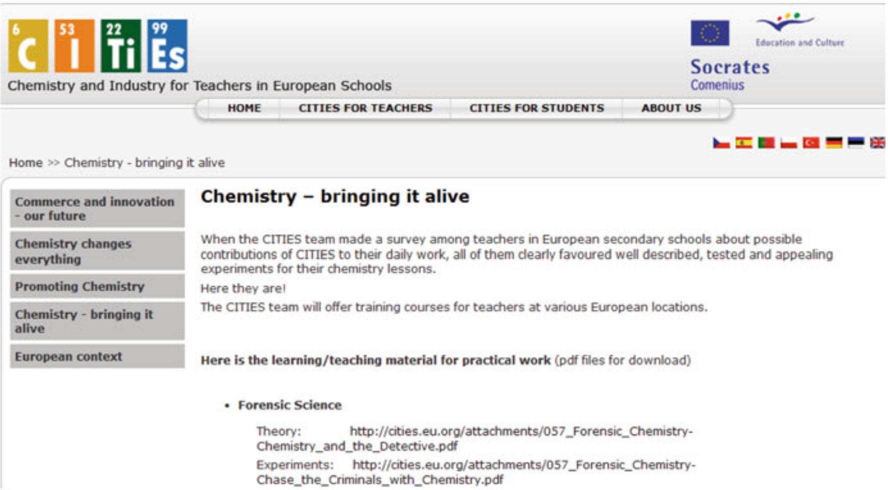


**Fig. 5** Screenshot http://cities.eu.org/

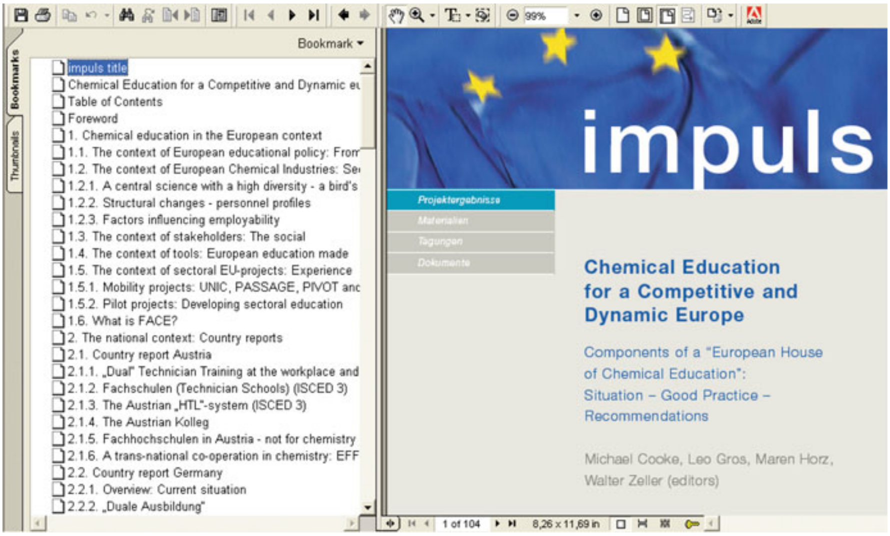


**Fig. 6** Screenshot http://face.fh-fresenius.de/whitebook.pdf

"The purpose of dissemination could be defined as: 'to influence people's behaviors, so that they will adopt, or at least become aware of a new idea, product or service'" (Leonardo da Vinci Pilot Project, 2003)

Dissemination has many functions, including:

- Increasing the understanding and implementation of new ideas

- Changing practices
- Changing modes of thinking

For these reasons, dissemination of both "hard" and "soft" outcomes is important.

## 4 Beneficiaries

Several categories of project beneficiaries can be distinguished:

- Institutions: schools, higher education institutions (HEI), examination boards, teacher training centers, boards of education (pedagogical supervision), enterprises, national and local administrative units, chemical and related industries
- Associations (non-governmental organizations, or NGOs): parent/teacher/student associations, science societies, employer/employee associations
- Groups of people or individuals: decision makers, teachers, employers, employees, students, lecturers, scientists, parents, local authorities, school headmasters, curriculum developers
- Wider public: citizens, local society

In general, these groups can be divided into direct and indirect beneficiaries.

Target groups differ in many aspects. For instance, in number of members – they sometimes engage 20 people (e.g., teachers at local school) or 2 million (e.g., students in a particular country), or in formality – they can be more or less formalized and organized (e.g., parents or a national chemical society). They may also differ in homogeneity, activity, age, habits, knowledge, skills, and so on. Finally, they can operate under various conditions, for example, in the countryside or in cities, with or without Internet access, in poor or rich regions.

## 5 *Relations* (Factors Affecting the Mode of Dissemination)

Characteristics of the target group along with the type of deliverables obtained from a particular project determine the best mode of dissemination (Fig. 7).

Various communication materials can be used in dissemination activities, including web pages, press releases, articles, flyers, books, CDs, posters, video clips (DVD), and PowerPoint/Flash presentations . Other dissemination materials include handouts, bags for conferences, banners and poster roll-ups, equipment for conference stands, and stickers for the project cars and other equipment.

Dissemination takes place:

1. Directly – during meetings, workshops, conferences, summer courses, exhibitions, open days, and at information points

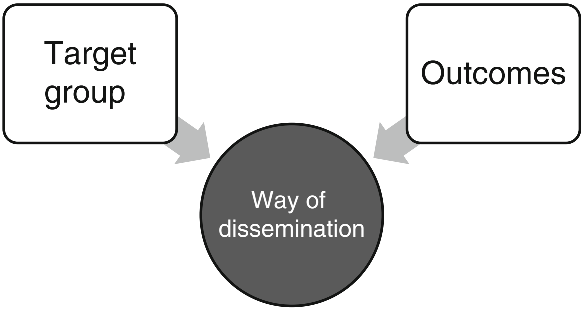


**Fig. 7** What affects the mode of dissemination

2. Indirectly through:

 - Projects and project-related media – flyers, the project's web page, European Commission web pages (e.g., SCIENTIX, http://www.scientix.eu/web/guest/projects)
 - Mass media – local, national, and international magazines, radio, and TV
 - Educational organizations and networks (e.g., ICASE, ESERA, IOSTE, ECTNA, and their mailing lists, web pages and newsletters)
 - Other bodies – chambers of commerce and industry, local authorities, and so on.

Project outcomes are often summarized during specially held final conferences open to wide audiences, such as the ECTN 4 Final Conference Dresden 9–10 September 2009 or Tuning Dissemination Conferences: I: Student Workload and Learning Outcomes; Key Components for (Re)Designing Degree Programmes – Brussels, 21-22 April 2008 and II: Competence-based Learning: the Approach for the Future? – Brussels, 12–13 June 2008.

## 6 Difficulties

Following conclusion of a project, a deficiency of funds for website maintenance distribution of materials may occur. An interesting solution has been proposed in the Tuning project. Enthusiasts of the Tuning methodology established information centers that are open even after the funding period has ended. People involved in formulating the Tuning methodology, based upon student-centered teaching and learning outcomes, wanted to avoid wasting their hard work and effort and decided to continue sharing their knowledge with others and to provide counseling in matters related to employing the project's outcomes. In Europe, such services are provided by the European Tuning Information and Counseling Centres (ETICCs) – two of them are established in Groningen and Bilbao – and national Tuning Information

Points (TIPs) that have been established in all countries that participated in the project. In some countries, single TIPs are available; other countries have separate TIPs for humanities and science or for languages spoken in the country. For example, in Poland there are three TIPs: one conducted by the Foundation for the Development of the Education System (National Agency of Erasmus) POLAND, one for humanities, and one for science and related subjects. The list of 43 national Tuning Information Points is available on the Tuning web page (http://tuning.unideusto.org/tuningeu/).

Several of obstacles may be encountered during the promotion and dissemination process. The biggest challenge is persuading project partners that "boasting" about a project's achievements is important. It is common for academic teachers to undermine this aspect by determining it is adequate to publish results of research in a niche journal. Incorporating this practice into a project's reality may have disastrous consequences. It sometimes happens that web pages are not updated or are even closed just after the end of a project, and publications are not sent to recipients. Linguistic matters constitute another problem. Some project publications do not engage their beneficiaries because of the style and presentation of the materials. They tend to be too advanced for wide public dissemination, too hermetic, or, at times, too colloquial for experts. Also, not all target groups speak English.

## 7 Copyright

In discussing dissemination, copyright must be taken into consideration. It is important to establish common rules and procedures to clarify all potential doubts at the beginning of the process, for example, by signing a copyright agreement or dissemination policy document. Otherwise, this issue may become point of contention and cause serious arguments between partners.

Copyright issues may be categorized into:

- Moral rights – rights to be maintained by the author, such as making decisions about changes
- Economic rights – rights to make the product available for the public (or not!); these rights are transferrable

It must be remembered that copyright only concerns the form of the presentation (text and illustrations) and not the information, ideas, or topics. The use of already-existing materials, copyrights of/for subcontractors, and so on should also be taken into account.

## 8 Conclusions and Implications

Based upon our experience, we offer the following recommendations. They are divided into several categories: those concerning time, mass media, and interpersonal communication.

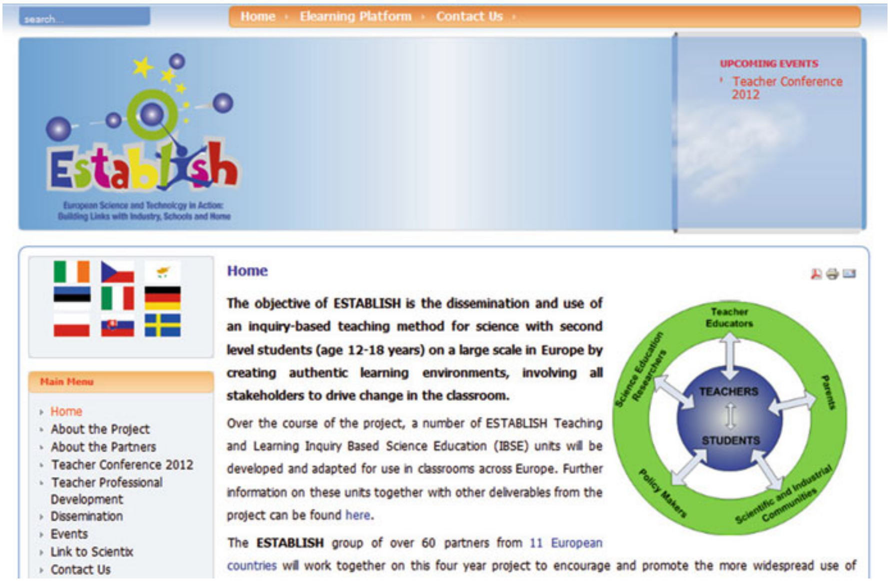


**Fig. 8** ESTABLISH web page http://www.establish-fp7.eu/

The dissemination strategy should be prepared as soon as possible and comprises three consecutive phases:

Awareness-oriented phase – the goal of this first phase is to raise awareness within target groups about the project and its aims

Outcome-oriented phase – this phase aims to promote the results of the project, in order to allow potentially interested parties to become familiar with the project's outcomes

Exploitation-oriented phase – this phase is specifically targeted at potential clients of a project. It includes upgrade of the project website, comprising optimization for search engines and optional registration, demonstrations for interested stakeholders during the negotiation of business projects, and new follow-up project(s) based on the results of the previous one (Dragon Project Dissemination Plan, 2011)

Agreeing upon a starting date for dissemination is often problematic. We suggest preparing a project brochure and home web page as early as possible after the start of the project (see Fig. 8). It should contain contact information, core message, schedule, and a list of partner institutions. It facilitates finding future participants and people to test products, and it also helps to build an image and adds to a project's credibility. It is essential to update a project brochure/home web page regularly, especially changes in contact data, product information, invitations for events, and links.

Mass media is a specific medium with its own rights. It is a medium aimed at a large public and diverse target groups. Press releases should be structured properly, with a headline, information (what, when, to whom), text, and pictures (if possible). The title should contain the necessary information and be catchy. The content

**Fig. 9** The logo of Tuning Project

should be written using simple language so that it can be easily understood by non-experts.

It is recommended that articles be checked for accuracy prior to publication. Some journalists use generalizations and shortcuts that can significantly distort the message the project wants to convey.

A consistent graphic identity in all dissemination tasks allows for better visibility and recognition as well as branding of the project (e.g., logos [see Fig. 9], layouts for leaflets, posters, and PowerPoint presentations). All publications based upon work funded by the EC should acknowledge their affiliation to the particular project and bear recognition of the funding.

Information on the project should be shared with colleagues and promoted inside partners institutions. Too often, only those researchers and deans who are directly involved know about a project. The project should be discussed among colleagues and permanent exhibitions could be opened in partner organizations. Creating a social network is important from both and institutional and a personal point of view. Developing a network and maintaining it demands effort, but it contributes to reaching a project's goals. Target groups should receive invitations to workshops, meetings, and press conferences. Such invitations should be personally addressed rather than to "Dear Sir/Colleague."

Detailed advanced planning of dissemination is key to the success of a project. All possible efforts should be made to reach the broadest target group and to contribute to the development of a knowledge society in the globalized world (European Commission, 2011).

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# Polish Education Reform and Resulting Changes in the Process of Chemical Education

**Hanna Gulińska**

Chemistry in junior high schools covers 130 h in the course of three years; in secondary schools, there are 30 h in the first year, and, providing the students choose to study chemistry, a total of 240 h in classes two and three (*matura* exam). If students decide not to take science, they will unlikely broaden their knowledge of chemistry, biology, or physics again.

The new structure of the education system in Poland has encouraged authors of new handbooks to prepare highly interesting multimedia formats that, as has been proven by extensive research, may positively influence students' interest in a subject and consequently increase students' likelihood of choosing to pursue that subject during subsequent stages of education. It is believed that teachers as well as teaching aids will continue to exert substantial influence on the student's choice.

## 1 Motivation

Current trends in contemporary education expand general access to information and knowledge but at the same time reveal the necessity to introduce changes in skills as well as the systems of work that need to be implemented. It is universally acknowledged that our society will be increasingly knowledge dependent (Cresson & Flynn, 1997).

In a report prepared for UNESCO, "Learning: The Treasure Within," four pillars of education on which the states are to build their educational systems and programs were presented (Delors, 1999). The pillars include:

- learning to live together, learning to live with others,
- learning to know,
- learning to do, and
- learning to be.

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A Polish member of the European Parliament, Bronisław Geremek, wrote, “Life-long learning remains in natural opposition to the most painful of exclusions – the exclusion due to ignorance. Changes which occur in information technology and communication, sometimes referred to as the information revolution, strengthen this danger and define the key role of learning in the twenty-first century. As a consequence, all forms of education should be implemented in order to prevent the threats of exclusion and to retain social cohesion.”

The above statement as well as the clauses of recent education reform in Poland (2009) encouraged various educational institutions to prepare new learning environments that could shape various key competencies, defined as a combination of:

- knowledge,
- skills, and
- appropriate stances (Gulińska, 2009a, b).

Key competencies are those that people need for:

- self-fulfillment,
- personal development,
- active citizenry,
- social integration, and
- employment.

## 2 Methodology

An educational project called *E-Academy for the Future* implemented in Poland in 2010 and sponsored by the European Union involves teaching with the aim of achieving seven key competencies:

1. communication in native language,
2. communication in foreign languages,
3. mathematics competencies and basic scientific and technical competencies,
4. IT competencies,
5. ability to learn,
6. social and citizenship competencies, and
7. initiative and entrepreneurship.

*“E-Academy for the Future” is going to be implemented within the years 2010–2013*. Students from 200 junior high schools in their first year (13–15 years of age) are to participate in the project. The aim is to help these students acquire the above competencies in the course of their school work as well as by means of a project method and e-learning units.

*Students will be able to participate in 168 e-learning units either on their own or guided by their teachers.* The units will cover such school subjects as chemistry, physics, biology, and geography as well as mathematics, information science, and civil knowledge. Each of the units shall constitute an attractive, multimedia program containing educational material, tests, and exercises shaping selected skills. The units are designed to make it easy for teachers to include them in the program. The project is an opportunity to make substantial progress in learning technology and to shape key competencies in Polish schools.

Additionally, in the first term of the school year, students who perform poorly on their final test in Class 6 will participate in *School Compensatory Groups* carried out by school teachers in the form of workshops. Their aim is to develop abstract thinking, increase self-esteem, awaken aspirations, and encourage creative problem solving as well as improve the ability to learn.

Students who excel while working with e-learning units will form *Virtual Science Groups* (Virtual School), whose members develop their talents under the supervision of teachers. After the first and the second year of the project implementation, the best virtual school students will participate in 5-day science camps in academic centers across the country.

In each school, *Local Project Teams* will prepare, in cooperation with their local communities, interdisciplinary projects that incorporate local environmental, social, and economic issues. The projects will be published on an e-learning platform and thus a *League of Local Project Groups* will be formed. The best projects will be invited to participate in the national overview (Gulińska, 2009c, d).

The following diagram shows how activities are interrelated in the *e-Academy for the Future*:

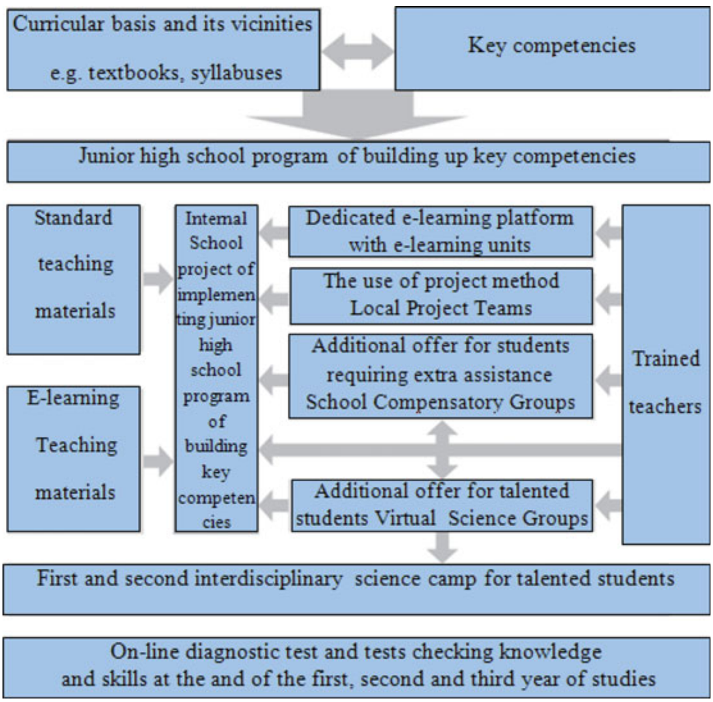



Diagram of *e-Academy for the Future*

While preparing the *e-Academy for the Future* project, it was decided that e-learning methods must not be considered as alternative forms of traditional classes (Gulińska, 2010). Practice has shown that a combination of new (electronic) and traditional teaching methods (*blended learning*) is most effective. In the future, the boundary between the two types of learning may become indiscernible. Therefore, the following has been assumed:

- blended learning will not be just an occasional type of work, but a process carefully planned in time, and
- effective acquisition of key competencies and fulfillment of curricular basis requirements will constitute the results of the applied type of teaching.

*Work within the project is done via an e-learning platform "EduPortal,"* where materials for teachers and students are published. Students can use the e-learning units independently or with their teachers' assistance; they also can communicate with peers participating in the project. Each teacher and student has continuous access to the platform, regardless of time and space.

The basic form of organization of learning is a unit, which is a complete lesson where students acquire not only knowledge but also skills pertaining to at least one competency. Within the e-learning unit, students work with multimedia material and obtain knowledge and skills and use the opportunity to receive feedback and evaluation as well as self-assessment.

Tools for teachers working in the *e-Academy for the Future* involve the following:

- access to the e-learning platform,
- e-learning units prepared by experts and designed for learning key competencies,
- instruction (methodology handbooks) for each e-learning unit,
- an opportunity to model the didactic process by means of e-learning units in various configurations with traditional teaching,
- the potential to quickly modify, update, and expand blended learning, and
- the ability to administer the elements of the learning process as well as monitor students' progress.

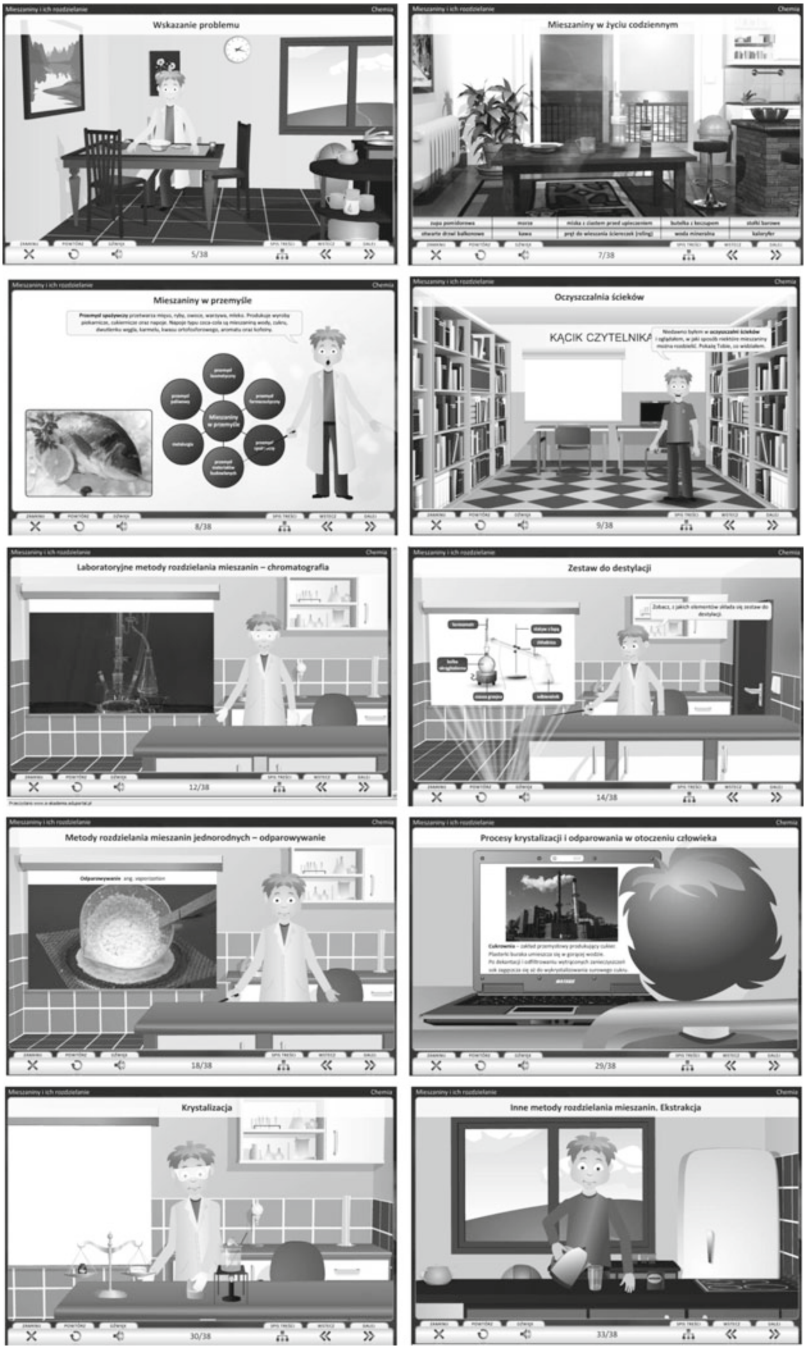
## 2.1 Structure of an e-Learning Unit

Each e-learning unit teaches a particular competency. For example, for a language competency, the student will learn the most important content (definitions and names) in English. If the competency is initiative and entrepreneurship, then the student's task is to collect materials on a particular subject from the student's immediate environment (their home, their community) and to prepare a report, a poster, or a movie.

| | |
|---|---|
| INTRODUCTION | Title page and introduction to the contents of the unit. |
| AIM | Defining the expected results that might be achieved via working with the unit. |
| RELATIONSHIPS | Essential relationships of the unit with other e-learning units. |
| MODULE – KNOWLEDGE | The multimedia part of the unit, which makes it possible to acquire the knowledge required to develop at least one competency. |
| | Practical, interactive use of the skill learned in the context of the newly learned knowledge. |
| MODULE – EXERCISE | Remembering the acquired knowledge and skills:<br>1. summary of the most important content of the unit,<br>2. interactive practice of the new skill. |
| MODULE – TEST | Feedback and self-check – to what degree was the aim achieved?<br>If it was not achieved, suggest further necessary actions. |

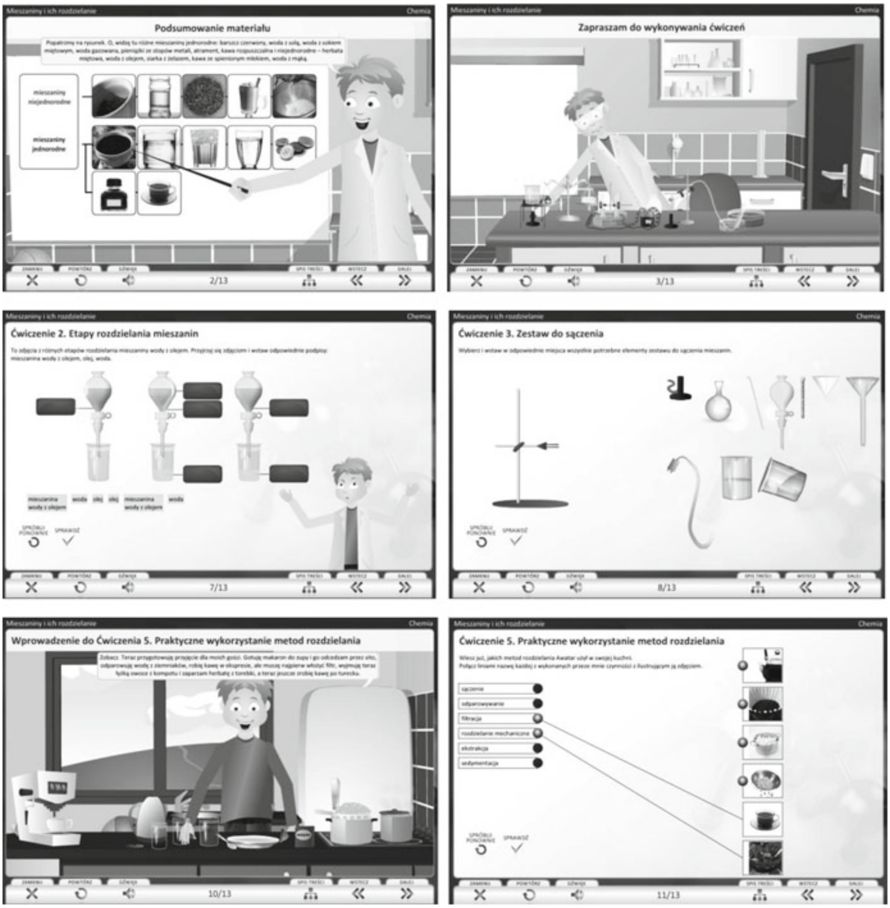
## 2.2 Unit Separating Mixtures – KNOWLEDGE

The content in this unit pertains to an issue that is discussed in relation to other subjects and everyday life. The unit begins with a scene where an avatar is faced with a difficult situation and needs to find a solution to this problem. The student watches interesting films and, together with the avatar, carries out simple chemistry experiments. Discovering new formation is intertwined with several short exercises. The lesson is crowned with a graphically interesting summary.



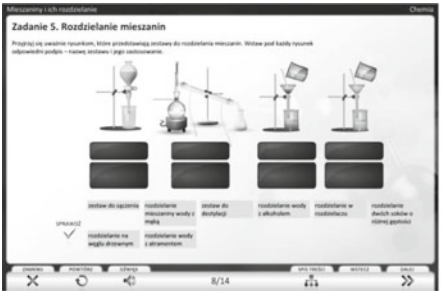
## 2.3 *Unit Separating Mixtures – EXERCISE*

This part of the unit reviews all of the new information and provides practice for new skills. All tasks are done with the avatar's supervision; he is a friend and a guide. Students receive feedback on their work and, when they do not know an answer, they are given some prompts. There are various types of tasks that might involve making models, writing down chemical equations, building laboratory apparatuses, and carrying out simple experiments. The tasks are not evaluated and the student does not receive any points.



### 2.4 Unit Separating Mixtures – TEST

The tasks in the test make it possible for students to do a self-check of their knowledge and skills. The assignments are graphically interesting and of varied character (e.g., drag & drop, matching, filling the gaps, building laboratory kits, designing experiments, drawing conclusions from the experiments). The student is continuously accompanied by the avatar, whose role is now slightly different; the student does not receive any prompts, just a bit of encouragement. The only feedback the student receives is whether or not an answer is correct. Each test can be taken as many times as students need until they decide that their answers are satisfactory. Finally, results are registered on the platform and sent to the teachers as well as to a central database. Students must solve all 21 tests in each of the 7 subjects.





## 3 Findings and Discussion

Each of the e-learning units might be used:

- during the lesson process (in the classroom or in the computer room),
- at home (when working on *EduPortal*),
- as part of students' activity outside of school (project method),
- as part of homework (independent work with e-learning units), and
- as an integral part of classes by means of project work method.

The above is definitely not an easy task for teachers who might not be familiar with working on e-learning platforms (Gulińska & Bartoszewicz, 2008). Therefore, *within the project, several teacher trainings are to be carried out to teach them how to use "EduPortal" and to carry out classes with the use of e-learning units.* The teachers will create virtual classes, with some assistance from school IT teachers, and they will monitor students' progress and achievements.

At the first session, which took place in August 2010, participating teachers received laptop computers for personal use; the schools participating in the project received SmartBoards. During the training sessions the teachers learned how to use the resources published on *EduPortal*, how to prepare tests and homework, how to publish them on the platform, and how to work with interactive boards.

Detailed information and instructions are also to be found in the Guidebook published on *EduPortal*. The guidebook contains instructions for each unit, lesson scenarios and open tasks that encourage teachers to use activating forms of work with their students. If teachers encounter difficulties, they can receive assistance from their school's IT teacher.

The tasks to be accomplished by teachers working with the unit:

- study and analyze the methodological materials for the unit,
- review the tasks to be performed by students in the unit, role-playing,
- analyze how the unit might be the source of knowledge and motivation to develop key competencies for particular groups of students,
- analyze and decide how and when the unit might be used in teaching, and
- build the unit into the process of teaching particular key competencies.

## 4 Conclusions and Implications

It is assumed that in the project, the teacher of a given class will also be the class e-teacher, that is, that they will teach regular classes as well as those carried out in the computer room using the e-learning units. The teacher will do the experiments suggested by the avatar and use the interactive board. They must also use the platform for checking student progress in their independent work with e-learning units, and they will use the platform for discussion with the students. Some other tasks will be performed on the platform as well. This method of work will make it possible for the teachers across the country to share their experiences within the *e-Academy for the Future* project as well as to share their skills in using technology for teaching (Gulińska & Bartoszewicz, 2010).

It will not be possible to know whether the project is a success or a failure until it has been underway for at 3 years. Nonetheless, the project is enormous; it involves many schools and students; and we assume that it will help schools to creatively and attractively implement the requirements of the new curricular basis. What is most important, however, is that the project prepares the next generation to live and work in the new world that we all face.

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# Part II
# Learning and Conceptual Change in Chemistry

**Jing-Wen Lin**

The challenges of globalization are many. As foresighted chemistry educators, we should renew the investment in the future through education, research, and innovation. Before making any investment, exploring the characteristics of "*students' learning, understanding and conceptual change in chemistry*" is the most important step. Fortunately, chemistry educators around the world have created or adapted an innovate array of research practices and conceptual tools that we can use to analyze student learning in chemistry classrooms. This section consists of four chapters that focus on these impressive methodologies. In the first chapter, Chen reveals that paying attention to the chemistry anxiety of students is important to school teachers in practice in Malaysia. Her findings can be used to implement strategies to reduce chemistry anxiety and to improve students' attitudes toward chemistry. In the second chapter, Mammino outlines an approach utilizing in-class written questions as a tool to enhance classroom interactions. When the teaching time is limited or there exists diffuse shyness toward verbal interactions, this method can be an important alternative to attain comparable benefits. The chapter by Chang, Chen, Tsai, Chen, Chou, and Chang proposes a cyclic Predict-Observe-Explain (POE) strategy for probing and fostering students' reasoning abilities. In a cyclic POE process, three or more POE activities are performed but in each cycle students encounter a different value or situation of the same variable. They found this method induced a positive effect on students' reasoning. In the last chapter, Ogawa and Fujii introduce a lesson model, Special Emphasis on Imagination Leading to Creation (SEIC). They found this model enhanced students' creativity. The chapters in this section give us new insights into chemistry learning as it occurs in individual students and in social, cultural, historical, and institutional contexts.

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# Assessment of Chemistry Anxiety Among College Students

**Chen@Chong Sheau Huey**

## 1 Introduction

Chemistry is considered the central science, filled with spectacular phenomena and interesting experimental activities. Numerous breakthroughs in biology and physics have been made possible with the use of principles from chemistry. One of the purposes of chemistry education is to develop students' positive attitudes toward this subject in the school curriculum (Cheung, 2007). However, despite being readily accepted as an important and fundamental science by the scientific community, the current perception of chemistry held by many students contravenes its true nature. Chemistry has a reputation for being a complicated, highly theoretical, and boring science. Students often fail to make the connection between the macroscopic and the microscopic world of atoms and molecules (Gillespie, 1997). As a result, they look upon chemistry more as a burden to be endured than as an experience to be valued. When students possess this negative attitude, learning chemistry becomes stressful and this leads to chemistry anxiety (chemophobia).

Anxiety is one of the fundamental sensations of human beings. It is a negative mood state characterized by bodily symptoms of physical tension and by apprehension about the future (Barlow & Durand, 2009). Everyone becomes anxious to different degrees when they are worried or frightened (Akbas & Kan, 2007). According to the *Cambridge International Dictionary of English* (1997, p. 1058), phobia means "an extreme fear of a particular thing or situation, especially one that cannot be reasonably explained." According to Akbas and Kan (2007), being anxious might be beneficial to

Note: Diploma (chemistry and biology) is a double major course at TARC. Seven semesters (2 years and 4 months) are required to complete the course.

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motivate students to bear responsibility for their learning, but the anxiety caused by excessive stress has a negative impact on the learning and performance of students. Research by Eddy (2000) indicated that “chemophobia” does exist in the college classroom. However, there is no clear definition of the term “chemophobia.” The term appears to be used in two contexts: fear of chemicals (Breslow, 1993) and fear of chemistry as a course (*CHED Newsletter*, 1995).

This phenomenon impedes the effective learning of chemistry, and the fear of this discipline is thought to be one of the reasons behind declining enrollment in chemistry and chemistry-related courses in Malaysia. According to Keeves and Morgenstern (1992), students’ fear towards chemistry makes them lose interest in science. Past research has indicated that chemistry anxiety also affects students’ performance in chemistry negatively (Eddy, 2000). Chemistry is too challenging, chemistry is too abstract, and chemistry is only for bright students are reasons given by local students for shunning chemistry courses at the tertiary level. Even when students do choose chemistry as a subject at the pre-university level, it is because chemistry is a compulsory subject for them to gain entry into fields, such as medicine, dentistry, and pharmacy. Similarly, there are some students who choose chemistry at the university level only to fulfill their degree requirements. However, compared with the research conducted on pure and applied chemistry, few studies have addressed the issue of teaching and learning chemistry within Malaysia specifically. It this author’s opinion that the exchange of information between the technical knowledge in chemistry and chemical education is crucial in fostering mutual understanding and appreciation. Thus, students who fail to enroll in chemistry courses, or fail to fully participate in mandatory chemistry courses, due to fear and anxiety miss an opportunity to become better citizens of the world.

## 2 Objective

The purpose of this study was to ascertain whether chemistry anxieties exist among Tunku Abdul Rahman College (TARC), Malaysia, first-year diploma (chemistry and biology) students. The author hopes the findings can be used to implement strategies to reduce chemistry anxiety and to improve students’ attitudes about chemistry.

## 3 Research Questions

This chapter aims to provide answers to the following research questions:

1. To what extent does chemistry anxiety exist among Tunku Abdul Rahman College (TARC), Malaysia, first-year diploma (chemistry and biology) students?
2. Is there a meaningful difference between chemistry anxiety levels in terms of gender?

## 4 Methodology

The research was conducted with 67 first-year diploma (chemistry and biology) students. There were 38 female students and 27 male students involved in the study (two students did not indicate their gender and were excluded from the analyses). Research participants were required to complete 36 items from the Derived Chemistry Anxiety Rating Scale (DCARS) (Appendix 1) developed by Eddy (1996). Items 1–17 (factor 1) assessed students' anxiety in learning chemistry; items 18–26 (factor 2) assessed anxiety in chemistry evaluation; and items 27–36 (factor 3) assessed anxiety in handling chemicals. For each of item, participants were required to use a scale of 1–5 to rate their level of anxiety, with 1 being not at all anxious and 5 being extremely anxious.

## 5 Findings and Discussion

A pilot study was conducted on 24 second-year diploma (chemistry and biology) students to determine the internal consistency (reliability) of the DCARS. Cronbach's alpha values >0.900 (Table 1) for all the three factors showed that the instrument was reliable in assessing the same construct (chemistry anxiety).

The analysis of the data revealed scores with overall means of 1.96, 3.44, and 2.19 for learning-chemistry anxiety, chemistry-evaluation anxiety, and handling-chemicals anxiety, respectively. The results show that being evaluated in chemistry (such as with a test, quiz, or end-of-semester examination) was rated by students as the most anxiety-provoking type of chemistry activity. Chemistry evaluation accounted for nine out of ten of the sources for the highest anxiety items (see Table 2).

Results obtained from analysis (SPSS software version 16) on Pearson correlation found that chemistry-learning anxiety, chemistry-evaluation anxiety, and chemical-handling anxiety were positively correlated with each other at $p<0.01$ (i.e., 99% confidence limit; see Table 3).

Three $t$-tests for paired samples at $p<0.05$ (i.e., 95% confidence interval) were performed. The results showed that the mean anxiety levels for the three factors of the DCARS were all significantly different from each other (SPSS $\rho = 0.000$ when chemistry-evaluation anxiety factor was involved; see Table 4).

Similarly, data was analyzed to ascertain whether meaningful differences existed between female students and male students in terms of chemistry anxiety level.

**Table 1** Cronbach's alpha values of DCARS from pilot study

| Items | Cronbach's alpha | Number of items |
|---|---|---|
| Factor 1: (Chemistry-learning anxiety) | 0.930 | 17 |
| Factor 2: (Chemistry-evaluation anxiety) | 0.902 | 9 |
| Factor 3: (Chemical-handling anxiety) | 0.940 | 10 |

**Table 2** Sources associated with highest anxiety for chemistry anxiety items

| Items | Mean (SD) |
|---|---|
| Taking an examination (final) in a chemistry course. | 4.05 (1.110) |
| Solving a difficult problem on a chemistry test. | 3.71 (1.114) |
| Taking an examination (quiz) in a chemistry class. | 3.66 (1.144) |
| Thinking about an upcoming chemistry test 1 day before. | 3.64 (1.213) |
| Being given a homework assignment of many difficult problems which is due the next chemistry class meeting. | 3.60 (1.260) |
| Waiting to get a chemistry test returned in which you expected to do well. | 3.46 (1.251) |
| Being given a "pop" quiz in a chemistry class. | 3.25 (1.250) |
| Getting ready to study for a chemistry test. | 3.06 (1.296) |
| Spilling a chemical. | 2.74 (1.302) |
| Working on an abstract chemistry problem, such as "if x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen." | 2.68 (1.239) |

*SD* Standard deviation

**Table 3** Significant correlation among the three anxiety factors

| | Chemistry-learning anxiety | Chemistry-evaluation anxiety | Chemical-handling anxiety |
|---|---|---|---|
| Chemistry-learning anxiety | | .506 | .535 |
| Chemistry-evaluation anxiety | | | .500 |

**Table 4** *t*-test results for paired samples

| | Factors | *t* | Sig (2-tailed) |
|---|---|---|---|
| Pair 1 | Chemistry-learning anxiety – Chemistry-evaluation anxiety | 14.744 | 0.000 |
| Pair 2 | Chemistry-learning anxiety – Chemical-handling anxiety | −2.409 | 0.019 |
| Pair 3 | Chemistry-evaluation anxiety – Chemical-handling anxiety | 11.315 | 0.000 |

Figure 1 shows that the mean scores of female students were higher than those of male students for all three chemistry anxiety factors. However, according to the independent *t*-test results, as shown in Table 5, there was no meaningful difference between the mean anxieties (for all three factors) in terms of gender ($p > 0.05$).

The interview data suggested that an overloaded syllabus is a factor that contributes to widespread anxiety regarding chemistry among college students. For example, first-year diploma students are required to complete physical chemistry (Level 1), which covers topics such as atomic structure, nature of chemical bonds, gaseous states, basic properties of solutions, thermochemistry, reaction kinetics, chemical equilibrium, and fundamental of electrochemistry in 14 weeks (one semester). Insufficient mathematic preparation causes chemistry anxiety, too, as basic algebra, geometry, and unit conversions are essential tools for mastering chemistry. In addition, the examination-oriented education system in Malaysia causes students

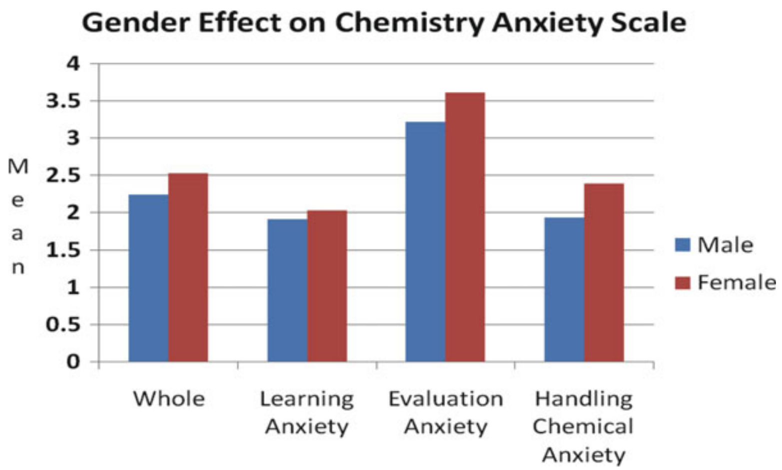


**Fig. 1** Gender effect: Mean scores on the whole chemistry anxiety scale and each of the factors

**Table 5** Gender-based *t* results related with the student scores of chemistry anxiety

| | Gender | *N* | Mean | Standard deviation | *t* | Sig (2-tailed) |
|---|---|---|---|---|---|---|
| Chemistry-learning anxiety | Female | 38 | 2.0205 | 0.70484 | −0.625 | 0.534 |
| | Male | 27 | 1.9115 | 0.67669 | | |
| Chemistry-evaluation anxiety | Female | 38 | 3.6345 | 0.82570 | −1.859 | 0.068 |
| | Male | 27 | 3.2141 | 0.99306 | | |
| Chemical-handling anxiety | Female | 38 | 2.3797 | 0.91532 | −1.886 | 0.064 |
| | Male | 27 | 1.9593 | 0.84136 | | |

**Table 6** Grading system at TARC

| From | To |
|---|---|
| Coursework (quizzes, tests, assignments): 15% | 20% |
| Laboratory session (hands-on practical): 15% | 20% |
| End-of-semester examination: 70% | 60% |

to feel pressure to perform well on their examinations. Many students resort to memorization and rote learning instead of understanding in the learning process. These combined factors contribute to the anxiety.

In view of this, TARC has changed the grading system for most of the subjects including chemistry, as shown in Table 6.

This revised grading system is aimed at alleviating some of the pressure students face in the final examination. Continuous assessment is encouraged throughout the semester to find out what students know and to promote learning for understanding. However, at the time of writing, this system has been underway for only a year and its effectiveness has not yet been studied.

## 6 Conclusions and Implications

This study, as with all research, has its limitations. Because a convenience sample was used for the study, and due to the limited numbers of participants, the findings may not be generalized to other samples and populations. However, the results obtained from this study indicate that chemophobia does exist at Tunku Abdul Rahman College. The study showed that students were more anxious about evaluation (mean = 3.44) followed by handling chemicals (mean = 2.19) and learning chemistry itself (mean = 1.96). There was no significant difference between the mean anxieties (for all the three factors) in terms of gender. Chemistry anxiety is a barrier to students' success. Recognizing the presence of chemistry anxiety is crucial in trying to reduce negative attitudes toward chemistry. It is imperative that the process of teaching and learning and evaluation methods be modified with the goals of reducing chemistry anxiety and increasing academic performance.

## Appendix A

### *Derived Chemistry Anxiety Rating Scale (DCARS)*

1 = not at all
2 = a little bit
3 = moderately
4 = quite a bit
5 = extremely anxious

**Factor 1**: Chemistry-learning anxiety

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1) Reading and interpreting graphs or charts that show the results of chemistry experiment. | | | | | |
| 2) Starting a new chapter in a chemistry book. | | | | | |
| 3) Reading a formula in chemistry. | | | | | |
| 4) Picking up a chemistry textbook to begin working on a homework assignment. | | | | | |
| 5) Watching a teacher work a chemistry problem on the blackboard. | | | | | |
| 6) Walking into a chemistry class. | | | | | |
| 7) Being told how to interpret chemical equations. | | | | | |
| 8) Signing up for a chemistry course. | | | | | |
| 9) Listening to a lecture on chemicals. | | | | | |
| 10) Having to use the tables in a chemistry book. | | | | | |
| 11) Looking through the pages in a chemistry book. | | | | | |

(continued)

**Factor 1**: Chemistry-learning anxiety (continued)

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 12) Reading the word "chemistry." | | | | | |
| 13) Walking on campus and thinking about chemistry course. | | | | | |
| 14) Walking on campus and thinking about chemistry lab. | | | | | |
| 15) Buying a chemistry textbook. | | | | | |
| 16) Listening to another student explain a chemical reaction. | | | | | |
| 17) Listening to a lecture in a chemistry class. | | | | | |

1 = not at all; 2 = a little bit; 3 = moderately; 4 = quite a bit; 5 = extremely anxious

**Factor 2**: Chemistry-evaluation anxiety

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1) Working on an abstract chemistry problem, such as "if x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen." | | | | | |
| 2) Waiting to get a chemistry test returned in which you expected to do well. | | | | | |
| 3) Being given a "pop" quiz in a chemistry class. | | | | | |
| 4) Taking an examination (quiz) in a chemistry class. | | | | | |
| 5) Getting ready to study for a chemistry test. | | | | | |
| 6) Being given a homework assignment of many difficult problems which is due the next chemistry class meeting. | | | | | |
| 7) Solving a difficult problem on a chemistry test. | | | | | |
| 8) Taking an examination (final) in a chemistry course. | | | | | |
| 9) Thinking about an upcoming chemistry test 1 day before. | | | | | |

1 = not at all; 2 = a little bit; 3 = moderately; 4 = quite a bit; 5 = extremely anxious

**Factor 3**: Chemical-handling anxiety

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1) Spilling a chemical. | | | | | |
| 2) Listening to another student describe an accident in the chemistry lab. | | | | | |
| 3) Being told how to handle the chemicals for the laboratory experiment. | | | | | |
| 4) Working with acids in the lab. | | | | | |
| 5) Getting chemicals on your hands during the experiment. | | | | | |
| 6) Breathing the air in the chemistry laboratory. | | | | | |
| 7) Working with a chemical whose identity you don't know. | | | | | |
| 8) Mixing chemical reagents in the laboratory. | | | | | |
| 9) Heating a chemical in the Bunsen burner flame. | | | | | |
| 10) Walking into a chemistry laboratory. | | | | | |

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# Teacher-Student Interactions: The Roles of In-Class Written Questions

**Liliana Mammino**

## 1 Nature, Motivations, and Objectives of the Approach Presented

In-class written questions have been utilized for more than 12 years (since 1998) at the University of Venda (UNIVEN) in South Africa, for the purpose of maximizing classroom interactions by circumventing identified contextual difficulties toward verbal interaction. The approach has been employed mostly within the physical chemistry courses, but also in the first-year general chemistry course and the third-year process technology course. The implementation details have been progressively optimized over the years, above all by increasing flexibility to facilitate adaptations to the characteristics of different student groups (characteristics that may differ both across courses and in relation to the changing attitudes and preparation of incoming groups of students from year to year).

UNIVEN is a "historically black university" located in a poor rural region. It is thus an underprivileged institution mostly caring for underprivileged students. The disadvantage-generating factors and their impacts on the educational (teaching and learning) efforts have been analyzed in detail in Mammino's (2008) work and will be only briefly summarized here. The two dominant aspects posing major challenges to the educational efforts are the dire under-preparedness of most incoming students and the use of a second language as the medium of instruction; the under-preparedness is largely determined by the scarcity of qualified secondary school science teachers and by the use of a second language as the medium of instruction, as the poor mastering of the second language constitutes a major obstacle to conceptual understanding at all instructional levels (Mammino, 2010b). These factors turn out to constitute substantial obstacles to the possibility of classroom interactions, as the awareness of both their inadequate preparation and their inadequate expression

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abilities makes most students insurmountably shy toward participating in verbal interactions. In addition, the passive attitude acquired throughout pre-university instruction – often equating learning solely to passive memorization, without deeper reflection or engagement – makes the very concept of classroom interactions unfamiliar to most students, so that they find it difficult to come to acknowledge interactions as a component of the learning activity.

On the other hand, classroom interactions can play fundamental roles in the efforts aimed at overcoming the impact of contextual disadvantages and can enable students to attain adequate knowledge and mastery-level of the content of individual courses and of chemistry in general. By their nature, classroom interactions engage students actively in their learning process. They are apt to attract and maintain students' attention, to stimulate reflection, and to highlight aspects and details that would not be adequately focused upon otherwise. They provide continuous feedback to the teacher, thus enabling real-time responses to clarification needs. It is important that these benefits are not missed because of underprivileged students' emotional non-availability to verbal interactions. Therefore, it becomes important to realize classroom interactions through alternative options ensuring benefits comparable to those of verbal interactions.

The approach presented here involves the frequent resort to short questions demanding written answers on the spot and immediately followed by an extensive analysis of the answers. The major advantages of this approach can be summarized as follows:

- It enables a form of in-class collaborative work, thus enabling a mode of teaching and learning different from that of a formal lecture in which students play the sole role of recipients.
- It maintains the major benefits of classroom interactions (engaging students actively, enabling real-time responses to clarification needs) and extends the active participation to all students, as each student is expected to write an answer.
- It combines the benefits of classroom interactions with the benefits of writing – a tool that can be particularly helpful for chemistry understanding.
- It provides suitable opportunities and extensive material for error analysis – a powerful explanation tool whose benefits are greatly enhanced within interactive approaches.

After a literature review, the next sections describe the implementation details of the approach with particular attention to its main novelty, that is, the utilization of in-class writing as an integral component of in-class interactions and of the whole teaching/learning activity.

## 2 Literature Review

Some of the issues that are part of the background and motivational framework of the approach presented here are so important in chemical education (and science education in general), and the literature on them is so extensive, that even a basic literature review would require more space than is available here. It is the case of the importance and benefits of classroom interactions and of active learning. On the other hand, they can be rightly assumed as being common domain among chemical educators. Therefore, the literature review in this section focuses on the aspects that pertain specifically to the implementation of the approach considered.

Questions are an effective tool to stimulate reflection. Suitable sets of subsequent questions (Mammino, 2006) have the advantage of guiding reflection and simultaneously stimulating students' active engagement (guiding without providing answers "from above"). They were the tool chosen by Socrates in the implementation of his "maieutic method" – a vision in which the teacher has the function of a midwife for the students' minds, helping bring answers and knowledge into light. Within this vision, questions are thus simultaneously an investigation tool and an educational tool. The use of questions in classroom interactions responds to analogous criteria and objectives.

Writing is extensively viewed as an effective instrument for chemistry teaching (Beall & Trimbur, 1993) and learning (Castro, 1995; Kovacs, 1999), in the perspective of "writing about chemistry in order to learn chemistry" (Castro, 1995). Writing may comprise a broad range of out-of-class options, from essays (Beall, 1993) to laboratory reports (Gragson & Hagen, 2010), assignments underlining the meaning of laboratory activities (Sunderwirth, 1993), reports on literature searches and other projects (Ablin, 2008; Bressette & Breton, 2001; Rossi, 1997; Whelan & Zare, 2003), or problem solving designed to support learning (Wilson, 1994). It is functional to objectives such as enhancing students' active engagement, moving "from instructor-centred to student-centred" perspectives (Nicotera, Shibley, & Milakofsky, 2001) and increasing mutual communication between students and teacher (Cooper, 1993). In-class writing proves particularly functional for large-enrolment classes (Beall, 1991; Cooper, 1993). The classical works by Beall (1991, 1994) showed how 5 min of writing tasks with preselected questions in general chemistry courses enabled better identification of students' conceptions, including misconceptions about thermodynamics. Among the implementation features highlighted in these classical works, the absence of assessment for the writing tasks (Beall, 1991) and the informal character of the writing assignments aimed at increasing student-teacher communication (Cooper, 1993) constitute key aspects for writing activities meant to enhance interactions.

Error analysis is a powerful explanation tool, providing opportunities to focus students' attention on the nature of individual concepts, and on implications and details that would often remain unnoticed otherwise. It is optimal for integrated consideration of conceptual aspects and language aspects (Love & Mammino, 1997), which makes it particularly beneficial for second-language contexts, as it can help counteract the difficulties inherent in second-language instruction (Mammino, 2010b). The decrease in students' language mastery levels, observed in many contexts in recent years (Mammino, 2010a), also increases its significance for mother-tongue-instruction contexts to promote understanding through integrated consideration of concepts and their expression.

## 3 Methodology of the Approach

The description of the implementation features of the approach involves the consideration of different components: the set of operations for each question given; the selection of the questions; the selection of the occasions in which written questions are more constructive; the selection of an optimal frequency for their utilization; the criteria to evaluate the outcomes; and the identification of routes for continuous optimization.

### *3.1 Operational Aspects*

The operational aspects for each question are straightforward. A question is given, usually by writing it on the board to maintain its availability throughout the time in which students may need to go back to it. All students write an answer in their notebooks. After a reasonable time, the teacher checks all the answers (or as many as needed to have a representative picture if the group is large) and proposes for discussion both the correct answers and those that highlight misconceptions or errors whose discussion enables the clarification of significant aspects and details of the topic concerned. The discussion/analysis of errors is interactive and this interaction often involves additional questions guiding students through the relevant steps of the analysis (Love & Mammino, 1997). Except for advanced courses (e.g., quantum chemistry), the questions are such as to require sufficiently short answers that can be written in 5–10 min (preferably 5); this is important for the activity to be fully integrated into the overall classroom activity without overshadowing the other components or shrinking the time available to them.

### *3.2 Selection of Questions*

The selection of the questions apt for this type of approach is not done *a priori*, but is prompted by the classroom activities themselves, so that the questions fit "naturally" into the ongoing explanation, revision, analysis, or discussion. This criterion of fitting "naturally" into the ongoing activity actually applies to in-class questions independently of whether they require oral or written answers, as the most important criterion relates to the benefits that can be expected from a given question. Practice over the years provides experience-based criteria about the greater or lesser suitability of specific questions before or after instruction on a given topic. Before instruction, questions are particularly suitable to recall information that students are already expected to know (but have often forgotten), to check the clarity of their recall, and to stimulate inferences from it. After instruction, they are particularly suitable to verify the extent to which students have understood the new material and to stimulate students to find inferences (e.g., identification of trends or of implications) on the basis of the new material, or of the combination of the new material with the previously learned material. When experience has shown the possibility of misconceptions arising in relation to some aspects of a given topic, or the persistence of already-existing misconceptions notwithstanding instruction, then questions aimed at attracting students' attention on the specific aspects are added to verify whether and to what extent the new information has replaced the misconceptions and to create an additional opportunity for focused clarifications.

## *3.3 Selection of the Occasions in Which to Utilize Written Questions*

The occasions in which questions requiring written answers are utilized are of a rather regular type. Because the most important role is that of ensuring active participation, the approach is utilized whenever students do not answer a verbal question (questions requiring answers through sentences are initially given verbally). Moreover, it is employed when the answer requires drawing (a diagram, a molecular structure, or other types of images) because, in this case, verbal interactions may be less apt or require a higher degree of students' participation (Mammino, 1999). Finally, it is used when it is particularly important to have an extensive overview of students' conceptions on a certain issue, so as to ensure that all the aspects that might require clarification are taken into adequate account; this prevents the risk that some aspects might be overlooked following the natural tendency of taking for granted aspects that one perceives as simple, while they may not be simple or straightforward for a certain group of students (even if they had been perceived as simple by other groups).

## *3.4 Frequency with Which Written Questions Are Utilized*

The frequency with which the approach is utilized needs to reach an optimal balance between the need to use it frequently enough to ensure adequate students involvement and time constraints. Thus, the frequency varies with the nature of the content, with the students' responses to the ongoing classroom activity, and with the size of the group. Experience shows that it is functional to have at least one or two questions requiring written answers per contact time (i.e., for each of the lecture periods ascribed to a course), in order to ensure continuity in students' active engagement throughout the period and to make the option an integral component of the learning process (regularity being an important feature to foster the perception of it being an integral component). In some cases, the number of questions may increase up to 5 or 6, above all when the in-class activity is centered on recalling material that students are expected to know; then, using questions that require written answers may become the main instrument to go through the material concerned and to focus specifically on the aspects that are relevant for the new information that will be the next object of interest. In large groups (e.g., the first year course, which, at UNIVEN, comprises about 420 students, all taught in one group), the size of the group restricts the frequency and the approach is utilized when it is expected to bring particularly important contributions to the scope and effectiveness of the ongoing activity.

## 3.5 Other Important Features of the Modus Operandi

For the approach to be an integral and constructive component of the teaching/learning process, it is important that students feel completely free and unthreatened. This is ensured through the combination of two modus operandi, namely:

- The activity is not associated with formal evaluation of the answers. In this way, students feel free to answer according to their actual conceptions or perceptions and to explore those pathways that may appear more interesting to them for a given issue.
- Although error analysis is a major component of the activity, the anonymity of the errors' authors is strictly preserved, through easily implementable options. When the answers are sufficiently short, the teacher rewrites the most significant errors on the board without mentioning which student (or students) made them. For longer answers, each student writes his/her answer on a sheet that the teacher collects; then the teacher reads the answers, with appropriate interruptions to enable the integration of reading and discussion.

## 3.6 Some Illustrative Examples

The consideration of some illustrative examples may be important to confer concreteness to the features outlined in the previous paragraphs. The examples are selected from different courses to better highlight the basic similarity of the approach throughout different course content, and also to offer illustration on a broader range of content. They are also selected among the questions that appear more routinely from year to year, that is, questions responding to identified recurrent difficulties or misconceptions (as already mentioned, most questions are not routine but are invented *ex prompto* in tune with the development of ongoing in-class activities and with the needs that surface at a given moment for the issue or topic under consideration in that moment).

In the first-year general chemistry course, the approach is mostly employed for issues about which students frequently retain uncertainties after instruction, or to create opportunities to discuss misconceptions identified as recurrent, or to foster familiarization with important components of how to approach problem solving.

After introducing the molecule concept, students are asked to draw ball-and-stick models of selected molecules on the basis of provided geometry information. The information is minimal (only what is needed to enable students to draw a correct structure) and is given in terms that require reflection; for example, for the $H_2SO_4$ molecule, the information comprises the following pieces (Mammino, 1994): no H atom is bonded to the S atom; no two O atoms are bonded to each other; an H atom can form only one bond. Such exercises would be ideal for the utilization of imagery as a tool for interaction (Mammino, 1999), but the vast majority of first-year students are not ready for verbal interaction. For questions of this type, a reasonably quick survey of the answers remains possible despite the size of the group, and also because it can be interrupted when the recurrence of specific errors becomes frequent. The survey provides information on the extent to which students have understood the molecular structure concept and the meaning of its ball-and-stick visualization (atoms as spheres and bonds as sticks) – the latter also being important to initialize the familiarization with visualization in chemistry. In most cases, the answers that have not been checked individually in the survey are automatically included in the discussion because of recurrence patterns. To ensure that no student's needs are overlooked, after the discussion of the errors identified in the survey, the teacher invites students who have different answers to propose them for discussion (students are often more available to show something on their notebooks than to engage in verbal interaction).

Experience has shown the presence of generalized misconceptions about the difference between solids and liquids at the microscopic level, with most students believing that the distance between molecules in the liquid is intermediate between that of the solid and that of the gas, and that this constitutes the main or sole difference between the two states. A combination of questions requiring written answers and questions for which some students are likely to give oral answers is utilized, along the Socratic pattern of guiding reflections until students identify knowledge with which they have somehow already come into contact. This is usually done after presenting the phases of matter, to verify whether the messages meant to counteract the diffuse misconception have been perceived and internalized on instruction. The first question requires a written answer about the differences between solids and liquids. Despite instruction, students usually answer that the main (or only) difference is that molecules are close to each other in solids and farther apart in liquids, which highlights the need to attract their attention in a more catching way than what is attained at the "normal" explanation level. The survey of the written answers is then followed by a question asking what happens when a bottle of water is put in a deep freezer. As this is often part of direct experience, some students answer (orally) that the bottle cracks. The next question asks students to reflect whether this phenomenon (the cracking of the bottle) can be compatible with the idea that the water molecules are closer to each other in the ice than in the liquid. Finally, students are invited to search for a more fundamental difference between the two states, by checking through the notes that they have taken during lectures, until some of them find (either by stating it or by showing the corresponding part in the notes) that the main difference is the presence of an ordered structure in the solid but not in the liquid.

Any approach to solving a problem starts with the identification of what is already known. Training students to identify all the available information is therefore fundamental. When a new type of problem is encountered for the first time, all students are asked to write the *data* for that problem. The errors, in this case, are more frequently of an omission nature; their analysis stresses the importance of identifying *all* the pieces of information and, at the same time, shows how to identify them from the wording of the question.

Because of the conceptual demands of physical chemistry courses, the level of understanding suffers extensively from factors such as poor language mastery and poor visualization mastery (Mammino, 2009). Misinterpretations in the meaning of terms easily generate misconceptions, and the resort to questions requiring written answers is particularly apt to attract students' attention on the meaning of individual terms and on the corresponding conceptual aspects. For instance, the absence of intermolecular interactions in ideal gases is often interpreted as excluding collisions between the molecules of the gas, because the contact inherent in a collision is viewed as a form of interaction. Thus, one of the questions routinely given in the early stages of the second-year physical chemistry course (essentially a chemical thermodynamics course), after instruction on ideal and real gases, asks students to explain what we mean when we say that there are no intermolecular interactions in ideal gases. The answers usually provide ample opportunity for specific clarifications about the intermolecular interactions and the collisions concepts.

The smaller size of the third-year group enables higher frequency in the utilization of questions requiring written answers, up to the point that the recalling of relevant material is realized mainly through such questions. The initial part of the chemical kinetics component of the third-year physical chemistry course requires recalling already-known information about chemical reactions and trying to identify all its implications. This is realized through a number of questions focusing on the main aspects of the chemical reaction phenomenon, with particular attention to what happens as a reaction proceeds; it includes questions whose answers require diagrams (e.g., what happens to the concentration of the reactants, or to the concentration of the products, as the reaction proceeds). The initial part of the third-year process technology course (providing the bases of chemical engineering) also requires deep understanding of chemical reactions. The recalling of expectedly known concepts is realized through apt questions, many of which focus on conservation aspects that are important as a prelude to the understanding of material balances. For instance, questions may ask whether quantities like the total mass, the mass of a substance, the mass of an element, the total number of moles, the number of moles of a substance, or the number of moles of an element are conserved or not in a chemical reaction.

The quantum chemistry course is an advanced course pertaining to the intermediate year between the triennial B.Sc. degree and the beginning of M.Sc. studies, and leading to a degree termed *B.Sc. Honours*. Questions given before instruction are often meant to recall material expected to be known, mostly from mathematics, such as the meaning of linear combination or the trends of the sin and cos functions; they usually require short answers, which can be rewritten on the board to propose them for discussion. Questions given after instruction focus on important aspects of the new material presented. For instance, after the presentation of the photoelectric effect, questions may ask students to outline which features of the photoelectric effect could not be explained on the basis of classical physics, or the novelties of Einstein's explanation. In this case, the answers are rather long and are therefore written on sheets that can be easily collected. Reading each of the answers and discussing them sentence-by-sentence or paragraph-by-paragraph (depending on whether single sentences or groups of sentences in the answer convey a complete meaning about a given aspect) enables interesting and articulated clarifications.

## 4 Findings and Discussion

Direct experience over many years confirms the expected advantages of combining the benefits of interactions and the benefits of writing. The approach:

- Ensures that all students answer the given question, thus ensuring active participation by all the students (including those who are not ready for verbal interactions) and, at the same time, provides more complete feedback on difficulties and misconceptions (including a rough evaluation of their extent, based on the proportion of students providing a specific answer).
- Enables the inclusion of images in the interactions, that is, it adds an important component to the scope of interaction. This provides precious opportunities for familiarizing students with the use of visualization in chemistry and, at the same time, adds to the information about students' conceptions, making it more complete because images highlight details that would not be diagnosed otherwise, as they would not be expressed through sentences.
- Provides opportunities for clarifications whose need might not surface otherwise and whose benefits extend to all the students.
- Responds to the concept of *writing chemistry to learn chemistry*. The writing action requires efforts to reach an answer consisting of at least one complete sentence – an exercise that is particularly important when one of the major problems is students' inadequate language mastery. In this way, it stimulates deeper reflection, which is fundamental to pursuing understanding. By doing so, it also enables more detailed surfacing of uncertainties, difficulties, and misunderstandings.
- Is particularly apt for interactive analysis of errors, as the written answers provide a broad range of imprecisions and errors, thus enabling the discussion of a high number of aspects of a given discourse and the consideration and analysis of many alternative conceptions and misconceptions, altogether resulting in enhanced clarification.

While the features just mentioned constitute advantages with respect to questions expecting verbal answers, questions requiring written answers have also some limitations with respect to verbal interactions, namely:

- They narrow the cooperative extent of the interactions, as they do not foster student-student interactions. The impact of this limitation is, however, minimal in contexts (e.g., UNIVEN) where shyness towards verbal interaction would in any case minimize the extent of in-class student-student interactions.
- They are not adequate for use in sets of many consecutive questions, in which each subsequent question is based on the responses to previous ones, and the whole set is aimed at guiding reflection to specific objectives.

The latter limitation may deserve some elaboration. Sets of many consecutive questions may cover broader ranges than those accessible to one or few questions requiring written answers. They may be functional to guide students' reasoning toward the identification and critical evaluation of already-known pieces of information, or toward and through the development of logical pathways, stimulating the comprehension of each stage by guiding the reasoning articulation step-wise (Mammino, 2006); in this way, for example, they are optimal for collaborative identification of the logic of derivation-proofs or problem-solving procedures (including the logic of computational procedures). They may also aim at broad-range objectives such as identifying relationships between chemistry and other disciplines, or between chemistry and everyday life, or at stimulating reflections on method-related aspects, thus expanding the scope of chemistry teaching to aspects that pertain to science practice in general, across science disciplines. A simple example is offered by the set of questions utilized at the beginning of the first-year general chemistry course and aimed at simultaneously finding out what students know about chemistry and setting the first identification of the scope of chemistry as the science of substances (the general thread of this set of questions is outlined in Mammino [2006], although the set is never the same from year to year, as each subsequent question is prompted by the answers to the previous one).

Although both have the benefits of the use of questions to stimulate reflection, questions within verbal interactions and questions requiring written answers have a number of different features in the types of intellectual stimulations that they foster and in the types of explanation opportunities that they offer. Therefore, an ideal approach would make use of both of them, balancing the resort to each of them according to the characteristics of the group of students and the characteristics of the course content, and exploring possibilities of combined sets comprising both question requiring written answers and questions expecting oral ones. On the other hand, specific contextual factors may determine a more massive use of one or the other option (e.g., diffuse shyness towards verbal interactions determines a larger resort to questions requiring written answers).

Students' responses to the systematic use of written questions in the mentioned courses are interesting. They find the approach demanding, but this is an inherent feature, as it is meant to stimulate reflection leading to understanding, thus counteracting the diffuse passive attitude equating learning to mere memorization.

Some students go beyond the provision of a written answer and respond to the subsequent collaborative search; interestingly enough, they become more available to verbal interaction during the discussion based on the quick survey of the written answers than they were when the question was initially given. Finally, because the approach is employed within the courses taught by the physical chemistry lecturer, they start associating it with the "peculiarities" of physical chemistry, along with the extensive presence of mathematics, the request that laboratory reports link theory and experimental observations, and the insistence on conceptual and expression rigor.

The continuous optimization of teaching approaches is an inherent feature of educational perspectives. The currently envisaged refinements of the approach utilizing questions requiring written answers include:

- Maximizing the collaborative aspects of the discussion after the answers' survey. This discussion constitutes the moment of students' maximum availability to verbal interactions observed so far and, therefore, needs to be used as an opportunity to maximize the benefits of verbal interaction attainable in the given context.
- Maximizing the attention to the relationships between concepts and language (i.e., the significance of the way in which we express the concepts), thus training students to scientific modes of expression while clarifying concepts. This is meant to respond to the severe language-related difficulties experienced by most UNIVEN students (often constituting the greatest barrier affecting the possibility of understanding and attaining real contact with the subject content) and, simultaneously, to the diffuse misconception that language does not play relevant roles in the sciences.
- Maximizing the option's utilization to foster visual literacy, by increasing the number of questions requiring answers through images and by emphasizing the communication role of images in the discussion of answers and errors. This is meant to respond to the inadequacies in students' familiarity with the use of images (including diagrams), often reaching down to poor visual literacy levels (Mammino, 2008).

Although the features of the approach (as outlined here and employed over many years at UNIVEN) respond more specifically to the needs of an underprivileged population – in particular, to the needs determined by students' severe under-preparedness, language-related difficulties, and general passive attitude – the approach can be beneficial for any context, with aptly tuned adjustments to respond to the specific characteristics of a given context. The balance between the extent of verbal interactions and interactions based on questions requiring written answers may shift in favor of the former where students are more available for verbal interactions. However, questions requiring written answers remain advantageous when students, although not shying away from verbal interactions, do not manage to find satisfactory answers to a given question; then, the different type of mental engagement required by the search for a written answer provides opportunity for more intensive reflection leading to different outcomes which, in turn, trigger a different type of interactive analysis. And, as already mentioned, questions requiring written answers remain the sole option when the answer is expected to be given through imagery and it is important to diagnose students' familiarity with expression through visualization (whether images or graphs).

## 5 Conclusions and Implications

Questions – whether requiring verbal or written answers – constitute an important instrument of classroom interactions. They have fundamental roles in guiding students' reflection through responses to their responses, along the perspective of "responding to students in ways that encourage thinking" (Kovacs-Boerger, 1994). They provide valuable feedback enabling continuous adaptation of the teaching process to the clarification needs highlighted by students' answers. Questions requiring written answers are particularly beneficial:

- when students are not sufficiently ready to engage in verbal interactions;
- when it is important to engage each and every student actively;
- when the question requires the type of intensive reflection more frequently associated with the search for written answers;
- when it is important to underline the relationships between language and concepts, and to stimulate students' awareness of these relationships;
- when it is important to have an idea of the extent of the presence of a given conception, perception, or difficulty;
- when visualization is involved.

In its entirety, the approach ensures students' active participation, provides broad opportunities for error analysis (which, in turn, enables sharp focusing on individual concepts and their details and implications, on the relationships between language and scientific knowledge and on the identification and discussion of misconceptions) and is instrumental to fostering visual literacy. Direct experience has proven that questions requiring written answers can be used as an integral and regular component of in-class activities, combining the benefits of interactions and the benefits of writing as a learning instrument. The balance between questions within verbal interactions and questions requiring written answers needs to be adapted to the characteristics of individual educational contexts, but the presence of both options enriches the teaching/learning routes, thus enhancing the quality of learning.

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# Probing and Fostering Students' Reasoning Abilities with a Cyclic Predict-Observe-Explain Strategy

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## 1 Introduction

Scientific reasoning is a higher-order thinking skill that can affect the quality of science learning; it can be trained and transferred (Chen & Klahr, 1999; Lawson, 2005; Musheno & Lawson, 1999; Schauble, 1996). Fostering students' reasoning abilities plays an important role in modern science, including chemical education (Bao et al., 2009). With such abilities, students are anticipated to be more powerful in making reasonable decisions when they are stuck in complicated situations in their daily lives. In this chapter, we propose a cyclic predict-observe-explain (POE) strategy for probing and fostering students' reasoning abilities in chemical education. However, this strategy is not limited to chemical problems and can be applied to any branch of science education.

The prototype of the POE approach was first developed by Champagne, Klopfer, and Anderson (1980), known as demonstrate-observe-explain (DOE). In a DOE process, the teacher first demonstrated an experiment, students observed the results, and then finally they were asked to explain the observed phenomena. In some cases, students were requested to predict the results prior to the observation. Later, Gunstone and White (1981) advocated the importance and advantage of prediction activity in DOE and modified the approach to POE. The prediction activity usually increased students' motivation to participate in the learning process. Meanwhile, reconciling any conflict between prediction and observation was the key for probing students' understanding and reasoning by the POE strategy (White & Gunstone, 1992). The advantage of implementing a prediction activity was also found for other instruction methods, such as the learning cycle approach (Lavoie, 1999).

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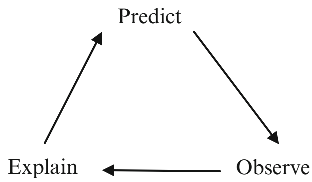


**Fig. 1** Concept of the cyclic POE strategy

Research indicates that the POE strategy is powerful in triggering students' conceptual change, and students show positive attitudes toward such a nonconventional instructional method (White & Gunstone, 1992). Palmer (1995) reported that the POE was also a suitable technique for primary science education, in addition to its success at secondary and tertiary levels of schooling. Liew and Treagust (1995) found that students' prior knowledge and beliefs could affect their observations and interpretations of new learning.

A conventional POE design usually involves a sequence of POE and concerns about a specific topic of science (White & Gunstone, 1992; Palmer, 1995). Sometimes multi-task POE is performed, but the tasks usually correspond to different scientific principles. Nonetheless, we have found that students can learn by themselves in a multi-task POE process if the tasks share the same principle. With such a design, students can modify their concepts and reasoning to predict new situations based on prior observations. Figure 1 depicts the concept of the cyclic POE strategy.

We propose that at least three cycles must be implemented in a cyclic POE process. In the first cycle, students may form some hypotheses about the observed phenomenon in order to modify their incorrect predictions. We anticipate that they will use the hypotheses for prediction in the second cycle. After the second observation, their hypotheses and inference may be either supported or discouraged. It is interesting to see how students respond to the situations they encounter. Finally, the third cycle is for confirmation/abandonment of their new/old notions. If possible, more cycles can be designed such that students' confidence about reasoning can be reinforced.

## 2 Method

Thirty-one ninth graders (17 boys and 14 girls with an average age of 15 years), who were in the same class, were selected by purposeful sampling in central Taiwan and were individually interviewed in a cyclic POE process. It took about 30 min for each individual interview. While students' predictions were written on worksheets, their reasons and explanations were probed by interview. Responses from students' interviews were tape recorded and transcribed for data analyses. Their conceptual change and reasoning performance through the cyclic POE process were analyzed.

Two cyclic POE designs are illustrated as follows, in which the latter is reported herein. Both of them concern students' concepts of color formation of matter. Figure 2 shows the experimental setup.

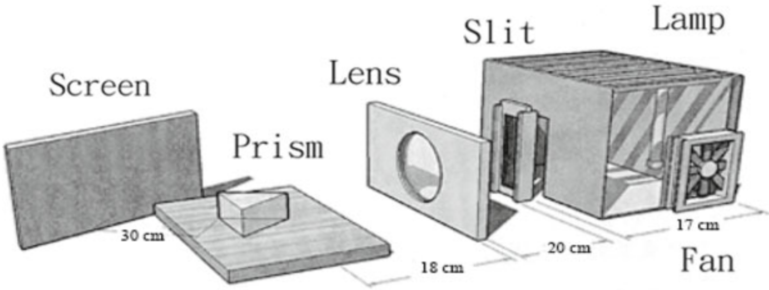



**Fig. 2** Experimental setup of the cyclic POE activities

A 500-W halogen lamp produced white light in a homemade box equipped with a fan for cooling. The white light passed through a slit and a convex lens. The light beam was then dispersed by a prism and imaged on a white screen (Fig. 2). The first cyclic POE design used a single sheet of cellophane positioned over the slit. Six colors of cellophane, with one in each cycle, were utilized in the order: red, orange, yellow, green, blue, and purple. In each cycle, the student was asked:

*What color or colors of light will show on the screen?*
*Please explain your reasoning.*

After the student's response, the colored cellophane was positioned over the slit. Then, the student observed the result and was asked:

*Is the result consistent with your prediction?*
*What is your explanation?*

In the first few cycles, students might make wrong predictions. However, after one or more observations, they would gain some information about the hidden rules of the observed phenomenon. In this experiment, the screen showed the colors of light that were not efficiently absorbed by cellophane. However, a majority of students regarded that only a single color, which was the color of the cellophane, would appear on the screen. It was therefore interesting to probe whether students would modify their reasoning in the subsequent cycles and whether students could discover the principle of color formation of cellophane.

The second design was similar to the first one, except that two sheets of cellophane of different colors were positioned over the slit. Before the cyclic POE process, the experiment of the first design was demonstrated to and recorded by students, without interviews. The recorded data served as clues for students to predict and understand the outcome of the second design. Five POE cycles were administered to students with the combinations of cellophane in the order: red & orange, orange & yellow, yellow & green, green & purple, and purple & red, where a sheet of cellophane was changed between two sequential cycles. Accordingly, a student had a total of ten opportunities to present their reasoning through five prediction and five explanation activities. In this way, students' reasoning abilities could be fostered and probed.

Finally, the absorption spectra of the cellophane used in this study were recorded by a UV/VIS spectrometer. The color of a substance is determined by how it absorbs visible light. For example, when white light passes through a sheet of cellophane that absorbs green light, the color of cellophane will be red because red is the complement of green. In other words, if a substance absorbs light of one color, we see the complement of that color (Miessler & Tarr, 2004). However, most commercial cellophane products absorb multiple colors, and the outcome is to the result of mixing of the remaining colors of light. The relation between the color of cellophane and its absorption spectra can be learned from this study.

## 3 Results and Discussion

Table 1 shows the observed colors of the first design. In conflict with the general alternative concept that there should be only the color of cellophane, the dispersed spectrum of cellophane contained multiple colors. The observed colors were due to dispersed light that passed through cellophane without being efficiently absorbed.

**Table 1** Colors observed when a beam of white light penetrated a sheet of cellophane and was dispersed by a prism

| | Observed color | | | | | |
|---|---|---|---|---|---|---|
| Cellophane | Red | Orange | Yellow | Green | Blue | Violet |
| Red | √ | √ | | | | |
| Orange | √ | √ | √ | √ | | |
| Yellow | √ | √ | √ | √ | | √ |
| Green | √ | √ | √ | √ | | |
| Blue | √ | √ | √ | √ | √ | √ |
| Purple | √ | √ | | | | √ |

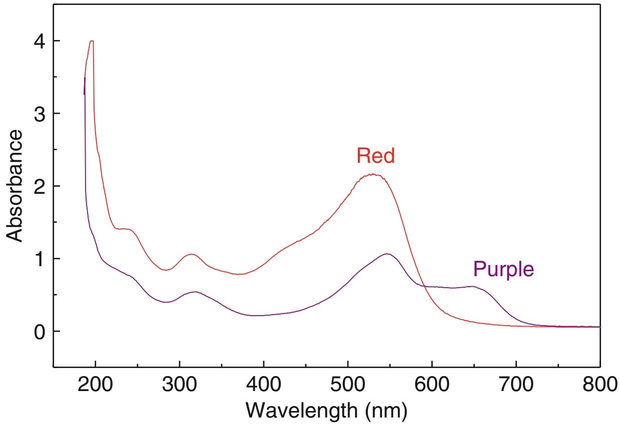


**Fig. 3** Absorption spectra of red and purple cellophane

**Table 2** Colors observed when a beam of white light penetrated two sheets of cellophane of different colors and was dispersed by a prism. Students' predictions were recorded on worksheets similar to this table

| | Observed color | | | | | |
|---|---|---|---|---|---|---|
| Cellophane | Red | Orange | Yellow | Green | Blue | Violet |
| Red & Orange | √ | √ | | | | |
| Orange & Yellow | √ | √ | √ | √ | | |
| Yellow & Green | √ | √ | √ | √ | | |
| Green & Purple | √ | √ | | | | |
| Purple & Red | √ | √ | | | | |

As an example to illustrate the principle of color formation, Fig. 3 depicts the absorption spectra of the red and purple cellophane. Only light with lower values of absorbance can penetrate cellophane. As shown in Fig. 3, red and orange light with wavelengths greater than about 600 nm can penetrate the red cellophane, whereas violet light (wavelength < 450 nm) can also penetrate the purple cellophane, in addition to red and orange light (Table 1). The mixing of stronger red and weaker orange light makes up the color of the red cellophane, whereas mixing with additional violet light forms that of the purple cellophane. Note that the blue cellophane was very transparent and all colors were observed (Table 1). Therefore, we did not use the blue one for the combination of two cellophane sheets in the second design.

Table 2 shows the observed colors of the second design. The observed colors can be inferred from Table 1 by finding light that can survive after penetrating two sheets of cellophane. Once students realized the principle from prior knowledge or from the POE cycles, they made correct predictions in response to the requested tasks.

**Table 3** The science and alternative concepts possessed by students about the properties of light

| Code | Concept | Frequency |
|---|---|---|
| S1 | The colored lights that can penetrate through two sheets of cellophane are those not being absorbed by either sheet. | 152 |
| S2 | The colored-lights being absorbed will not penetrate cellophane. | 46 |
| S3 | The intensity of light will be decreased when the light beam penetrates cellophane. | 1 |
| A1 | The outcome of mixing colored-lights is the same as that for mixing watercolors with the same colors as light. | 23 |
| A2 | Only the light with the same color of cellophane will penetrate the cellophane. | 22 |
| A3 | The stronger colored-light will cover the weaker one and make the weaker one indistinguishable. | 11 |
| A4 | The colored-light absorbed by the first cellophane can still appear after the light beam penetrates the second cellophane. | 10 |
| A5 | The light penetrating two sheets of cellophane will show, after dispersion, a single color combined from two cellophane colors. | 3 |
| A6 | The prism will change the color of light which can be observed. | 2 |
| A7 | The three primary colors of light are not red, green and blue, but others. | 2 |

*S* science concept; *A* alternative concept

We have identified three science concepts and seven alternative concepts that students possessed about the properties of light, shown in Table 3.

In Table 3, the frequency is the total number of times that students mentioned the corresponding concept during the prediction and explanation stages. A majority of students adhered to Science Concept S1, which was the key to understanding the dispersed spectrum (colors) of cellophane. However, it was found that 48.4% of students had reported S1 in their first cycle, but this increased to 61.3% in the last cycle, indicating that some students had changed their concepts during the cyclic POE process. On the other hand, the alternative concept A1 arose from students' experiences of using watercolors. A2 and A5 stemmed from their observation of colors of cellophane and unawareness of the effect of dispersing light.

In order to analyze students' reasoning in the cyclic POE process, we developed a system of notation, called "reasoning equations," explained as follows. For the following cases of students' responses,

(1) It will show red and orange because both of them can penetrate the red and orange cellophane. (Prediction in the first cycle, P1.)
(2) Using watercolors…green and purple will produce such colors. (Explanation for the observed result in the fourth cycle, O4.)
(3) It will show red and orange because they were observed in the first and second experiments. (Prediction in the third cycle, P3.)
(4) I don't know…I guess it should be the result. (Explanation for the observed result in the second cycle, O2.)
(5) Light passed though cellophane will be darker. Red light will be blocked by purple cellophane because it allows only purple to pass through. (Prediction in the fifth cycle, P5.)

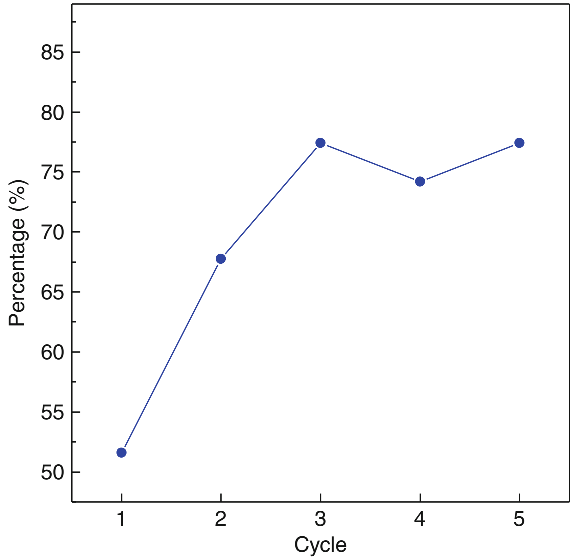


**Fig. 4** Percentage of students who made correct predictions in the POE cycles

We denoted them as

(1) S1 → P1 (Reasoning from Science Concept One to make prediction.)
(2) A1 → O4 (Reasoning from Alternative Concept One to explain the observed result.)
(3) O1 + O2 → P3 (Reasoning from Observation One and Two to make prediction.)
(4) NR → O2 (Explanation for the observed result with No Reason.)
(5) S3 + A2 → P5 (Reasoning from Science Concept Three and Alternative Concept Two to make prediction.)

The last case shows an interesting phenomenon: Sometimes students use both science and alternative concepts to solve a problem. Case (4) demonstrates how students' understanding about a specific problem was deficient. Moreover, students' reasoning skills can be identified from the above notations. In Cases (1), (2), and (5), students used the deduction reasoning skill, while in Case (3) induction. On the contrary, it was non-logic reasoning in Case (3).

After analyzing the interplay between students' concepts and reasoning, whose details were beyond the scope of this short report, it was found that alternative concepts played a role in students' understanding of the principle related to the POE tasks. Their reasoning performance was also influenced by alternative concepts. However, Fig. 4 shows that the subjects' correct prediction increased from 51.6% in the first cycle to 77.4% in the last one, indicating that the cyclic POE process induced a positive effect on students' reasoning.

## 4 Conclusions and Implications

We have proposed a cyclic POE strategy for probing and fostering students' reasoning abilities. The POE tasks provide opportunities for students to predict and explain well-designed events that share the same physical or chemical principle. Therefore, their reasoning abilities can be applied to tackle the problems. More importantly, students can actively learn the corresponding rules or principles, if the activities are so designed that regularity of specific phenomena can be discovered through the cyclic POE process. In other words, the cyclic POE can be regarded as one of the discovery learning strategies (McDaniel & Schlager, 1990).

A five-cycle POE process was designed to probe students' concepts and reasoning about the colors of light due to its interaction with two sheets of cellophane of different colors. A notation system of "reasoning equations" was developed for analyzing the interplay between students' concepts and their reasoning performance. The participants (ninth graders) showed moderately good reasoning abilities. However, some of them were unable to grasp the implicit principle because their reasoning was based on alternative concepts. Nevertheless, the present study indicates that the cyclic POE process produces a positive effect on students' reasoning.

The present study also suggests that the cyclic POE process can be applied for instruction, similar to the conventional POE (Palmer, 1995; White & Gunstone, 1992). Teachers can design suitable cyclic POE activities for their inquiry-based science instruction. It is ideal that hands-on experiments be incorporated into the observation stage. However, when applying the cyclic POE in classroom instruction, the experiments can also be replaced by photographs, illustrations, or texts. Finding clues in the POE process is similar to treasure hunting. Students can describe or explain the observed phenomena by deduction or induction. This will stimulate students to enhance their reasoning abilities and make the class more interesting.

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# A Trial of Placement and Embodiment of Images for Chemical Concepts in the Lesson Model of a "Surface Active Agent" Through SEIC

**Haruo Ogawa and Hiroki Fujii**

## 1 Introduction

International evaluations of PISA (OECD, 2004) and TIMSS (Martin, 2004) show that Japan places a high level of importance on the education of its students. However, these international tests simultaneously demonstrate some weak points in the Japanese educational system, namely in the areas of logical thinking, students achieving excellence, and creativity. Our interest is in improving science and chemical education via experimental study, where the lessons require dialogue between students and teacher, a minimum time commitment, and independent work by students.

We conducted a survey of current science textbooks in primary school and junior high school and Chemistry I, II in senior high school, based on the Japanese course of study (MEXT, 1999). The survey revealed that the textbook content could be grouped by knowledge area (Ogawa, Okada, Takehara, & Ikuo, 2006), skills for experimental study (Ogawa, Takano, Ikuo, Yoshinaga, & Fujii, 2009), and schemes as representative of images (Ogawa, Ishiwaki, Ikuo, Yoshinaga, & Fujii, 2008). Large numbers of knowledge area, schemes, and skills were cited in present-day textbooks in Japan in order to teach and understand scientific concepts, topics, and methodology. We have introduced a fundamental feature in school lessons in science and chemistry in which a special emphasis is placed on imagination leading to creation (SEIC) (Ogawa, Fujii, & Sumida, 2009). Promoting creativity in science has been reported and discussed in previous research (e.g., Höhn & Harsh, 2009; Jarvis, 2009; Longshaw, 2009; Ohshima, 1920). It is important for students to be

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able to think and act imaginatively (Wardle, 2009). In this chapter, development and trials of a lesson model for a "surface-active agent" and an evaluation of the lesson model are reported.

## 2 Development of the Lesson Model Through SEIC

### *2.1 The Lesson Model*

The lesson model for a "surface-active agent" was developed and proposed. A chemistry class in primary school is composed of 15 lessons. The fundamental content and lesson topics have been chosen on the basis of basic chemistry, that is, chemistry is roughly composed of three frames: structure, equilibrium, and change. Fifteen lessons in the model covered them moderately. This lesson model of "surface-active agent" includes the fundamental concept of an isoelectric point (*IP*), and lesson content is listed in Table 1, in which the lesson proceeds toward the theme of "shampoo and rinse *vs.* hair," with a discussion from the standpoint of surfactant and *IP*.

### *2.2 Timetable*

The lesson is typically divided into five activities as described below.

The first 10 min of the lesson is spent reviewing the previous lesson, by use of samples of the pictures drawn by students, under the lecturer's guidance.

The next 45 min is used for lecture, putting a special emphasis on operations of the brain such as discussion, brainstorming, and recitation under the teacher's guidance, without competition, in a class where students use only their own thinking. These processes enable students to develop essential knowledge and skills, while

**Table 1** Contents of the lesson

| |
|---|
| 1. Soap and detergent |
| 2. Surface-active agent: anionic surfactant and cationic surfactant (invert soap) |
| 2.1 Structure and characteristics |
| 2.2 Shampoo and rinse |
| 2.3 Hydrophilic group and lipophilic group |
| 3. Surface tension (Demonstration experiment: floating coin on the surface of water) |
| 4. Polarization of water (Demonstration experiment: winding track of falling water by static electricity) |
| 5. Emulsion (Type of oil dispersion in water and that of water dispersion in oil) |
| 6. Property of protein (isoelectric point *IP*) |

Acquisition-knowledge anticipated (Chemical terms designated):
Cation/Anion/Positive charge/Negative charge/Ionic bond/Covalent bond/Polarity/Non-polar molecule/Polar molecule/Coulomb force/Hydrophobic/Hydrophilic/Micelle/Alkyl group/Functional group/Protein/Soap/Shampoo/Rinse/Detergent/Invert soap/Surface/Surface tension/"+ Hydrophilic group/Hydrophobic group"

they compare the activities and opinions of others with their own. Students' concentration on their own thinking is also promoted by a later step – drawing.

A period of 10 min is then set aside to provide students an opportunity to commit their acquisitions to memory.

The fourth step of the lesson is 15 min devoted to drawing pictures, sometimes forming clay, and perhaps doing experiments on the theme presented by the lecturer. Students' understasnd of a certain chemical concepts or phenomena are expressed in these drawings, sometimes with their own explanations written outside the drawing area using chemical terms. Student-initiative-operations proceed in the lessons, and the lessons place a special emphasis on operations using handwork, which helps students with concentration.

In the final 10 min of the lesson, students explain their pictures or other work on a self-explanation sheet (Appendix 1) with the best use of their own knowledge of chemical terms. The explanation should show sufficient knowledge of the lesson's objectives regarding chemical concepts and phenomena. The lesson thus fosters creativity through thinking, expression, and reasoning.

## 3 Practice of the Lesson Model

The lessons were carried out in chemistry classes (for teaching training for primary school) of 45 undergraduate students of junior (third-year) level in Tokyo Gakugei University (TGU) and 175 analogues in Bunkyo University (BU) in the spring semester in 2009. The lesson on surface-active agents was also performed at a course for the renewal of teacher's licenses for in-service teachers of primary schools, mainly in Tokyo, in 2009.

The lesson lasted about 90 min. A lecture was given, with frequent discussions without memorization (Fig. 1), and the lesson proceeded on the theme of "shampoo and rinse *vs.* hair," with discussion from the standpoint of surfactant and isoelectric point (*IP*). The task of making images of chemical concepts and phenomena was advanced. Students drew pictures and/or formed clay in three dimensions (3-D) for 15 min around the theme presented by the lecturer.

Students concentrated their attention on the creation of drawings. Drawings could include descriptions of text, marks, lines, arrows, and illustrations with simile in a drawing area. Written explanations were available outside the drawing area on a sheet using chemical terms by solid-parting line. Examples are shown in Fig. 2. Drawings featured a large variety of representations and vivid descriptions, along with good examples of forming clay in 3-D (Fig. 3). Students' understanding of certain chemical concepts and phenomena were expressed in drawings, sometimes with their own written explanations outside the drawing area, using many of the chemical terms acquired from the lecture. On subsequent practices of their explanations, students could explain adequately their own understanding of drawings on the self-explanation sheet (Appendix 1), where many chemical terms and chemical concepts were used in each document to explain certain chemical concepts or phenomena.

**Fig. 1** Lesson scene

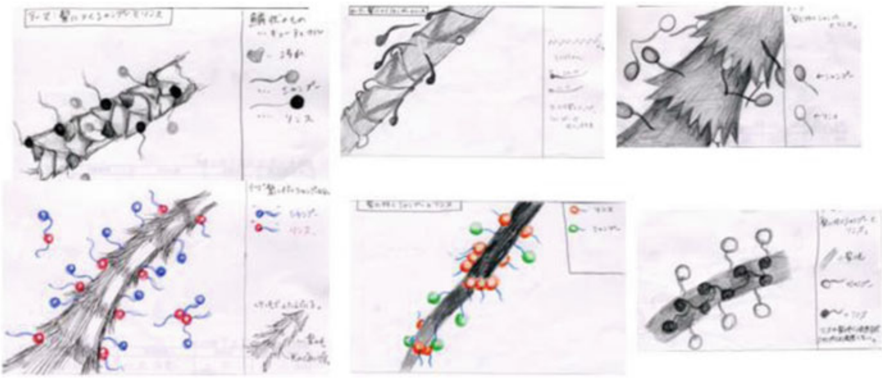


**Fig. 2** Drawings

**Fig. 3** Clay works

# 4 Evaluation of the Trial of the Lesson Model

## *4.1 Self-explanation*

The explanation of the drawings with the use of knowledge of chemical terms was performed in the last 10 min of the lesson. Learners used many chemical terms acquired in the lesson. They could explain adequately their own drawings. Designated and related chemical terms are listed in Table 2, in which the former was presented in the self-explanation sheet, and the latter was newly given in a document in the sheet. The number of chemical terms in the self-explanation before and after drawings changed. The number used after the drawings showed a tendency to increase, and numbers of lines in a document also exhibited a similar tendency, as shown in Fig. 4. Both use of chemical terms and number of lines tended to multiply through the drawing of the student's understanding. With regard to the variety of chemical terms, the fluctuation of numbers did not always increase, and rather decreased in the related chemical terms. The tendency implied that students used definitive terms of relevance for explanation of their own images toward their drawings. The related chemical terms used for the explanation were addressed. Frequency of related chemical terms before and after the drawing was then analyzed (Fig. 5). The terms were used with restriction; the use of the terms "adsorption" "water," and "negative charge" increased drastically, whereas there was a decrease in use of "hydrophobic group," "hydrophilic group," and "surfactant." The focus was on use of appropriate terms for the explanation of the images.

## *4.2 Appraisal of the Lesson Model*

An appraisal of the lesson model was conducted through a questionnaire (Appendix 2). The questions asked of learners included the following: "Did you have any knowledge about a "surfactant" before the lesson?" (Item number 1); "Did you have a clearer understanding of a "surfactant" after the drawing than right after the lecture?" (Item number 2); "Did the drawing help you to better understand the idea of a "surfactant" after the lecture?" (Item number 3); "Which did you prefer for gaining a better understanding

**Table 2** Chemical terms designated and related

| Designated chemical terms | Related chemical terms |
|---|---|
| Cation/Anion/Positive charge/Negative charge/Ionic bond/Covalent bond/Polarity/ Non-polar molecule/Polar molecule/ Coulomb force/Hydrophobic/Hydrophilic/ Micelle/Alkyl group/Functional group/ Protein/Soap/Shampoo/Rinse/Detergent/ Invert soap/Surface/Surface tension/ | Surfactant/Hydrophobic group/Hydrophilic group/Oil/Adsorption/Charge/Lipophilic group/Structure/Water/Affinity/Permeation/ Disinfection/Negative charge/Bond/ Character/Friction/Resistance/Molecule/ Repulsion/Dispersion/Suspension/ |

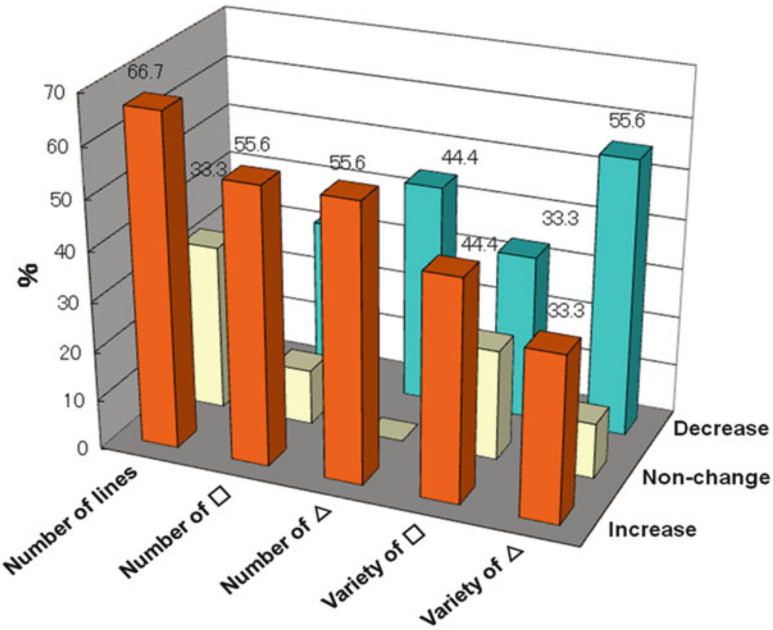



**Fig. 4** Fluctuation of numbers of lines and chemical terms filled in the self-explanation sheet by comparison with before and after drawings in the lesson of surface-active agent (11 teachers). Overlap was available in the number of chemical terms (□: Chemical terms designated; Δ: Related chemical terms)

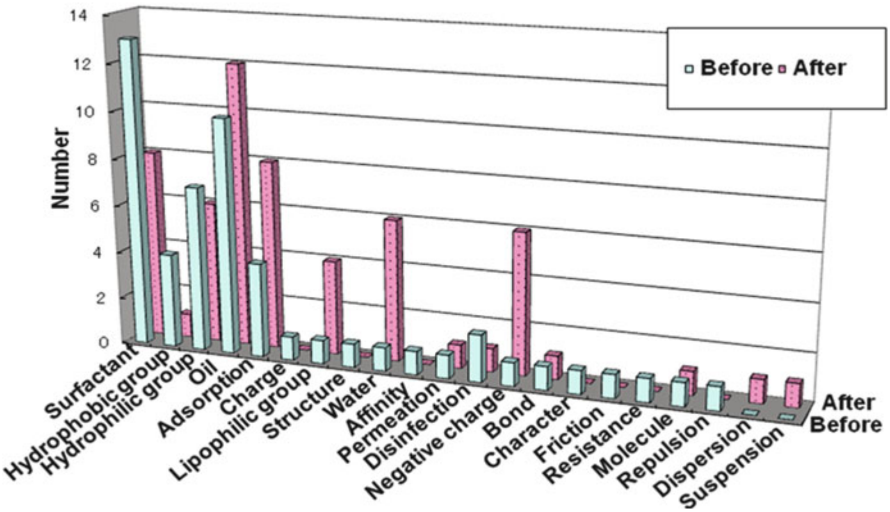



**Fig. 5** Frequency of related chemical terms before and after the drawing (Overall) (11 teachers) (Color figure online)

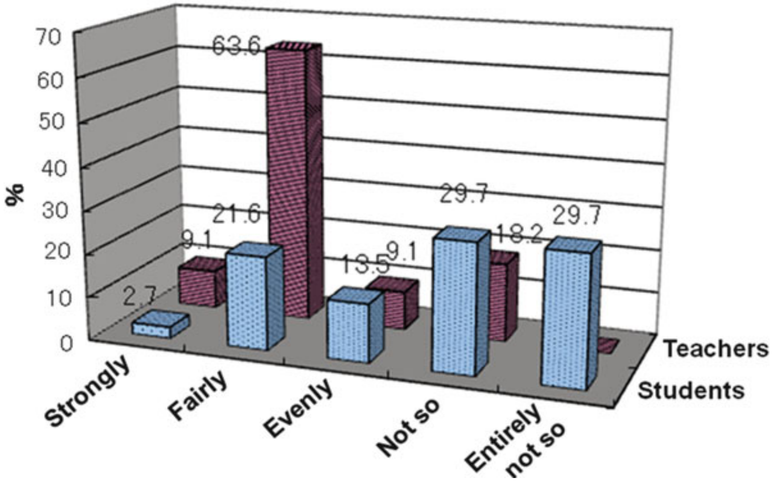



**Fig. 6** Distribution of numbers to the question, "Did you have any knowledge about a "surfactant" before the lesson?" (36 students, 11 teachers)

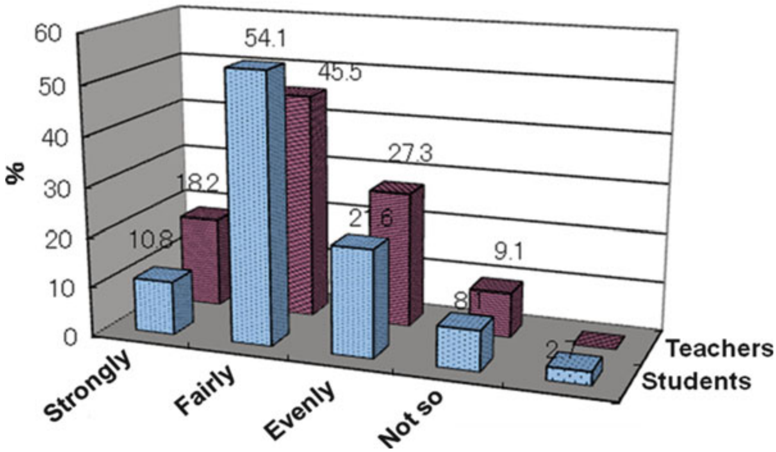



**Fig. 7** Distribution of numbers to the question, "Did you have a clearer understanding of a "surfactant" after the drawing than right after the lecture?" (36 students, 11 teachers)

of a "surfactant": drawing or clay work?" (Item number 4); and "Did you become aware of the difference between drawing and clay work?" (Item number 5). The results of each question for both students and teachers showed a similar tendency, with equivalent numbers of "yes" answers, including "strongly" and "fairly" in whole lessons, and overall were increased drastically in item numbers from 1 to 3 (Figs. 6, 7, 8). The activity of drawing could enhance making images and make them clearer. There was a preference comparatively for drawing for realization of acquiring images in item number 4 (Fig. 9). In addition, the free description answers showed that "clearer images about

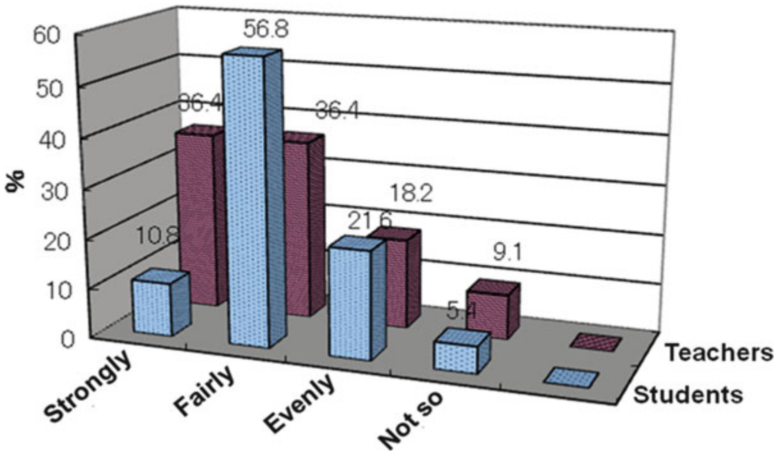



**Fig. 8** Distribution of numbers to the question, "Did the drawing help you to better understand the idea of a "surfactant"?" (36 students, 11 teachers)

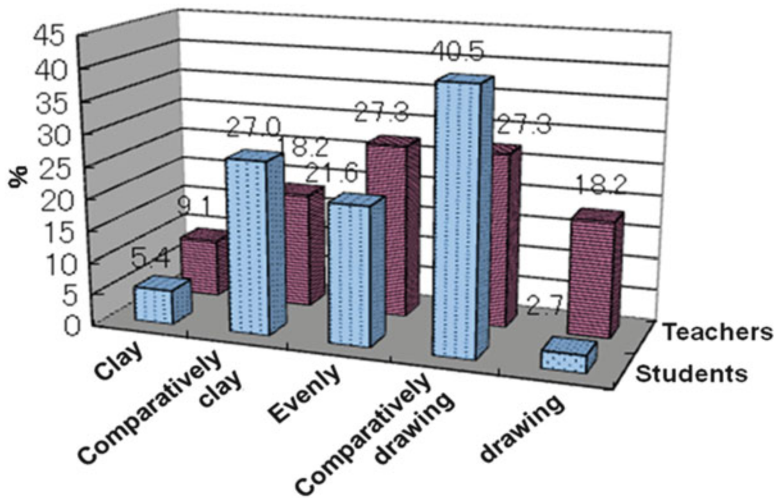


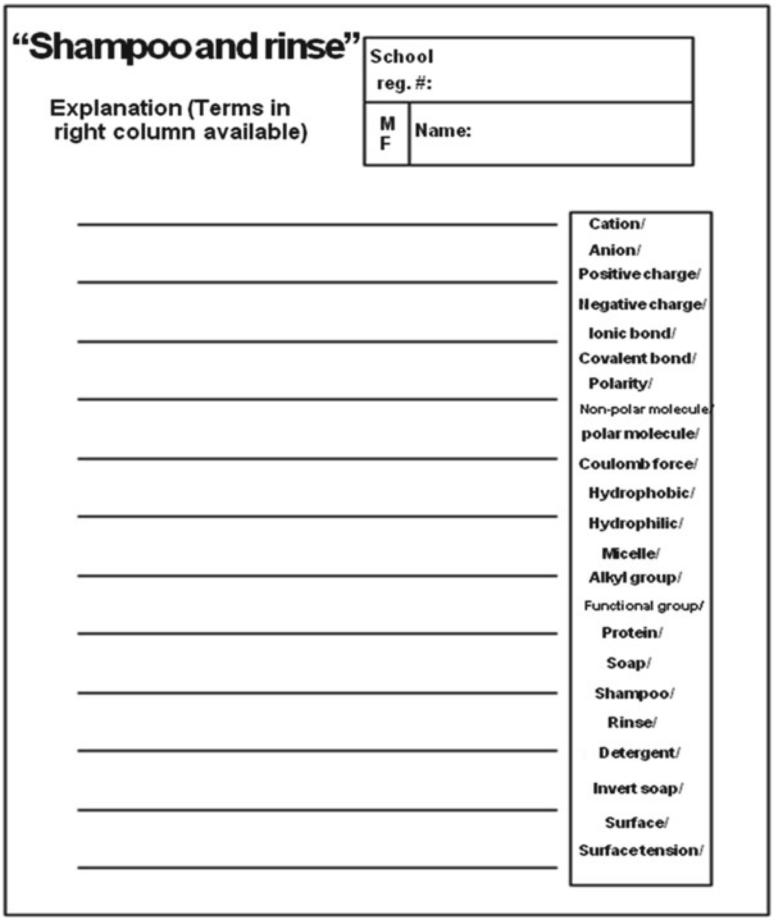

**Fig. 9** Distribution of numbers to the question, "Did you become aware of the difference between drawing and clay work?" (36 students, 11 teachers)

surfactant were realized," "understanding deepened," and there was "an awakening to a lack of understanding." Thinking and behaving imaginatively in science promote creativity as an outcome along with serving the primary pedagogical objective (e.g., Finke, Ward, & Smith, 1992; Ohshima, 1920; Wardle, 2009). The answers to the questions overall implied that the method of using lessons attached to drawings was enhanced concepts of the chemical reaction.

## 5 Conclusion

The students' drawings showed great variety in representation and vivid descriptions, occasionally with good practices of forming clay in 3-D. Students' understanding of certain chemical concepts and phenomenon were expressed in drawings, sometimes with their own explanations written outside the drawing area using chemical terms, many acquired from the lecture of the lesson. On subsequent practices of their explanations, students could articulate adequately their own understanding of drawings on the self-explanation sheet, where many chemical terms were used in each document to explain certain chemical concepts or phenomena. The answers to the questionnaire overall suggested using drawing as part of the lesson r enhanced understanding of the chemical reaction. Further emphasis on creativity at the appropriate level in each grade may be beneficial to students.

## Appendix 1. Self-explanation Sheet


"Shampoo and rinse"

Explanation (Terms in right column available)

School reg. #:

M F | Name:

Cation/
Anion/
Positive charge/
Negative charge/
Ionic bond/
Covalent bond/
Polarity/
Non-polar molecule/
polar molecule/
Coulomb force/
Hydrophobic/
Hydrophilic/
Micelle/
Alkyl group/
Functional group/
Protein/
Soap/
Shampoo/
Rinse/
Detergent/
Invert soap/
Surface/
Surface tension/

## Appendix 2. Checklist Through the Lesson of "Surface-Active Agent"

1: Strongly, 2: Fairly, 3: Evenly, 4: Not so, 5: Entirely not so

| No. | Items | Scale |
|---|---|---|
| **1.** | **Did you have any images about "surfactant" before the lesson?** | **1-2-3-4-5** |
| **2.** | **Did you have more clear images about "surfactant" after the drawing than those right after the lecture?** | **1-2-3-4-5** |
| **3.** | **Did the drawing help you to better understand the idea of a "surfactant "?** | **1-2-3-4-5** |
| **4.** | **Which did you have preference for realization of acquiring images about "surfactant" drawing or clay work?** [1: Clay, 2: Comparatively clay, 3: Evenly, 4: Comparatively drawing, 5: drawing] | **1-2-3-4-5** |
| **5.** | **Did you become aware of the difference between drawing and clay work?** [For example; understanding, difficulty, interest, appeal , *etc.*] Free description; | |

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# Part III
# Teaching Chemistry

**Hsiao-Lin Tuan**

The eight chapters in this section relate to chemistry teacher education and chemistry teaching. In the category of chemistry teacher education, Sulaiman and Ismail investigated Malaysian pre-service chemistry teachers' mental models of science teaching and learning, and found these pre-service chemistry teachers practice mainly teacher-centered teaching and learning. Lu, Chen, Shen, and Li used video case instruction to enhance Chinese pre-service chemistry teachers' instructional design and implementing competency and found these teachers' instructional design and implementation in "electron configuration of the atom" increases after 3 months of implementation. Mamlok-Naaman, Blonder, and Hofstein introduce an Israeli chemistry teacher education program that consists of three steps: course lectures to enhance teachers' content knowledge, follow-up tutoring lessons that aim to elaborate students' understanding of content knowledge, and, the final step, the workshop coordinated by science teaching groups that addresses how to apply science knowledge into teaching contexts. This teacher education program approach can enhance chemistry teachers' content knowledge and pedagogical knowledge. Finally, Mohamed, Abdullah and Ismail investigated 78 Malaysian primary teachers about their perceptions about practical science activities implemented in primary schools. The practical science activities provided opportunities for students to engage in scientific investigations through hands-on activities and experimentation. They found teachers were concerned about the cost, safety, waste disposal, and teacher preparation in implementation of practical science activities. The authors suggest the microscience approach is feasible for implementing future practical science activities in primary schools.

The second part of this section focuses on chemistry teaching. Kyle, Bacon, Park, Griffin, Cummins, Hooks, Qian, and Fan examined several instructional approaches: hands-on demonstration, technology concentrated online learning tool,

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and process-oriented guided inquiry learning to connect chemistry and engineering to a group of engineering majors. Toward the end of their study, students perceived the usefulness of these instructions in building their understanding of the connections between chemistry and engineering. Teh and Yakob used a quasi-experimental design to investigate the effectiveness of a problem-based learning (PBL) technique to teach cell potential of electrochemistry to a group of 18-year-old college students. Findings indicated that PBL instruction enhanced students' understanding of cell potential. Grunwald introduces teaching catalysis by means of enzymes and microorganisms. This teaching example does not only reduce the time for teaching but also provides interdisciplinary element. Finally, Golemi presents a method for explaining the module "Metabolism of Organic Substances" in biochemistry through diagram drawing and explaining.

# Chemistry Pre-service Teachers' Mental Models of Science Teaching and Learning in Malaysia

**Maryam Sulaiman and Zurida Haji Ismail**

## 1 Introduction

A mental model is a cognitive construct that describes a person's understanding of a particular content domain in the world. Mental models are cognitive representations of reality, or ways in which reality is codified in terms of how one understands it. It is an explanation of someone's thought process for how something works in the real world. Mental models are the *internal* representations of situations, both real and imaginary (Johnson-Laird & Byrne, 2002), that people use to understand specific phenomena. Johnson-Laird (1983) proposed that mental models are the basic structure of cognition and "play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life" (p. 397). Mental models affect what we see in situations and create reinforcing patterns of behavior.

According to cognitive schema theory, people draw from their prior experiences, training and instruction to develop mental models that provide the framework for understanding events (Anderson, 2004; Norman, 1988). The mind constructs mental models as a result of perception, imagination and knowledge, and the understanding of discourse. Mental models represent our assumptions and beliefs about how the

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world around us works and influence a person's judgment and decision making. Gentner and Stevens (1983) noted that these internal models provide predictive and explanatory power for understanding interactions with the world around us. Mental models allow people to describe and understand phenomena, draw inferences, make predictions, decide which actions to take, and experience events vicariously (Johnson-Laird, 1983).

Barnes (1992) suggested that one's mental model is organized in "frames" or clustered sets of expectations. Teachers' professional frames are both individually and socially derived – shaped by experiences as well as expectations and values (from the outside as well as the inside). These clustered sets of expectations or frames, similar to mental models, may provide valuable insights into the beliefs that teachers hold about the teaching and learning of science. Norman (1983) suggested that mental models may represent one's belief system, holding predictive and explanatory power. An organized collection of individual beliefs can be viewed as forming a mental model (Chi, 2008). The visible part of the cycle, behavior, reinforces the invisible part, the beliefs or mental models.

Mental model formation depends heavily on the conceptualizations brought to a task and includes our views, beliefs, and attitudes concerning the world, ourselves as learners or teachers, our capabilities and prior experiences, the tasks we undertake, the issues we confront, and the strategies we employ. Our mental models (or schemas) affect how we interpret new concepts and events. As such, mental models are important because one's beliefs, expectations, and interactions with those systems profoundly influence one's ultimate actions with regard to those systems (Norman, 1983). Hence, mental models are dynamic and can be changed by experience or expectations.

Because mental models are developed through particular interactions with a system, individuals' unique experiences will result in interaction-specific or functionally idiosyncratic mental models. Studies by Calderhead and Robson (1991) reported that pre-service teachers held vivid images of teaching from their experiences as students. These images may affect teachers' interpretations of course experiences and powerfully influence the translated knowledge and projected practice they would apply as teachers. Students need to develop good-quality mental models about teaching and learning, because those mental models will inform their plans and actions in their prospective classrooms. Kerr (1981) proposed that good-quality teaching actions are informed by good-quality intentions and plans, which are in turn informed by good-quality knowledge about teaching and learning. Studies have shown that learners with access to good mental models demonstrate greater learning outcomes and efficiency compared with those with less adequate models in various domains (e.g., Mayer, 1989; White & Frederiksen, 1989).

To assess mental models, researchers often rely on learners' construction of external representations (e.g., concept maps) as a proxy for what resides inside the learner's head. Thomas, Pederson, and Finson (2001) developed and validated the Draw-A-Science-Teacher Test Checklist (DASTT-C) to explore mental models and teacher beliefs of pre-service teachers in the beginning of their science methods course. The DASTT-C includes both illustration and a narrative data component to provide a clearer picture of pre-service teachers' self-perceptions of themselves as science teachers. Inasmuch as oral interviewing of each pre-service teacher is considered impractical, a written narrative component was developed as an alternative. The tool could be used to help teachers recollect memorable episodes within their beliefs about how to teach science, consider alternative methodological approaches, and develop a preferred image of themselves as science teachers.

Markic (2008) modified the Draw-A-Science-Teacher-Test Checklist to achieve a more open and explorative questionnaire. The approach tries to uncover more information from pre-service teachers' drawings and their descriptions of their teaching objectives. The approach towards the teaching situation is illustrated in their drawings. These drawings that science pre-service teachers make are considered an important package of information that can be read and decoded. Data analysis based on Grounded Theory (GT; Glaser & Strauss, 1967; Strauss & Corbin, 1990) consists of three steps: open, axial, and selective coding. This approach to data analysis allows for a richer description of the pre-service teacher beliefs about classroom organization, teaching objectives, and epistemological beliefs (Markic & Eilks, 2008). The articulation of the pre-service teachers' beliefs is made more accessible through a graphic approach using three-dimensional (3D) diagrams.

## 2 Purpose

The purpose of this chapter is to investigate chemistry pre-service teachers' mental models of science teaching and learning.

## 3 Methodology

The sample consisted of 43 pre-service science teachers who were in their third year of the Science with Education Degree Program at the Universiti Sains Malaysia. These pre-service science teachers were enrolled in the chemistry teaching methods course, which is a required course for all chemistry majors and minors. Out of the 43 pre-service science teachers involved, 10 were chemistry majors while the remainder minored in chemistry. Data were collected through the Draw-A-Science-Teacher-Test Checklist (DASTT-C), which was administered to the pre-service science teachers during the first meeting of the course. The following instructions were given by the instructor:

Select a class stage, to which your thoughts refer and indicate the stage (Form 4 or Form 5). Draw yourself and pupils during instruction. In the design you should play a role as teacher, the pupils, media, the area or other device. Explain your drawing by answering the following questions:

1. What is the teacher doing? Describe your activity as teacher in this instructional situation.
2. What are the students doing? Describe the activities of your pupils in this instructional situation.

**Table 1** Evaluation pattern

| | | |
|---|---|---|
| Beliefs about classroom organization | *−2* | Strongly teacher-centered: The teacher is in the centre of any activity; dominates activity; lectures; uses media to focus students' attention |
| | *−1* | Rather teacher-centered: The teacher is in the centre of the activity, but interacts with the students; (s)he requires short answers from students, but dominates and directs every activity in the classroom. |
| | *0* | Neither … nor: Teacher- and student-centered activities are in balance, the teacher shifts from teacher- to student-centered teaching. |
| | *1* | Rather student-centered: Students' activities are at the core, but teacher initiates and controls students' activities. |
| | *2* | Strongly student-centered: Students' activities are at the core; students are at least partially able to choose and control their activities. |
| Beliefs about teaching objectives | *−2* | Exclusively content-structure focused: Learning content is the central objective. |
| | *−1* | Rather content-structure focused: Learning content is in the fore-ground; but some non-cognitive objectives are targeted. |
| | *0* | Neither … nor: Learning of contents and applications/non-cognitive objectives is in balance; or motivational objectives are the core. |
| | *1* | Rather scientific literacy oriented: Learning of competencies, problem solving, or thinking in relevant contexts and other affective outcomes are important. |
| | *2* | Strongly scientific literacy oriented: Learning of competencies, problem solving, or thinking in relevant contexts and other affective outcomes are the main focus of teaching. |
| Epistemological beliefs | *−2* | Learning is receptive: Learning is passive and over-directed; learning is a dissemination of information. |
| | *−1* | Over-directed learning with student-active phases: Learning follows a storyboard written by the teacher; conducted by the students, but organized and directed by the teacher. |
| | *0* | Over-directed learning with elements of constructivism: Learning is directed by the teacher taking into consideration students' preconceptions or problem solving, but the learning process stays over-directed. |
| | *1* | Rather constructive learning: Learning is an autonomous and self-directed activity, but is initiated and partially directed by the teacher. |
| | *2* | Strongly constructive learning: Learning is an autonomous and self-directed activity, starting from students' ideas and initiatives. |

Markic & Eilks (2008)

3. What goals are pursued (trying to be achieved within the given time) by the teacher in the instructional situation?
4. What preceded the drawn situation? Explain your approach to achieve your goals.

The measurement of the beliefs is quantified using the scales and description of the codes from selective coding developed by Markic and Eilks (2008), presented in Table 1.

## 4 Results and Discussion

Two examples (diagram 1 and diagram 2) of the pre-service science teacher drawings are presented in Fig. 1. The drawings were chosen because they illustrated the range of values (−2,−2,−2) and (+2,+2,+2) used in coding the drawing of the science teaching as well as the diversity of personal beliefs held by the pre-service science teachers. Diagram 1 shows a typical arrangement in the Malaysian classroom where pupils are seated facing the teacher in the front. The teacher is truly the "sage at the center of the stage." Diagram 2 shows the opposite atmosphere to diagram 1, where the class is held outside and pupils were depicted to be exploring the environment. The diagram illustrates a constructivist approach to learning where students have to discover and build their own understanding of the knowledge.

The findings from the data collected showed that none of the drawings by pre-service science teachers who majored in chemistry scored the combined codes of (+2,+2,+2). However, two of the drawings by the chemistry majors scored a combination code of (−2,−2,−2) as shown in diagram 1 (see Appendix 1). Figure 2 (diagram 3) shows an example of the best drawing by a chemistry major pre-service teacher. The scores given for this diagram were (+2,+2,+1), which means that this pre-service science teacher was strongly student-centered, believed strongly in attaining scientific literacy, and believed teachers still have some say in the teaching and learning process. The drawing illustrated a typical laboratory environment where students could be seen working together on an activity at their respective tables.

Figure 3 shows the codes assigned to the drawings of all the pre-service science teachers according to the three categories (Table 1): beliefs about classroom organization, beliefs about teaching objectives, and epistemological beliefs. The results showed quite a homogenous distribution within the codes $-2 \rightarrow +1$ for the beliefs about classroom organization, with less than five pre-service science teachers receiving a code of +2. This finding shows that the pre-service science teachers were strongly teacher-centered and only somewhat student-centered. In a strongly teacher-centered classroom organization, the teacher dominates and lectures form the major activity, with media used to focus student attention. The teacher may occasionally plan for a student-centered classroom organization; however, the teacher still initiates and controls the activities that are reflective of the teacher-centered classroom organization. It is possible that at this stage pre-service science teachers still lack knowledge about what constitutes a teacher-centered and student-centered classroom. It is also possible that their view about classroom organization is still being influenced by their prior experiences as students, where the teacher was more traditionally the "sage at the center of the stage."

One example as written:

Teacher activities*:* The teacher teaches to their student about the effect of the catalyst on the rate of reaction. **The teacher asks the student** to draw a diagram of the rate of reaction before and after the catalyst is added. **The teacher also asks the student** to conduct an experiment to show the effect of the catalyst on the rate of reaction.

Student activities: Students focus on what the teacher teaches them. They also **follow their teacher's instruction when** the **teacher asks** them to draw.

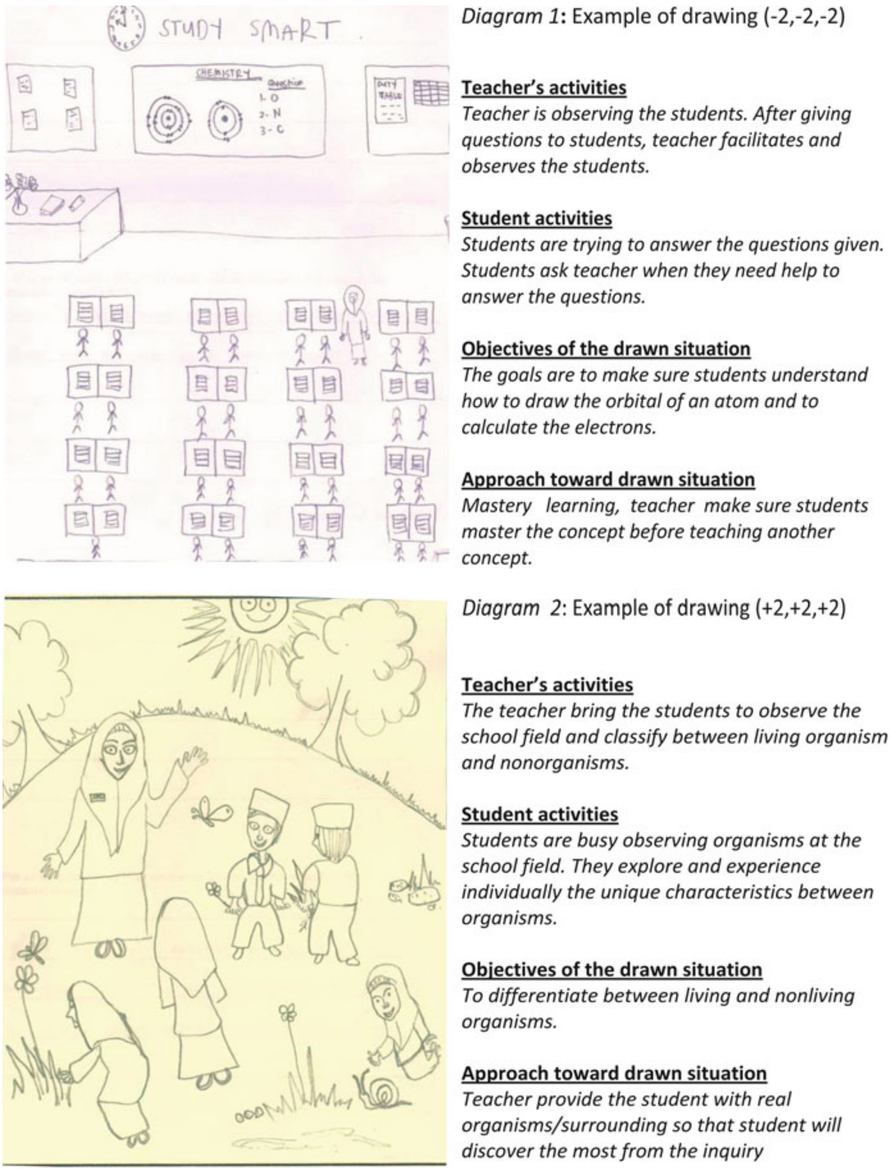


**Fig. 1** Example of the pre-service science teacher's drawing

The beliefs about teaching objectives are distributed in the range of −2 to +1. Only a few of the pre-service science teachers received codes 0 and +2. The lowest code, −2, illustrates that participants preferred to be exclusively content-structure focused, with learning content as the central objective.

The distribution for the epistemological beliefs showed that most of the pre-service science teachers were assigned a code of −1 followed by +1, −2 and 0.

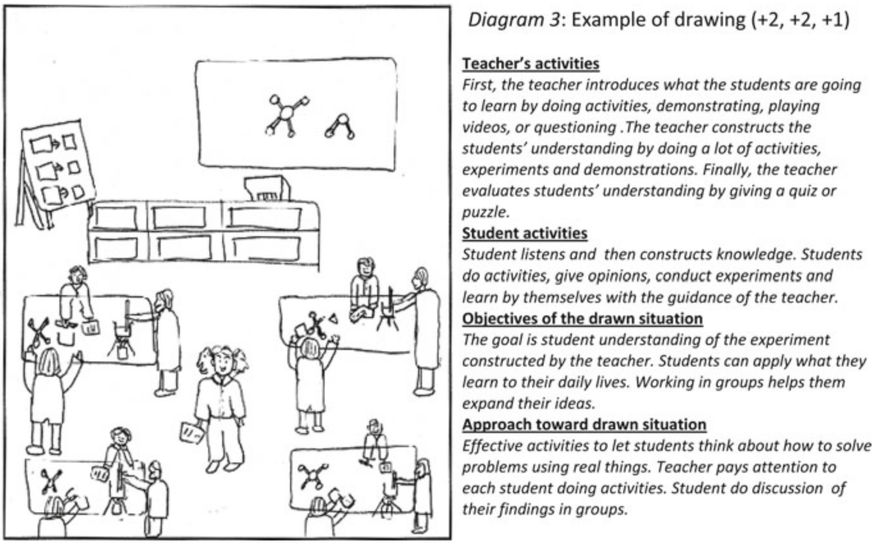


**Fig. 2** Example of a chemistry pre-service teacher's drawing

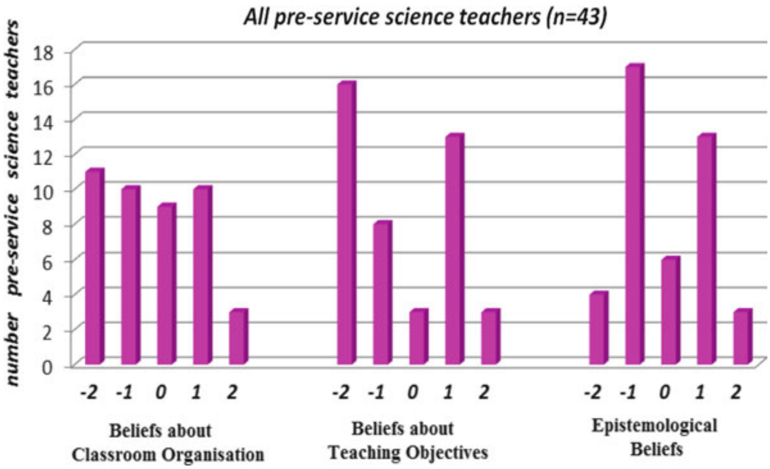


**Fig. 3** Codes for all of the pre-service science teachers (n = 43)

A code of −1 indicates that the teacher is still the director of the teaching and learning process while the students are the active participants in the process. The teacher dictates the flow of the activities while students are responsible for completing all the assigned tasks and activities. About four of the chemistry pre-service teachers held a rather constructive perspective of learning while none subscribed strongly to the constructive perspective.

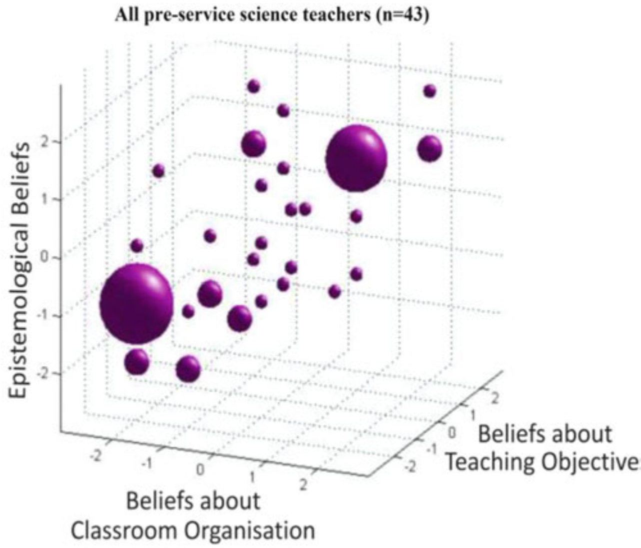


**Fig. 4** Joint representation of the data from the three dimensions within one single diagram. The size of the spheres represents the number of the pre-service science teachers

The three categorical beliefs can be connected together and represented in 3D diagram (Markic & Eilks, 2008). The 3D diagram is considered an elegant and sophisticated form of data analysis because the three categorical beliefs can be depicted visually. The sphere represents the number of pre-service science teachers with the joint categorical beliefs. Figure 4 shows the joint representation of the three categorical beliefs held by the chemistry pre-service teachers. The size of the spheres corresponds with the number of pre-service science teachers with the joint codes for each categorical belief: beliefs about classroom organization, beliefs about teaching objectives, and epistemological beliefs. The figure shows heterogeneous spheres, with the two largest spheres at the diagonal (–2,–2,–1) and (+1,+1,+1) and others distributed diversely along the axes. The findings indicate that the beliefs of all the pre-service science teachers in this study were mostly in traditional teaching, with some moving towards modern constructivist teaching. The chemistry pre-service teachers believed in teacher-centered classroom organization rather than a student-centered classroom. Most of the chemistry pre-service teachers preferred teaching with an exclusively content-structured focus with learning content as the central objective. The findings are similar to the findings by Markic and Eilks (2008) from their study on German first-year chemistry student teachers' beliefs about chemistry teaching and learning (Figs. 5, 6).

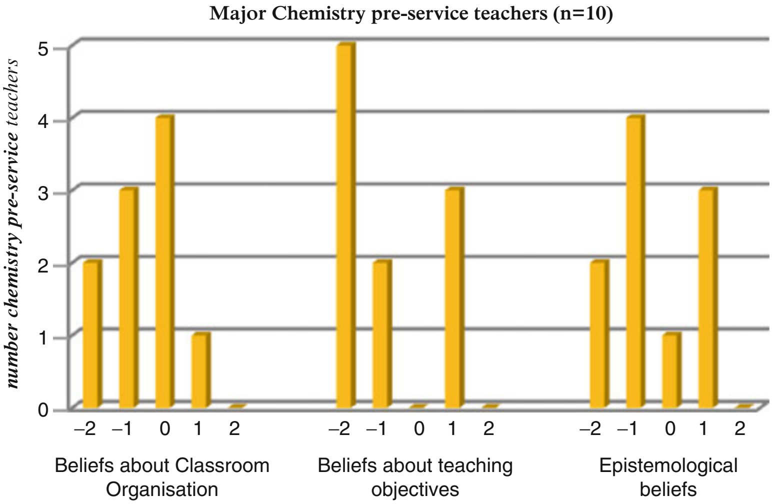


**Fig. 5** Codes for the chemistry pre-service teachers (n = 10)

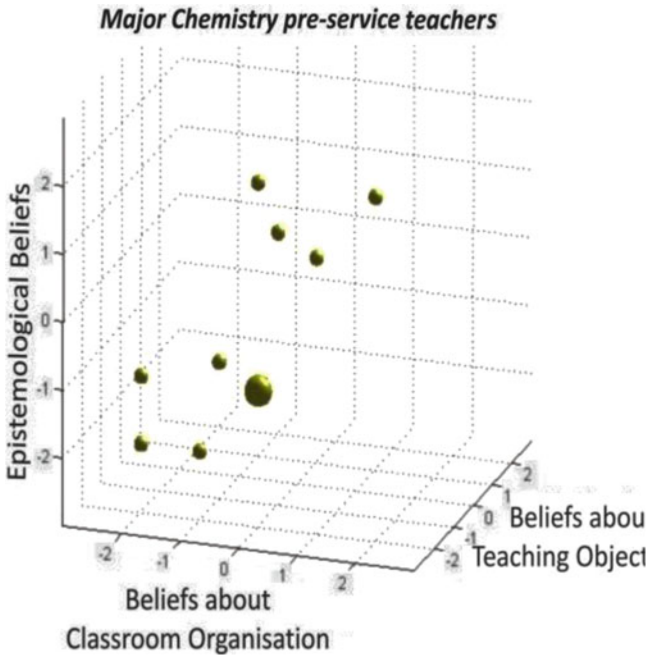


**Fig. 6** Joint representation of the data from the three dimensions within one single diagram. The size of the spheres represents the number of the major chemistry pre-service teachers

## 5 Conclusions and Implications

A learner's mental model is highly individualized and constantly changing as more input and learning take place. Learners construct new knowledge and modify existing knowledge as they experience situations, problems, circumstances, and other events in learning settings. The models continue to change as more knowledge is gained. A person must have a working model of the phenomenon in his or her mind in order to understand a real-world phenomenon. Authentic learning environments have the potential to provide an environment that allows students to experience learning in situated contexts, and these experiences enrich and change their mental models. Hence, understanding the mental models in teaching and learning science is crucial at the beginning of the methods course in teaching chemistry. This understanding can help teacher educators to improve and support teaching and learning experiences in the methods course and the teacher education program. As evidenced in the representations, the chemistry pre-service teachers in this study still held traditional beliefs about teaching and learning. Teacher educators need to consider the existing mental models held by pre-service teachers and plan a teacher preparation program to shape these mental models according to the current educational theory in teaching chemistry. Instructors who are more aware of the role that mental models play in learning ill-structured knowledge are more likely to succeed in supporting learners' experiences (Eckert & Bell, 2005). Visualization of mental models can help both instructors and students understand the knowledge-building process (Yehezkel, Ben-Ari, & Dreyfus, 2005).

**Acknowledgment** Our appreciation and thanks to Dr. Silvija Markic, University of Bremen, Department of Biology and Chemistry, Institute of Science Education (IDN) – Didactics of Chemistry for the instruments and assistance in data analysis.

## Appendix A

Numbers and percentage of the pre-service science teachers in the respective categories. The categories refer to Table 1 in the sequence Classroom Organization, Teaching Objectives, and Epistemological Beliefs. For single students not all codes were given in every category.

| Code combination | All Science (n = 43) | Chemistry (n = 10) | Code combination | All Science (n = 43) | Chemistry (n = 10) |
|---|---|---|---|---|---|
| (−2,−2,−2) | 2 (4.7%) | 1 (10.0%) | (0,0,+1) | 2 (4.7%) | |
| (−2,−2,−1) | 6 (14.0%) | 1 (10.0%) | (0,−1,+1) | 1 (2.3%) | 1 (10.0%) |
| (−2,−2,0) | 1 (2.3%) | | (0,−1,−1) | 1 (2.3%) | |
| (−2,−1,−1) | 1 (2.3%) | | (0,−1,0) | 1 (2.3%) | |
| (−2,−1,+1) | 1 (2.3%) | | (0,−2,−1) | 2 (4.7%) | 2 (20.0%) |
| (−1,−2,−2) | 2 (4.7%) | 1 (10.0%) | (0,+1,0) | 1 (2.3%) | 1 (10.0%) |

(continued)

(continued)

| Code combination | All Science (n=43) | Chemistry (n=10) | Code combination | All Science (n=43) | Chemistry (n=10) |
|---|---|---|---|---|---|
| (−1,+1,+1) | 1 (2.3%) | | (+1,−2,+1) | 1 (2.3%) | |
| (−1,−2,−1) | 1 (2.3%) | | (+1,−2,0) | 1 (2.3%) | |
| (−1,−1,−1) | 2 (4.7%) | 1 (10.0%) | (+1,0,−1) | 1 (2.3%) | |
| (−1,−1,0) | 1 (2.3%) | | (+1,+1,−1) | 1 (2.3%) | |
| (−1,+1,+2) | 1 (2.3%) | | (+1,+1,+1) | 5 (11.6%) | 1 (10.0%) |
| (−1,+1,0) | 1 (2.3%) | | (+2,+2,+1) | 2 (4.7%) | |
| (−1,+1,+1) | 2 (4.7%) | 1 (10.0%) | (+2,+2,+2) | 1 (2.3%) | |
| (0,0,+2) | 1 (2.3%) | | | | |

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# Chemistry Teachers Enhance Their Knowledge in Contemporary Scientific Areas

**Rachel Mamlok-Naaman, Ron Blonder, and Avi Hofstein**

## 1 Introduction

The new standards (National Research Council [NRC], 1996) are shaping the ways that the sciences are taught both in formal and informal educational settings. Moreover, this need is intensified by the concern raised in Israeli society about the apparent decrease in the outcomes of the educational system in Israel, and, in particular, the urgent need to raise the quality of science education so that students will be scientifically literate and able to cope in an increasingly science-oriented society.

The critical role of teachers in attaining the goal of quality education in the sciences is highlighted in the research literature. A recent international policy document written by Osborne and Dillon (2008), as well as other reports (e.g., Dillon & Osborne, 2007; European Commission [EC], 2004, 2007) reflect a consensus on the importance of good-quality teachers:

> Good quality teachers with up-to-date knowledge and skills are the foundation of any system of formal science education. Systems to ensure the recruitment, retention, and continuous professional training of those individuals must be a policy priority in Europe. (Osborne & Dillon, 2008, p. 25)

The idea of teacher knowledge first came to prominence a quarter of a century ago, and there has been a burgeoning literature on what teachers know and do in order to carry out their work (Bell & Gilbert, 1994; Mulholland & Wallace, 2005). By acknowledging the central role of teachers in teaching, the movement to enhance teachers' knowledge places the practicing teacher at the heart of attempts to reform classrooms and improve student achievement. Although there is agreement

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about the importance of teachers' knowledge, there have also been numerous discussions, debates, and concerns regarding how teachers' knowledge is constructed, organized, and effectively used (Kempa, 1983; Kind, 2009; Munby, Russell, & Martin, 2001). Many teachers currently practicing in school systems around the world completed their training many years ago (over 10 years). As a result, their science knowledge and knowledge of important recent developments regarding science teaching (pedagogical knowledge and knowledge of new learning environments) is limited. This consequently inhibits their ability to implement curricula that require contemporary scientific and pedagogical knowledge and to teach at an appropriate level and with appropriate methodology (Henze, van Driel, & Verloop, 2006). Moreover, even though teachers continuously attend professional development programs, as recommended by the National Research Council (1996) and by other science educators (e.g., Loucks-Horsley & Matsumoto, 1999), these programs emphasize teachers' pedagogical knowledge more than their content knowledge (Krajcik, Mamlok, & Hug, 2001; Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008).

## 2 A Program for Enhancing Chemistry Teachers' Content Knowledge as Well as Their Pedagogical Content Knowledge

The program for enhancing chemistry teachers' content knowledge as well as their pedagogical content knowledge (PCK) is intended to empower teachers and increase their motivation by providing them with opportunities to develop professionally and be involved in innovative activities (e.g., involvement in academic research labs, scientific workshops, and seminars that deal with frontiers in science, and in science education). It was anticipated that during this program the teachers would gain the necessary knowledge that will enable them to successfully guide their students (Windschitl, 2003). This program was designed to initiate a meaningful and profound change in teachers' teaching styles and enhance their professional development, as well as their knowledge of teaching and pedagogy (Bell & Gilbert, 1994; Hofstein, Shore, & Kipnis, 2004; Loucks-Horsley, Hewson, Love, & Stiles, 1998; NRC, 1996). Continuous professional development should broaden teachers' pedagogical knowledge and content knowledge. From the teachers' point of view, the change in practice includes acquiring new knowledge and new PCK (Henze, van Driel, & Verloop, 2006).

The program, which started at the beginning of the 2008 academic year, was carried out collaboratively between science educators from the Science Teaching Department and representatives of science faculties. It involved teamwork and collaboration among three groups: scientists, science educators, and teachers.

Those courses that were important for practitioners in the field of education (e.g., implementation and customization of curricular resources) were emphasized. Moreover, the teachers were expected to participate in scientific research and

**Table 1** The level of CK, PK, and PCK in the three steps

| Step | CK | PK | PCK |
|---|---|---|---|
| Step 1. *Scientific lecture* | High | Low | Low |
| Step 2. *Follow-up* | High | Medium | Low |
| Step 3. *Adaptation to education* | Medium | Medium | High |

science teaching. It was assumed that the teachers, in collaboration with Weizmann Institute scientists and chemistry educators, would initiate and participate in innovative activities to advance science education in Israel.

In general, the teachers' program takes 3 years to complete. For the first 2 years the teachers spend 2 days per week at the Institute and are remunerated by half an MSc fellowship. In the third year they spend 1 day a week at the Institute using their free day or sabbatical (with no remuneration). In this way, they are allowed to continue teaching and to engage in innovative school-based activities in parallel to their study. Most of the courses take place during the first 2 years of the program, whereas the third year is mostly devoted to seminar work and school-based initiatives. The science teaching courses for the different groups of participants (teachers of biology, chemistry, mathematics, and physics) differ, although there is one course in which all the teachers participate. The scientific courses were specially designed for the teachers and focus on three aspects: enhancing their knowledge of school-related knowledge, advancing central and contemporary topics in the discipline, and providing general introductory courses to serve as a foundation for other disciplines (e.g., biology for the chemists and the physicists).

However, there was another model of science courses aimed specifically at the chemistry teachers. This model consists of three steps, in which the teachers attend (1) the course lectures together with the regular MSc students, (2) a follow-up tutoring lesson, which was prepared especially for teachers by one of the staff scientists and elaborates on the course lecture, and (3) a workshop coordinated by a researcher from the chemistry group of the science teaching department, in order to apply the scientific knowledge to the field of education. The three steps differ from each other in the knowledge aspect that each step provides to the teachers, as shown in Table 1.

The three-step model consists of the following steps:

- The first step focuses on a traditional lecture. The teachers are part of a large passive audience (including regular graduate students at the Weizmann Institute of Science), and this lecture was not aligned with their curriculum or with their ability to teach the content to their high-school students.
- The second step still focuses on CK, but with more attention to pedagogy. The tutor gives more attention to the teachers' needs and supports their ability to understand the content.
- The third step focuses on PCK. The teachers use their CK and PK, and transform them into PCK.

# 3 The Study

The study focuses on evaluating the three-step model for meaningful learning of advanced chemistry by high school teachers during their first year of the program. The main goal of the study was to explore the effectiveness of the three-step model. Thus, our research question was as follows:

How did the three-step model enhance teachers' content knowledge and their pedagogical content knowledge (PCK)?

## 3.1 Choosing the Topic of the Courses

Learning advanced chemistry courses is not an easy task for teachers who completed their formal education more than 10 years ago. Several factors in the teachers' backgrounds could act as learning inhibitors. Those teachers who completed their studies a long time ago may not fully remember the content of the basic courses that they took during their BSc studies. In addition, the scientific (chemistry) knowledge has greatly advanced since that time, and consequently there is a gap between the knowledge the teachers had originally learned and their knowledge of modern chemistry. After they finished their chemistry undergraduate studies, they became professional chemistry teachers and focused on the high school chemistry curricula. Hence, for the MSc science courses it was decided to choose advanced topics that are associated with the chemistry curriculum. We chose the courses from a given course list that the Weizmann Institute of Science offers to chemistry MSc and PhD students (academic year 2008–2009). Two courses met these criteria: "Organic reactions used in the total synthesis of natural products" and "Spectroscopy." The teachers who participate in the program teach organic chemistry and therefore know the underlying fundamental principles. Spectroscopy is not taught as such at the high school level in Israel; however, spectroscopy is integrated into other topics: environmental chemistry and physical chemistry. Choosing courses that are relevant to the teachers' work at school supports the teachers in two ways: They have the background knowledge that is essential for learning the advanced course, and they have sufficient professional interest and motivation to learn these subjects and to deepen their knowledge of topics that are relevant to teaching high-school chemistry.

# 4 Methodology

## 4.1 Participants

The program's participants consisted of seven chemistry teachers from seven different high schools in Israel. All had at least 10 years of high school science teaching experience, mainly in grades 10–12. All of them had completed their chemistry undergraduate studies more than 10 years ago. The whole chemistry program was coordinated by two researchers from the chemistry group. For the sake of privacy, all students and lecturers' names have been changed.

## *4.2 Course Description*

As described above, two courses were selected for implementation of the three-step model. In this chapter we will describe in detail how the three-step model was used in the course "Organic reactions used in the total synthesis of natural products." Nevertheless, data analysis and research findings will include the two courses.

### 4.2.1 Lecture

An advanced course in organic chemistry was taught by a PhD-level professor and included advanced topics in organic synthesis (e.g., retrosynthetic analysis, C–H acidity, C–C bond formation, hydroboration, regioselective enolates, enamines, acyl anion equivalents, and rearrangements). Table 1 highlights three of the lectures' topics: retrosynthetic analysis, hydroboration, and acyl anions. The course was open to MSc students (Weizmann Institute of Science, 2008–2009) whose work focused on organic synthesis as well as to those teachers who were engaged in the MSc program for chemistry teachers. The lectures included oral explanations that were taught together with organic chemistry equations that the lecturer wrote on the blackboard. A written exercise was given after every lesson. The evaluation of the course was based on a test that consisted of questions that were similar to those that were given in the exercises.

*Follow-up*. A tutoring lesson was given after each lecture by an assistant staff scientist in the organic chemistry department of the Weizmann Institute of Science. This lesson was given separately to the teachers, whereas the chemistry students had a different tutor. The follow-up lessons included three parts: The tutor answered students' questions and explained unclear issues that emerged after the lecture. Then the tutor gave more examples pertaining to the material that was taught in the lecture, and at the end of the lesson the tutor introduced new material in organic chemistry that supported the next lecture. The structure of each lesson was flexible, and it was changed each time according to the teachers' needs. The flexible structure of the follow-up is presented in Table 1. The tutor usually added more questions to the written exercise that was given by the lecturer.

## *4.3 Data Collection and Analysis*

The data that we were interested in referred to the main goal of the study, namely, determining whether the objectives of the three-step model were attained. The data consisted of a pre-post knowledge test, interviews with teachers, and an analysis of the posters (which were part of the course assignment), minutes of the course meetings, a lecturers' survey, based on the literature (Lawrenz, 2001), in which it was claimed that such instruments could be regarded as valid and reliable when administered and if the data were collected at times when a person's almost immediate response could be obtained.

The analyses of the interviews, the survey, and the minutes were done according to basic methods of qualitative data analysis (Glaser & Strauss, 1967; Tobin, 1995). We also used a pre-post knowledge test to examine the change in knowledge that the teacher underwent as a result of the course. In the following section we will elaborate on each analysis of the data collection.

### 4.3.1 Knowledge Test and Course Examination

The teachers completed a test assessing their knowledge at the beginning of the course and then again at its end. They were asked to give detailed explanations to items according to a list of basic concepts related to organic chemistry and to advanced concepts related to the course syllabus. We assumed that comparing the students' achievements in the pre- and post-knowledge tests would indicate the change in their conceptual understanding of basic organic chemistry as well as their understanding of the advanced organic course. The teachers' answers were graded as follows: 0 – wrong answer or no answer, 1 – partial answer, and 2 – full answer. At the end of each scientific course, the teachers took the regular course examination (together with the chemistry graduate students of the Weizmann Institute of Science), and these grades were part of their assessment.

### 4.3.2 Semi-structured Interviews with the Participating Teachers

Semi-structured individual interviews (about 60 min each) with all the teachers who participated in the program were conducted after the academic year was completed. Some of the questions were previously determined by the interviewer (Fontana & Frey, 1998) and others were more open-ended. (The interviewer was the second author of this chapter.) In the interviews, the teachers were asked to reflect on their learning experience during the academic year and were requested to describe their opinions regarding the three-step model. The interviews were audio-recorded, transcribed, and then analyzed by the second author of this chapter according to three main categories that emerged from the teachers' answers regarding the perceived model:

- The goals of each step
- The structure of the learning in the different steps
- The relationship and interactions with the lecturer, the tutor, and the teaching assistant

We also present their criticism and recommendations for the different steps.

#### 4.3.3 Minutes of the Course Meetings

The third author of this chapter wrote the protocol for the discussions held during the meetings involving all three steps. From reading the minutes, we could learn about the teachers' perceptions regarding their learning and their learning environment, as well as their specific difficulties. The minutes also helped us triangulate the data that were collected from the interviews and analyze the data according to issues that were revealed during the meetings. Moreover, the informal discussions between the teachers helped the researchers analyze the process of the poster production and evaluate the teachers' PK and PCK development.

#### 4.3.4 Lecturers' Survey

A questionnaire was administered to the lecturers and to the tutors after each course was completed. It consisted of three parts. The first part was aimed at determining to what extent the lecturers were aware of any differences between the teachers and the regular MSc students who attended the course at the Weizmann Institute of Science. In the second part, the lecturers were asked to describe whether they prepared special materials for the teachers. The third part consisted of their attitudes toward the three-step model.

#### 4.3.5 Poster Preparation and Poster Components

The posters were part of the course assignments; each teacher had to choose one of the course topics and produce a poster on that topic. These posters were supposed to help them teach the specific topic to their high school students. The teachers were guided by the course tutor and by the educational guide in (1) choosing a topic, (2) finding a component that was connected to students' everyday lives, and (3) integrating basic chemistry principles and concepts. The teachers presented their posters to their colleagues who participated in the program and received feedback before using the posters in class. The researchers (1) followed each step in the poster's creation, in order to determine how the teachers chose their topics, how they searched for additional data, and how they elaborated on it; and (2) analyzed the posters in order to determine how the teachers adapted the advanced knowledge to suit their students and, thus, how they used their subject matter knowledge and developed new pedagogical content knowledge (PCK) through the three-step model.

## 5 Findings

The findings are based on an analysis of (1) the knowledge test and the course examination, (2) the poster preparation/components, (3) the minutes, and (4) the teachers' interviews.

## 5.1 Research Question: How Did the Three-Step Model Enhance Teachers' Content Knowledge and Their Pedagogical Content Knowledge (PCK)?

The answers to this question are mainly based on the analysis of the knowledge test and the course examination, the minutes, and the poster components and their preparation.

### 5.1.1 Knowledge Test

Pre- and post-knowledge tests were administered before and after the course. Each knowledge test was divided into two parts: In the first part the teachers were asked to write an explanation of basic concepts in organic chemistry, which were not part of the course syllabus (e.g., "What is the connection between a base and a nucleophile?"). The second part included advanced concepts that were part of the course syllabus and were learned during the course (e.g., "Explain the following concept in organic chemistry – protection group."). The Wilcoxon signed rank test was applied to the overall difference between the average pre- and post-test scores, $p < 0.05$. The results show that in the post-test the students achieved average scores that were very close to the full answer (maximum), when they were asked about (1) the concepts that were discussed during the course, and (2) the basic concepts in organic chemistry. Another interesting observation was that there was no correlation between the pre- and the post-scores (i.e., the post-test scores were not related to students' pre-knowledge). Learning advanced concepts in organic chemistry influenced the teachers' understanding of basic concepts related to the high school curriculum in organic chemistry, even though they were outside the course's scope.

### 5.1.2 Course Exam

The average score of the teachers' examination in the course "Organic reactions used in the total synthesis of natural products" was 86.7. This average score was even higher than the average score of the chemistry graduate students at the Weizmann Institute of Science, who took the same course (and the same exam) with the teachers.

### 5.1.3 Posters

Although the teachers were guided in how to create the posters, they devoted much attention to planning them; namely, in defining (1) what should be included in them as advanced subject matter, (2) what basic concepts should the posters include, and (3) what kind of connections to everyday life should be made. The posters were also presented to other chemistry teachers' colleagues, in order to determine whether they could help the teachers in adapting the subject matter to their students. The teachers claimed that the comments and suggestions of their colleagues were taken into account in planning their lessons.

The analysis of the posters revealed that the teachers planned thoroughly the way that the posters' content could be adapted to high school students, who were the target population. The posters were esthetically created, and each issue was presented in a clear, short, and simple way, which could help the teachers better elaborate on the curriculum subject matter and enrich their students' knowledge. We suggest that these successful outcomes were to the result of the teachers' hard work in preparing the posters. They collected additional data, consulted the tutor in order to verify their scientific knowledge, asked for support from the educational tutor, presented them to their colleagues, collected feedback, and corrected their posters accordingly. The teachers actually elaborated on their subject matter knowledge and developed their pedagogical knowledge.

Another component that emerged from analyzing the posters was a "motivation component." The teachers invited the students to learn organic chemistry in order to be aware of future chemistry developments: "You are invited to be part of the work of organic chemistry researchers because the sky is the limit," "In order to fulfill the big potential of organic chemistry in the medicine industry, an in-depth understanding of the reaction mechanism is needed, and every year new students join this research community," and "If you think like a crime scene investigator you will be able to find a new way to prepare new organic compounds."

### 5.1.4 Minutes

The analysis of the minutes showed that the teachers gave each other comments regarding the students' previous knowledge, suggested connections to the chemistry curriculum, and even pointed out specific concepts that might not be clear to high school students.

## 6 Discussion

The three-step model was designed to support teachers in learning advanced scientific content and in making it part of their teaching repertoire, thus enhancing their pedagogical content knowledge (PCK). We can conclude that, for the most part, these goals were achieved. However, according to the teachers, there are many challenges that should be taken into account. In our discussion, we will refer to the challenges as well as to the contribution of the three-step model.

### 6.1 Challenges

During all three steps the teachers continuously requested that the course level and its demands be reduced. Given that all the lectures and the reading material were in English, the participating teachers felt quite intimidated at the beginning, but when the lecturers changed or the course level was reduced, the teachers again complained. These findings are in alignment with arguments that were raised by Schleicher (2009) in referring to dimensions of challenge and support, in order to describe successful changes in educational systems. He claimed that when teachers' ambitions are low and teachers and schools are poorly supported, nobody expects much. However, increasing the challenges by introducing new standards, new tests, new school inspections, publication of new school test scores, and so on without backing them up with better support often leads to conflict and demoralization. Among OECD countries, we have found that countless tests and reforms have resulted in increasing or decreasing school expenditures, and in devoting more or less attention to improving school standards, making classes larger or smaller, often without appreciable effects. On the other hand, strong support systems without clear plans tend to just strengthen schools that are already good while not raising performance systematically. Many of the best performing education systems combine challenge and support that characterizes the best-performing education systems.

The dimensions of challenge and support had to be carefully examined in each of the three steps of the model. Each of the three steps has a distinct role, structure, and unique learning environment. Although they are separate entities, each depends on the others and supports the others. To promote the success of the model, different connections among the steps are still needed: a connection involving the content and a connection between the lecturers.

The content of the tutorial should support the lecture's content without adding new content. The teachers expected the tutor to go over the material from the lecture with them. When the tutor introduced new content, the teachers did not have enough support and they had difficulties coping with the new lecture content.

### 6.2 Contribution of the Three-Step Model

We presented some evidence that the three-step model contributed to the teachers' knowledge, especially in the following aspects: the teachers' content knowledge, their pedagogical content knowledge (PCK), and the creation of a community of learners.

Based on the teachers' achievements in the course examination and their improvement on the knowledge test, we suggest that the model contributed to teachers' CK. The first two steps were directed at supporting the development of their CK, and the third step was aimed at converting CK to PCK. The analyses of the posters and the minutes showed that by mastering the subject matter knowledge and applying it to their requested assignment (the posters), the teachers also developed their pedagogy content knowledge. Interestingly, the teachers experienced each step differently. They used the third step (adaptation to education), which was carried out in small groups (with guidance) to solve the exercises that were given by the lecturer and the tutor during the first two steps. They claimed that the three-step model supported their conceptual learning and enhanced their understanding of the course (Henze et al., 2006; Munby et al., 2001). They were unable to connect the newly learned content to education until the last month of the course (Tuvi-Arad & Blonder, 2010). Nevertheless, when they managed to do so, they appreciated the contribution of the third step to their teaching profession and to their PCK (Marks et al., 2008).

A crucial contribution that emerged from the teachers' interviews was the creation of a "community of learners" (Bell & Gilbert, 1994; Mamlok-Naaman, Hofstein, & Penick, 2007). This occurred especially in the second and third steps, in which the teachers worked in small groups for two academic hours. The formation of such a community of learners contributed to their ability to implement their ability to cope with the demands of the program (Mamlok-Naaman et al., 2007), to their learning, and to their teaching, and as a result, it enhanced their PCK (Taitelbaum et al., 2008).

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# Practical Science Activities in Primary Schools in Malaysia

**Norita Mohamed, Mashita Abdullah, and Zurida Haji Ismail**

## 1 Research Background

The aspiration of the nation to become an industrialized society depends on science and technology. It is envisaged that success in providing quality science education to Malaysians from an early age will serve to spearhead the nation into becoming a knowledgeable society and a competitive player in the global arena. The science curriculum has been designed not only to provide opportunities for pupils to acquire science knowledge and skills, develop thinking skills and strategies, and to apply this knowledge and skills in everyday life, but also to inculcate in them noble values and the spirit of patriotism (Curriculum Development Centre, 2005).

In providing pupils with opportunities to develop their science process skills, thinking skills, and creativity, they should be given ample opportunities to engage in scientific investigations through hands-on activities and experiments. Practical science activities are a vital part of science teaching because they provide students with laboratory experiences where they can interact directly with materials, using tools, models, data collection techniques, and theories of science (National Research Council, 2006). However, these experiences are not sufficiently provided in most primary schools for several reasons: cost, safety, waste disposal, and teacher preparation. Many science teachers appear to discount the value of laboratory experiences when faced with the realities of organization, materials procurement, time constraints, and lack of familiarity with investigative approaches to laboratory instruction.

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Primary science practical work is conducted in science resource rooms. There are no science laboratories provided; most of the Malaysian primary schools only have science resource rooms. This room provides all science resources for teaching and learning activities, such as microscopes, magnifying glasses, magnets, and basic science glassware. The set-up of the room is like an ordinary classroom, which is not convenient for the pupils to conduct science activities, especially using glassware and other science apparatus. Students and teachers are often fearful about working with expensive and breakable glassware and equipment. Thus, apparatus that are simple and convenient need to be used to conduct the primary science activities because most of the skills and abilities involve procedures that, to some extent, require materials and apparatus.

This study reported on the status and problems in primary practical science activities through a survey conducted with primary science teachers teaching science and on the feasibilities of using a microscience approach for the primary level.

## 2 Primary Science Curriculum in Malaysia

The aims of the primary school science curriculum are to provide opportunities for pupils to learn about themselves and the environment through everyday experiences and scientific investigations, to acquire knowledge and skills in science and technology and to enable pupils to apply their knowledge and skills based on scientific attitudes and noble values to make decisions and solve problems in everyday life (Curriculum Development Centre, 2003). The curriculum also aims to provide a strong foundation in science and technology to prepare pupils for the learning of science in secondary schools. The curriculum contents for years 4–6 are organized around five themes, which include investigating living things, force and energy, materials, the earth and the universe, and technology.

The objectives of the science curriculum for primary schools include (Curriculum Development Centre, 2003):

1. Stimulate pupils' curiosity and develop their interest about the world around them.
2. Provide pupils with opportunities to develop science process skills and thinking skills.
3. Develop pupils' creativity.
4. Provide pupils with basic science knowledge and concepts.
5. Provide learning opportunities for pupils to apply knowledge and skills in a creative and critical manner for problem solving and decision making.
6. Inculcate scientific attitudes and positive values.
7. Foster an appreciation for the contributions of science and technology towards national development and the well-being of humankind.
8. Be aware of the need to protect and care for the environment.

**Fig. 1** Primary microscience kit

An effective way to achieve such objectives is by conducting science practical work. Part and parcel of learning science is conducting practical work. It would be hard for students to imagine and describe phenomena that did not involve practical work.

Microscience is an alternative approach to overcome some of the problems associated with conducting practical work in the science classroom. Microscience provides hands-on activities and personal experiences for students using reduced amounts of substances and miniature labware that is plastic based and safer than glass. The primary microscience kits from the Centre for Research and Development in Mathematics, Science and Technology Education (RADMASTE), South Africa, are designed to be easy to use, robust, and versatile. With the microscale approach, students can do experiments safely and at a lesser cost. Most of the components in the kit are plastic based, such as the microspatula to transfer solids, the hand lens that serves as a magnifying glass, the propette and syringe to transfer liquids, the filter funnel, the petri dish as a specimen container, the bulb and bulb holder for electricity experiments, and the comboplate and vials as a container and a microburner for heating (RADMASTE, 2006). Figure 1 shows components of the primary microscience kit:

## 3 Methodology

The survey on the status and problems of practical science activities in primary schools was carried out with urban and rural schools from two states in Malaysia (Perak and Penang). A total of 78 primary science teachers responded to the survey out of 80 questionnaires that were sent out to the schools. The questionnaire consists of items to survey the teachers' background in terms of gender, qualifications, position, race, and their experience in teaching primary science, as well as items based on science practical activities in years 4, 5, and 6 (list of experiments). Teachers were asked to categorize the listed practical activities into the following: conducted individually (I), conducted in a group (G), by demonstration (D), and not conducted at all (N). Open-ended questions were also asked to elicit the teachers' comments on:

- Whether or not the objectives of conducted experiments were achieved
- Importance of chemistry experiments
- Why were experiments conducted by demonstration?
- Why were experiments not conducted at all?
- Problems faced during the laboratory period

The questionnaire was administered by mail and teachers were asked to return their responses to the researcher in a week's time.

For the purpose of studying the feasibility of using a microscience approach, the trials of the experiment were conducted based on the primary science curriculum for years 4, 5, and 6 (Curriculum Development Center, 2005, 2006). Trials of experiments were conducted using the Microscience Kit (RADMASTE, 2004), which is basically made up of plastic equipment. Before the trials, the survey was conducted on the syllabus to check the suitability of incorporating the microscience concept into the Malaysian primary science syllabus.

## 4 Findings and Discussion

The **t**eachers' background information is presented in Table 1. Data showed that most of the teachers were from rural schools and a majority of them were female. In terms of qualifications and experience, most of them had more than 5 years of experience in teaching science, had at least a diploma, and were the subject specialist in their respective schools. The teachers' background showed that they were appropriate respondents for this research.

**Table 1** Teachers' background

| Biodata | | % | Biodata | | % |
|---|---|---|---|---|---|
| School location | Urban | 38.96 | Qualification | Diploma | 55.26 |
| | Rural | 61.04 | | Degree | 43.42 |
| Gender | Female | 72.72 | | Masters | 1.32 |
| | Male | 27.27 | Race | Malay | 76.32 |
| Experience (years) | <5 | 5.48 | | Chinese | 15.79 |
| | 1–5 | 21.92 | | Indian | 7.89 |
| | 6–10 | 27.39 | Position | Senior Teacher | 3.95 |
| | 11–15 | 23.29 | | Subject Head | 63.16 |
| | >15 | 21.39 | | Subject Teacher | 34.21 |

**Table 2** List of experiments in year 4 primary science syllabus

| Topics and experiments / Percentage of samples (%) | I (%) | G (%) | D (%) | N (%) |
|---|---|---|---|---|
| 1. Living things have basic needs | | | | |
| Finding out if food is a basic need of animals | 9.35 | 54.66 | 17.33 | 18.66 |
| Finding out if water is a basic need of animals | 8.00 | 53.33 | 16.00 | 22.66 |
| Finding out if air is a basic need of animals | 9.21 | 55.27 | 14.47 | 21.05 |
| Finding out if water is a basic need of plants | 11.68 | 72.72 | 11.68 | 3.89 |
| Finding out if air is a basic need of plants | 9.09 | 70.13 | 9.09 | 9.09 |
| Finding out if sunlight is a basic need of plants | 9.21 | 80.26 | 7.89 | 2.63 |
| 2. Living things undergo life processes | | | | |
| Finding out if exhaled air contains less oxygen than inhaled air | 25.67 | 17.57 | 31.08 | 25.67 |
| Observing the harmful substances produced when a cigarette is burned | 5.40 | 24.22 | 50.00 | 20.27 |
| Studying the response of plants to water | 6.67 | 65.23 | 20.00 | 8.00 |
| Studying the response of plants to gravity | 4.00 | 65.23 | 22.67 | 8.00 |
| Studying the response of plants to light | 6.67 | 69.23 | 20.00 | 4.00 |
| Studying the response of plants to touch | 38.67 | 37.23 | 20.00 | 4.00 |
| 3. Animals and plants protect themselves | | | | |
| Finding out the type of plant that can survive in a dry habitat | 14.08 | 26.76 | 16.90 | 42.25 |
| 4. Measurement | | | | |
| Studying whether the dripping of water repeats uniformly | 10.28 | 59.74 | 29.87 | 0.00 |
| Studying whether the swinging of a pendulum repeats uniformly | 7.79 | 70.12 | 22.07 | 0.00 |
| Studying whether the human pulse repeats uniformly | 64.93 | 25.97 | 9.09 | 0.00 |
| 5. Properties of materials | | | | |
| Testing and finding out the ability of different materials to allow light to pass through | 15.58 | 61.03 | 23.27 | 0.00 |
| Testing and finding out the ability of different materials to keep things cold | 2.59 | 63.34 | 24.87 | 9.09 |
| Testing and finding out the ability of different materials to keep things hot | 2.59 | 55.84 | 31.16 | 10.29 |
| Showing that a layer of air trapped between two insulators of heat is an effective way to keep things hot | 1.32 | 40.78 | 34.21 | 23.68 |
| Testing whether water is a factor that causes rusting | 3.89 | 77.92 | 14.28 | 3.89 |
| Testing whether air is a factor that causes rusting | 5.26 | 80.26 | 10.53 | 3.95 |
| 6. The Solar System | | | | |
| 7. Technology | | | | |

Tables 2, 3, 4 show the list of experiments in years 4, 5, and 6 and give a percentage of how the experiments were conducted: individually (I), by groups (G), as demonstration (D), or not conducted at all (N). The results show that among all the year 4, 5, and 6 experiments, about 85% (44 expts) were conducted in groups (2 or more), 7.7 % (4 expts) were shown as demonstrations, 3.8% (2 expts) were

**Table 3** List of experiments in year 5 primary science syllabus

| Topics and experiments / Percentage of samples (%) | I (%) | G (%) | D (%) | N (%) |
|---|---|---|---|---|
| 1. Microorganisms | | | | |
| Finding out whether yeasts breathe | 12.82 | 71.79 | 10.26 | 5.13 |
| Showing that microorganisms reproduce and grow | 19.48 | 58.44 | 14.28 | 7.79 |
| 2. Survival of the species | | | | |
| 3. Food chain and food web | | | | |
| 4. Energy | | | | |
| 5. Electricity | | | | |
| Comparing the brightness of bulbs in parallel and series circuits | 9.21 | 84.21 | 6.57 | 0.00 |
| Studying the effect of placing the switches in various positions in parallel and series circuits | 3.89 | 76.62 | 14.28 | 5.19 |
| 6. Light | | | | |
| Finding out how light travels | 15.58 | 63.63 | 19.48 | 1.29 |
| Finding out the factors that affect the size of an object's shadow | 3.89 | 71.42 | 24.67 | 0.00 |
| Finding out whether the shape of the shadow depends on the position of the light source | 5.19 | 63.63 | 29.87 | 1.29 |
| Finding out whether the shape of the shadow depends on the position of the object of the shadow | 5.19 | 67.53 | 27.27 | 0.00 |
| 7. Heat | | | | |
| Studying what happens when things absorb or lose heat | 6.57 | 64.47 | 25.00 | 3.95 |
| Studying the temperature of things when they gain or lose heat | 6.57 | 68.42 | 23.68 | 1.32 |
| Studying the effect of heat on things | 3.95 | 60.53 | 30.26 | 5.26 |
| Studying the effect of cooling on things | 2.63 | 61.84 | 30.26 | 5.26 |
| 8. States of matter | | | | |
| Studying the effect of the surrounding temperature on the rate of evaporation | 3.89 | 53.25 | 29.87 | 12.98 |
| Studying the effect of air movement (wind) on the rate of evaporation | 1.29 | 40.26 | 36.26 | 22.07 |
| Studying the effect of the size of the surface area of liquids on the rate of evaporation | 6.49 | 54.54 | 27.27 | 11.68 |
| 9. Acids and bases | | | | |
| Using litmus paper for testing | 37.66 | 58.44 | 3.89 | 0.00 |
| Finding out the properties of acidic, alkaline, and neutral substances | 24.67 | 68.83 | 5.19 | 1.29 |
| 10. Constellation | | | | |
| 11. The earth, the moon, and the sun | | | | |
| Finding out the direction that the earth rotates in | 3.95 | 23.68 | 59.21 | 13.16 |
| Studying what causes day and night | 4.00 | 22.67 | 58.67 | 14.67 |
| 12. Strength and stability | | | | |
| Studying the effect of the base area on the stability of objects | 5.26 | 72.26 | 21.05 | 1.32 |
| Studying the effect of height on the stability of objects | 6.57 | 68.42 | 22.27 | 2.63 |
| Studying the strength of different materials | 4.05 | 62.16 | 24.32 | 9.46 |
| Studying whether the way materials are placed will affect their strength | 4.00 | 61.33 | 18.67 | 16.00 |

**Table 4** List of experiments in year 6 primary science syllabus

| Topics and experiments / Percentage of samples (%) | I (%) | G (%) | D (%) | N (%) |
|---|---|---|---|---|
| 1. Interaction among living things | | | | |
| Investigating the effects of competition in animals | 18.18 | 42.85 | 14.28 | 24.67 |
| Investigating competition among seedlings | 29.48 | 65.38 | 3.85 | 1.28 |
| 2. Force | | | | |
| Studying what is force | 35.89 | 43.59 | 19.23 | 1.28 |
| Studying the effect of different surfaces on the movement of an object | 7.69 | 80.77 | 10.26 | 1.28 |
| 3. Movement | | | | |
| 4. Food preservation | | | | |
| Studying the growth of mucor | 23.68 | 59.21 | 7.89 | 9.21 |
| 5. Waste management | | | | |
| 6. Eclipse | | | | |
| 7. Machine | | | | |
| Investigating the effects of the height of an inclined plane on the effort taken to perform a task | 10.26 | 57.69 | 16.67 | 15.38 |
| Investigating the effects of machines on our daily activities | 7.89 | 35.53 | 35.53 | 21.05 |

conducted individually, and 3.8% (2 expts) were not conducted at all. This indicates that most of the experiments in years 4, 5, and 6 were conducted in groups. About 88% of the teachers agreed and 12% disagreed that objectives of science activities had been achieved and a majority of the teachers agreed on the importance of practical science activities. This indicates that most of the teachers agreed and realized the importance of science activities in enhancing science learning of students.

Teachers' responses about why experiments were conducted as demonstration or not conducted included:

- Time constraints (30%)
- Experiments are dangerous (27%)
- Apparatus provided is not enough for the students to do it individually or in groups (24%)
- Difficulty in controlling the students in the laboratory (10%)
- Most students were not confident enough to do experiments themselves (9%)

Problems faced by teachers during the laboratory period included:

- Not enough apparatus
- Insufficient time to complete activities
- Too many students in one class
- No assistants for preparation and cleanup
- Difficult to handle the students
- Students require teachers' assistance
- Poor-quality apparatus
- Resource room not conducive for activities

**Table 5** Topics in Malaysian primary science syllabus

| Year 4 | Chapter | Title | Convert to microscale |
|---|---|---|---|
| | 1 | Living things have basic needs | |
| | 2 | Living things undergo life processes | |
| | 3 | Animals and plants protect themselves | |
| | 4 | Measurement | |
| | 5 | Properties of materials | ✓ |
| | 6 | The solar system | |
| | 7 | Technology | |
| Year 5 | 8 | Microorganisms | ✓ |
| | 9 | Survival of the species | |
| | 10 | Food chain and food web | |
| | 11 | Energy | |
| | 12 | Electricity | ✓ |
| | 13 | Light | |
| | 14 | Heat | |
| | 15 | States of matter | |
| | 16 | Acids and bases | ✓ |
| | 17 | Constellation | |
| | 18 | The earth, the moon, and the sun | |
| | 19 | Strength and stability | |
| Year 6 | 20 | Interaction among living things | ✓ |
| | 21 | Force | |
| | 22 | Movement | |
| | 23 | Food preservation | ✓ |
| | 24 | Waste management | |
| | 25 | Eclipse | |
| | 26 | Machines | |

In conclusion, most of the experiments were conducted in groups. One of the main problems in conducting science activities was the time constraints for such classes. Although there are problems in the science activities, all the teachers agreed that science practical work is important for students.

Table 5 shows the topics covered for primary science years 4, 5, and 6 for the Malaysian primary science syllabus. Topics for which the microscience approach could be incorporated have been checked and include: Properties of materials, Microorganisms, Electricity, Acids and bases, and Interaction among living things. The microscale approach was deemed not suitable for the suggested practical activities in a majority of the topics in the primary science syllabus. However, other microscience activities for such topics could be developed and adopted. To date, trials have been conducted for the topics of electricity and acids and bases because of their importance and suitability to be conducted with the microscale approach.

## 5 Electricity

This topic involved series and parallel circuits, which require the pupils to recognize components in the circuit such as dry cells, bulb, wire, and switch and to know their functions. The activity involved in this topic includes comparing the brightness of a bulb in the parallel (Figs. 2 and 3) and series circuits (Figs. 4 and 5). Traditionally, this activity is conducted in groups of three or four students. This activity can be done individually and successfully with the microscale technique.

**Fig. 2** Parallel circuit in traditional set-up

**Fig. 3** Parallel circuit in microscale set-up

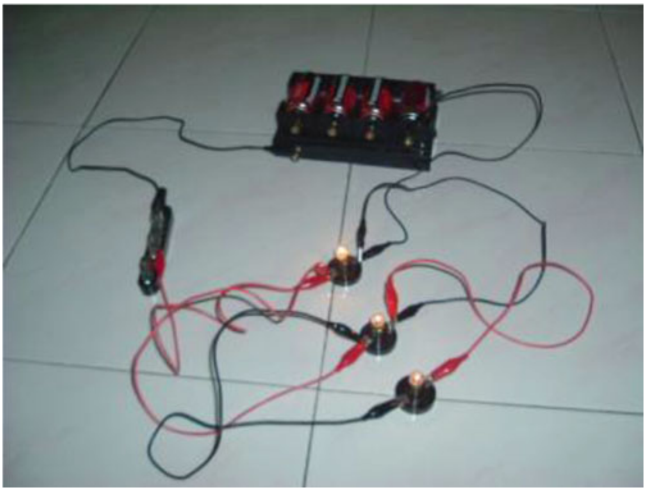

**Fig. 4** Series circuit in traditional set-up

**Fig. 5** Series circuit in microscale set-up

## 6 Acids and Bases

This topic involved the properties of acidic, alkaline, and neutral substances that require pupils to recognize acidic, alkaline, and neutral substances and how to test these properties using litmus paper. Traditionally, this activity is conducted using plates or test tubes (Fig. 6), whereas in the microscale set-up, the comboplate is

**Fig. 6** Properties of substances in traditional set-up

**Fig. 7** Properties of substances in microscale set-up

used (Fig. 7) as a container instead of test tubes. The microscience approach can significantly reduce the amount of substances used since only drops of substances are required.

Both activities can be done successfully with the microscience approach because this technique promotes significant reduction of substances. This approach also promotes hands-on experiences that allow pupils to conduct the activities individually. Hence, the objectives in conducting science activities such as development of scientific skills, process skills, and manipulative skills among the pupils can be achieved using this approach.

## 7 Conclusions and Implications

Most of the practical science activities for Malaysian primary schools have been conducted in groups. The microscale approach can be a solution for teaching and learning science in the Malaysian primary science curriculum because it is robust, versatile, safer, easier, and less expensive. This is beneficial for the student and convenient for the teacher because it is self-contained, compact and easily stored, and portable. This technique can increase students' interest in science concepts because they can do experiments individually and experiments can be readily repeated.

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# Teaching Chemistry Effectively with Engineering Majors: Teaching Beyond the Textbook

**Yermesha Kyle, Stephen Bacon, Amber Park, Jameka Griffin, Raicherylon Cummins, Raymond Hooks, Bailu Qian, and Hua-Jun Fan**

## 1 Background of the Research

Many students classify chemistry as one of the tougher science courses they must pass, even though chemistry, a science central to technology and engineering fields in many ways, is an easy subject to apply to real life. The examples and applications of chemistry are abundant and unavoidable in everyday life. For example, an understanding of fundamental chemistry concepts is required to solve the oncoming energy crisis, to develop environmentally friendly methods of production and waste management, to detect biological weapons in real time, to develop better pharmaceutical drugs, and to design newer functional nano-materials. Therefore, chemistry, along with other science courses such as physics and math, is usually woven into the university core courses that almost all incoming freshmen are required to take and pass. Depending on the major and classifications, most campuses will have a chemistry course for students majoring in non-science-related subjects such as nursing, technology, or engineering (CONFCHEM, 2004). Because the needs and the purposes of these courses are different at various campuses, there is no universal curriculum for them. However, not only do these non-science majors fail to consider chemistry as a significant contribution to their knowledge and/or to their majors, most of them are not well prepared to tackle the tasks and requirements in these science courses. To make the matter worse, the College of Engineering (CoE) at PVAMU recently requested that the chemistry credit hours be reduced to one semester. To better assist students to overcome their anxiety and frustration with chemistry and meet the requirements from CoE, a team of a professor and undergraduate students made changes to the contents and teaching approaches of chemistry for engineering courses. The survey data was collected as a part of course evaluation.

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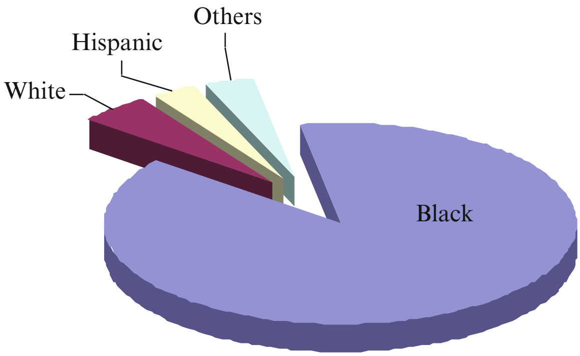
The teaching format was fine tuned according to the response from students and outcome of exams.

This research took place at Prairie View A&M University (PVAMU), which is one of 105 historically black colleges and universities (HBCU) in the United States (U.S. Department of Education, n.d.). PVAMU is part of the Texas A&M University System (TAMUS) and a land grant institution. The average enrollment at PVAMU for the past 5 years has been 90% African American students (see figure above). Like many other HBCUs in the United States, the science program at PVAMU faces its own share of challenges in recruitment and retention of students for various reasons. In particular, the poor performance of freshmen students in science courses led to a high rate of attrition and low number of science graduates at PVAMU. In return, the high attrition rate in these science gateway courses reinforces the perceptions of science as a difficult major among non-major students. Our survey of faculty and students clearly indicated two major obstacles in students' science learning:

- The study habits or attitudes/perceptions in terms of performing regular course work, catching up with homework assignments, and attending regular review sessions hinder their desire to pursue science careers, and
- The weak high school science training and lack of training opportunities at high school that create emotional anxiety towards the science classes at college. As such, students' performance level does not match their capabilities.




This chapter describes efforts to prepare engineering majors for the upcoming sequential chemistry and engineering courses. The course delivery is particularly designed to distinguish between essential and optional materials, emphasize the core chemistry concepts, focus on the application of chemistry to the engineering fields, and limit course contents to the following types of information:

- key points/concepts of chemistry and their application in engineering
- especially hard-to-understand materials
- important materials not addressed in the readings
- examples and illustrations
- materials of high interest to students

Students were led from observation of phenomena to structural and chemical interpretation by emphasizing descriptive analysis of unique engineering problems, followed by chemical implication and analogies (McKeachie & Svinicki, 2006).

## 2 Literature Review

Studies showed that, from the students' perspective, all science courses, chemistry, physics, and math, were unwelcome for many non-majors because

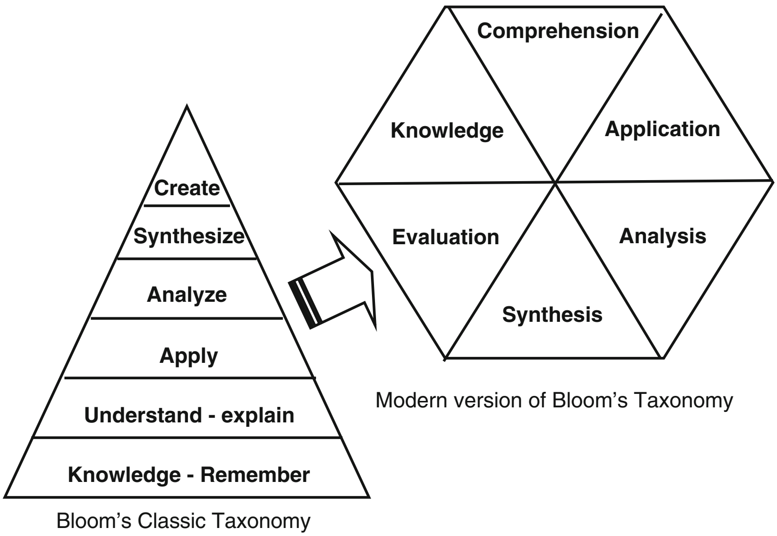
1. many non-science majors fear science and
2. students believe that such courses do not significantly contribute to their knowledge and/or to their majors.

On the other hand, these courses are also particularly challenging for professors who were assigned to teach these non-science courses because

1. the students were perceived to be less committed and
2. such teaching was viewed as step down from teaching majors because the students are indifferent and apathetic (Labianca & Reeves, 1987).

From the department's point of view, teaching non-major courses has long been considered the "science department's unwanted chore" (Schatz, 1982). However, these science requirements of the college curriculum are here to stay in order to train students to effectively deal with scientific and technical issues in their professions. Additionally, students don't realize these chemistry concepts are critical and important for them to successfully complete the Fundamentals of Engineering (FE) Exam, which is the first of two examinations that engineers must pass in order to be licensed as a professional engineer in the United States (NCEES, n.d.). With these two contradictory learning and teaching viewpoints between the non-majors and chemistry professors, there is a great need for the common ground, as well as compromises from both sides. Students must recognize that learning science is important to their professional development, and instructors must demonstrate to students the connection between science and its application to the engineering discipline.

Many studies suggest that good science instruction should start with well-drafted learning objectives and learning outcomes as one of essential tools for the success of the course and a guide for students' learning (National Research Council, 1997). Literature shows that learning objectives and learning outcomes follow more than two dozen taxonomies that have been developed to define the domains of learning, development, and cognition (Anderson & Krathwohl, 2001). However, most of them are based on Bloom's classic taxonomy developed in 1956 (Bloom, Engelhart, Furst, Hill, & Krathwohk, 1956) as shown in the diagram below. Whereas Bloom's classic *Taxonomy of Educational Objectives* defined six hierarchical levels of cognitive processing, (knowledge, understand, apply, analyze, synthesize, and create), a more modern version of Bloom's taxonomy is the non-hierarchical definition of learning (knowledge, comprehension, application, analysis, synthesis, and evaluation). Though the words used in these versions are similar, the approach to assisting students' learning is different. The classic hierarchical




approach assumes students progress gradually from the bottom up, while the non-hierarchical approach assumes students learn at all levels and from all aspects. These different learning skills develop concurrently, therefore training in these skills needs to be applied accordingly. There are other types of taxonomy such as foundational knowledge, application, integration, human dimension, caring, and learning how to learn (Fink, 2003). In this study, the objectives of the chemistry for engineering course were drafted by taking into account the concurrent approaches of learning (Fry, Ketteridge, & Marshall, 2003). Two levels of approach were adopted because (1) the surface approaches of learning include increasing knowledge, memorizing, and acquisition of procedures, and (2) the deep approaches of learning include abstraction of meaning and application.

Increasing amounts of research brought attention to a unique phenomenon that only emerged recently as technology advanced. Unlike previous generations, this new tech-savvy generation has too much technology in their hands, 24 hours a day, 7 days a week, causing a distraction from studies. It is imperative for educators to know where this new generation of students is and how to meet and bring them to the knowledge we intend to deliver. Educators must arm themselves with technology in order to teach effectively and deliver content at the students' level. While classroom teaching is still an important venue to educate students, the incorporation of social network concepts (see figure below from Facebook to myspace) into online learning and collaboration has yet to be achieved. Among the efforts, Web 2.0 was developed around 2004 as web sites and applications come together to foster interactive collaboration, user participation, and content sharing (Berger & Trexler, 2010). PowerPoint and colorful presentations are no longer enough for the demanding new generation of learners. Web 2.0 includes blogs, microblogs, wikis, social networks, tagging and bookmarking, online discussion boards, multimedia and file sharing, syndication, podcasts, and multi-user virtual environments (Anderson, 2007; Brown & Adler, 2008; David, 2007; Solomon & Schrum, 2007; Sreebny, 2007). A few existing proprietary classroom management systems such as WebCT, eCourses, and Blackboard Learning System, along with free web applications such as Moodle, were developed to help educators create effective online learning sites. Terminologies such as Course Management System (CMS), Learning Management System (LMS), or Virtual Learning Environment (VLE) are basically the same thing. There are many factors to consider when adopting the web-based applications, such as ease of use, security and privacy, data backup, intellectual property rights, support, and training. Because PVAMU adopted an eCourses platform campus-wide (now owned by Blackboard), chemistry courses have been developed around eCourses for course management and serve as a virtual learning environment. It includes assessment tools, homework assignments, calendar, chat and discussion boards, grade book, and peer-to-peer file sharing and multimedia sharing. The Office of Distance Learning has the capability of video streaming for big media files. It creates a personal learning environment that allows students to manage their academic work and progress online 24/7.

There are many published efforts and research has been invested in such endeavors to assist students' learning, and many of them are also available online, such as MIT's OpenCourseWare (MIT OpenCourseWare, n.d) and Process Oriented Guided Inquiry Learning website (POGIL, n.d.), which is a team research-based learning process. These websites are maintained by individuals, except those supported by funding agencies such as the National Science Foundation and/or private foundations. This work will develop, adopt, and implement these available modules with the consideration of students' learning styles and customization according to our students' academic developmental levels. Several approaches are used to assist students in learning chemistry: hands-on demonstration, technology concentrated

online learning tools, and POGIL learning modules. For example, college students need to be trusted to assume some responsibilities for teaching themselves and for teaching others. They would benefit from reflecting on what they have done and what they have learned. Under this vision, a team of undergraduate students and an instructor were assembled and worked together to introduce basic chemistry concepts and skills to freshmen engineering majors. The amalgamation of these approaches allows students to construct, visualize, and correlate the chemical concepts effectively, as well as with nanotechnology. This combination can tap into the current generation's maximum learning capability and allow for a better understanding of real-world applications of chemistry. These results and students' responses will be reported next.

## 3 Methodology

In order to meet the demands of science requirements for engineering majors, particular chemistry knowledge is needed. Examining a typical two-semester chemistry course, results show that topics needed by and of interest to engineering majors are normally included in the second semester of general chemistry. These concepts are critical for students to successfully complete the Fundamentals of Engineering (FE) Exam. Therefore, preliminary assessment of the current situation was carried out based on

1. choices of a suitable textbook with appropriate topics and available course materials;
2. alignment of course objectives with typical engineering needs such as Fundamentals of Engineering (FE) exam;
3. characteristics of students, particularly their learning styles and barriers; and
4. determination of the expectation of learning outcomes and the design of the lecture activities.

Because most chemistry textbooks are written for science majors with a two-semester layout and usually start with science-focused, atom-first approach, whereas most one-semester textbooks are for introductory or pre-health majors, these layouts did not fit well with the goals of the chemistry for engineering course, which assumes students have a basic chemistry background and are ready for more comprehensive chemistry knowledge and application in engineering. In addition, the existing *Chemistry for Engineering* textbook has little engineering perspective or applications (Landrum & Hormel, 2002). Based on students' feedback on the textbook and the demands from the College of Engineering at PVAMU, the decision was made by the team that extra activities would be designed/adopted and implemented to remedy the shortcomings of the textbook.

In order to help students to achieve the learning objectives, the guideline from the Process Oriented Guided Inquiry Learning (POGIL) framework was modified and implemented to form study groups among students. This approach was adopted based on (1) the pr-requisite requirement of the course and (2) to foster collaboration and teamwork. Not all students registered for this course had the basic chemistry knowledge needed to successfully finish the class. The POGIL approach would help students form a group to study and learn together inside and outside of the classroom. Furthermore, the present-day workplace requires teamwork because of the increasing complexity of the tasks. Researchers have identified many benefits to students working in small groups. Students tend to learn more and demonstrate better retention, are more satisfied with their classes, and experience a sense of shared responsibilities (Astin, 1993; Barkley, Cross, & Major, 2004; Pascarella & Terenzini, 2005; Prichard, Stratford, & Bizo, 2005).

In order to properly manage the students' learning profiles and promptly provide students with feedback on their progress, the eCourses platform (formerly known as WebCT) was implemented, along with an online homework system provided by the publisher. A survey to assess students' learning outcomes in the chemistry for engineering class was conducted at the end of the semester. The results are reported here.

## 4 Findings and Discussion

The chemistry for engineers course was instituted in spring 2009 upon the request of the College of Engineering at PVAMU. Engineering majors are usually required to take a two-semester chemistry course along with other science majors. In the revised degree plan installed by the College of Engineering at PVAMU, the required chemistry credit was slashed by half and reduced to one semester. As such, the course demands students to have some basic chemistry knowledge and basic math skills before they can be placed in this class. Considering a typical engineering student's hands-on learning styles, listening to lectures and note-taking would only take students so far in their academic and intellectual development. Furthermore, the authors believe higher education should train students to develop the analytical skill and capacity for higher-order thinking besides transmission of information. Below we report the results from activities installed in the chemistry for engineering course from the past three semesters. The results are based on the observations and surveys from these two categories: (i) teamwork and collaborative learning and (ii) the computer-based learning system.

### *4.1 Teamwork and Collaborative Learning*

As stated earlier, teamwork has become one of the buzzwords in the current job market, mainly because ever-increasing and complicated projects demand team effort. In response to this demand, we are interested in training students to work together, to develop interpersonal skills, and to learn to compromise in order to achieve win-win outcomes and project goals. In the past three semesters, the research team had students form three types of study groups in order to find out which format produced the best team efforts and learning outcomes:

1. limited-size group (typically four students per group) by themselves,
2. limited-size group around the appointed group leader, and
3. no-size limitation group around the appointed group leader.

According to POGIL style learning, each group will have a designated group leader/facilitator, a recorder, a reporter, and the rest are members/participants. The group leader sets the pace to allow full participation and coordinates the group activities from study schedule to distributing the assignment subtasks. The recorder records the group members' answers to allow the reporter to submit the answers to the class as requested. Therefore, there is no need for everyone to speak in the group. Because each member of the limited-size group was self-elected, students tended to work with students they were familiar with or already knew, which is not necessarily the best combination for the roles designated. Additionally, because students in the group already knew each other, they tended to slack off in the later part of semester. To remedy the situation, the group leader was selected based on academic performance, with the assumption that good academic performance will serve as a good role model and bring more responsibility. This "appointed group leader" style worked slightly better than the self-elected mode because it also spread out academically strong and weak students to ensure everyone's participation and progress.

We found that small, self-managed groups of students work best for producing team effort. The appointed team leader format worked well with student members who possess enough chemistry background; otherwise, the team seemed to be a one-person effort. It is critical to use specially designed activities that tailor the team's efforts and generally follow the learning cycle paradigm. Nevertheless, all the team formats produced promising learning outcomes and students mastered course content, as well as developed process skills. The role of the instructor in this setup was that of a facilitator to push the students' progress forward, especially in a stalled session. It is important to point out that the instructor here should play a more supportive than directive supervisory role, which is a different role from traditional classroom teaching. Such a role is important for the instructor to realize in order to allow students to develop the teamwork concept and interpersonal skills. Student surveys revealed the only time they learned teamwork is when there were difficulties encountered during the session, such as schedule conflicts, unexpected situations, deviations from the task, and challenges to team members. Through compromise and good leadership skills, every member was able to refocus and accomplish the project goals.

## *4.2 The Computer-Based Learning System*

Homework is an important component of students' learning because it provides the opportunity for students to reinforce concepts and allows hands-on practice and self-assessment. In the traditional homework setup, homework is assigned as paper and pencil-based and hand graded. This is a labor-intensive and time-consuming process. With the advancement of technology, classrooms are increasingly adopting web-based and algorithm generated homework systems (Bonham, Deardorff, & Beichner, 2003; Demirci, 2007; Woolf, Hart, Day, Botch,

**Table 1** The top nine reasons students favor computer-based learning systems

| | |
|---|---|
| The instructions for online homework and eCourse tests were easy to follow and use | 3.81 |
| Getting immediate result and feedback from online homework system motivated me | 3.81 |
| Doing homework online is a more modern approach than traditional paper and pencil | 3.79 |
| The online test is appropriate and convenient for test taking | 3.76 |
| Online homework provides me with more responsibility in managing my time | 3.60 |
| Student progress and results can be easily achieved via online homework system | 3.43 |
| The online homework helped me to prepare for exams | 3.36 |
| I want to continue taking homework online for the second part of chemistry | 3.31 |
| I prefer taking homework online | 3.31 |

**Table 2** The top eight reasons students dislike computer-based learning systems

| | |
|---|---|
| I do not want to take any homework/test online | 2.17 |
| The way in which the online homework is evaluated scares me | 2.55 |
| Taking homework online can NOT be easily controlled | 2.64 |
| Doing homework online has disadvantages for me | 2.69 |
| I had some difficulties getting access to a computer and/or internet | 2.71 |
| At the beginning I am frustrated with just getting the computer to take my answer | 2.93 |
| I know I got the right answer but computer wouldn't take it | 2.95 |
| The technical difficulty necessary reduced my score | 3.31 |

& Vining, 2000). Instead of giving the wrong and correct answers, the new homework system actually gives the step-by-step explanation, and in some cases even acts as tutor and based on a database of previously collected students' responses the system can use pattern and correlation to guide students through the problem solution. As an example, the top nine reasons students prefer computer-based learning systems are shown in Table 1.

These results were based on a survey given at the end of each semester. The sample size was 42 and students were asked to rate each question by giving 5 as the most favored score and 1 as the least favored. Among the top favored reasons, the convenience, availability, and feedback from such a system ranked high on the list. Most of the students found that such a system helped them study and perform better on exams. However, frustration also existed as computers might refuse to accept a correct answer simply because it was in the wrong format. The table below shows students' top eight reasons for disliking computer-based learning systems.

Table 2 shows that one of the main reasons for the dislike of computer-based learning systems is the availability of computers and the complicated evaluation scheme that is available to the instructor. At PVAMU many students receive financial support, which means some students cannot afford a computer at home. This forces them to study at school or the library instead of at their convenience.

Table 3 summarizes the survey of students' perceptions of traditional class lecturing, the online homework learning system, and in-class, hands-on exercises. The sample size was 78. Not surprisingly, the traditional class lecture was ranked the

**Table 3** Student opinion survey on in-class lectures, online homework learning system and in-class hands-on exercises

| | A great deal/a lot (%) | Somewhat (%) | A little/not at all (%) |
|---|---|---|---|
| Class lectures | 40 | 29 | 31 |
| Online homework | 53 | 24 | 23 |
| Hands-on | 68 | 19 | 13 |

lowest. Only 40% of students found classroom lecturing to be greatly helpful. Twenty-nine and thirty-one percent, respectively, ranked it as "somewhat" and "little or no help at all." The preference toward the online homework learning system inched up a little bit, with 53% of students rating it as "A great deal or a lot," versus 24% as "somewhat" and 23% as "little" or "no help" in their learning process. The percentile of students favoring the in-class, hands-on exercises are higher where 68 and 19% of students found the in-class, hands-on exercise helps their learning, and only 13% students felt unsatisfied with the hands-on exercise. These results strongly suggest that students prefer the hands-on exercises and online homework learning system over the traditional lecture style of learning.

## 5 Conclusion and Implications

Results from the newly implemented teaching strategies in this chemistry for engineering course suggest that combining the POGIL strategy, online homework, and hands-on exercises greatly helped our students in studying chemistry and developing the learning skills and peer collaboration skills. Through the three semesters of teaching and comparisons with books used with other general chemistry classes, we found that it was important to consider not only the quality of the content but also of the cost when making the textbook choices for the class. Additionally, it was necessary to consider the scope of the topics, level of difficulty, and students' interest. The ideal textbook should challenge students but should not be too difficult (Boyd, 2003). Most students preferred that the textbook have more practice questions.

For optimal learning experiences and outcomes, it is necessary to limit the group size, (e.g., four students per group), for the hands-on and group study. This greatly reduced the "idle" group members and freeloaders. Furthermore, the group study setup should occur in the early part of the semester rather than later so students have more time to get to know each other, become familiar with each other's different learning styles, and find the common ground for the group to meet and study. It is recommended to start with a short and easy group project as an icebreaker. Other things to consider are the time constraints for and differences between resident students and commuting students.

It is also important to make the expectations clear for the course, group project, and hands-on exercises. We found it is beneficial to emphasize to students not only the contents of each activity related to the course but also the development of processing skills (teamwork) and interpersonal skills (leadership and compromise). This could reduce the attrition rate in the group and enhance the learning outcomes.

It is understandable that extra time is needed initially for preparation of such a course, including course design and implementation of the learning objectives, preparing extra questions for students to practice, and design and validate the hands-on exercises. We discovered that in the group study session, the instructor should play a more supportive than directive role. Also, the instructor must know when to stop the group discussion and redirect the focus of the project. For future studies we would like to also incorporate self-evaluations, group evaluations, and peer evaluations into the study. These evaluations could provide valuable information and help students to better understand how they see themselves, through peer and group settings.

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# Problem-Based Learning as an Approach to Teach Cell Potential in Matriculation College, Malaysia

**Kai-Li Teh and Nooraida Yakob**

## 1 Introduction

With the development of science and technology, science subjects such as chemistry are no longer limited to rote learning by students. As stated by Bailey and Garratt (2002), chemistry students need a knowledge base, an understanding of the key principles, some special subject-specific skills (such as lab skills), an ability to solve problems and think critically, and a range of transferable skills. For Silverman (cited in Silverman, 1996), science subjects should be taught in a way that more closely resembles science as it is done by professional scientists. By doing this, students will develop their own understanding of what they have learned. Therefore, chemistry teachers should change their teaching approach to make it more learner centered. For that reason, active learning in chemistry education is suggested.

Active learning is a type of learning that involves students actively in the class. According to McKinney (2010) and Bonwell and Eison (1991), in active learning, students do more than simply listen to the lecture. Active learning involves activities such as exploring, analyzing, communicating, creating, reflecting, and actually using new information or experiences – involving students in doing things and thinking about what they are doing (Bonwell and Eison, 1991). Bonwell and Eison (cited in McKinney, 2010) state that some characteristics of active learning are:

> Students are involved in more than listening, less emphasis is placed on transmitting information and more on developing students' skills, students are involved in higher-order thinking (analysis, synthesis, evaluation), students are engaged in activities (e.g., reading discussing, writing), and greater emphasis is placed on students' exploration of their own attitudes and values. (p. 2)

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Thus, science teachers should modify their lectures by integrating active learning strategies in their teaching by using the problem-based learning (PBL) approach. PBL is a new model in higher education for training in schools and universities (Laquesta, Palacious, & Fernandez, 2009).

In Malaysia, between schools and universities, we have a preparatory program that is known as the Matriculation Programme. The Matriculation Curriculum is formulated in line with the concept of the Matriculation Programme and the National Education Policy for qualified Malaysian Certificate of Education students (or better known as Sijil Pelajaran Malaysia, a national examination taken by all fifth-year secondary school students) to pursue tertiary education at institutions of higher learning within Malaysia and overseas in the field of science, technology, and accounting. This curriculum is designed to be a bridge for students to embrace the first-year university curriculum for the respective courses (Matriculation Division Ministry of Education Malaysia, 2006). Hence, educators need to find ways to improve students' problem-solving abilities in order to achieve better academic results among Matriculation students and to succeed in their tertiary education.

PBL, one of the approaches to constructivism, can improve students' academic achievement, problem solving skills, and capability in order to prepare them to compete in the global market. Although research on PBL has been conducted at the university level, especially in medical education, it is still limited in the middle and high school level science classes (Tarhan & Acar, 2007). Studies of PBL implementation in middle and high school should be increased because the process of improving any skill takes time to show results. More research on PBL should be carried out in elementary, high school, and preparatory programs to investigate how PBL can improve students' construction of knowledge. Therefore, this study tries to investigate the effectiveness of PBL in matriculation students' learning of cell potential.

## 2 Problem-Based Learning (PBL)

According to the Office of Instructional Consulting, School of Education, Indiana University Bloomington (2000), PBL is a strategy based on constructivist learning theory that simultaneously develops both problem-solving strategies and disciplinary knowledge bases and skills by placing students in the active role of problem solvers. In the original version of PBL, Barrows and Tamblyn (1980), PBL was described as a method to enhance students' achievement of application of problem solving in new and future situations, collaboration in a group, identification of learning weaknesses and strengths, and promotion of self-directed learning (SDL). Schmidt (as cited in Gürses, Açıkyıldız, Doğar, & Sözbilir, 2007) wrote that PBL is an approach that focuses on problem analysis, SDL, and knowledge application. This approach has been used to build content knowledge and develop skills such as teambuilding, problem solving, and communication skills (Tan, 2008).

The PBL teaching method enhances students' knowledge of basic principles. Instead of burdened contents, the PBL model enables the student to learn new knowledge by presenting new problems to be solved (Çuhadaroğlu et al. as cited in Akınoğlu & Tandoğan, 2007). In addition, PBL provides opportunities for students to solve problems in their real lives. In order for students to face various problems and challenges in their lives, it is important for students to be prepared for the future by facing real or simulations of real problems in their learning environment and producing appropriate solutions to these problems (Akınoğlu & Tandoğan, 2007). PBL also has the potential to develop students' self-directed, life-long learning skills and communication skills, to increase students' ability to solve real world problems, and to increase students' motivation for learning (Nendaz & Tekian, 1999). PBL is an avenue for students to construct knowledge socially, reflect on their learning and thinking, and communicate knowledge obtained (Tan, 2008).

Therefore, in the twenty-first century, PBL is needed as an approach to build content knowledge and to develop skills such as teambuilding, problem solving, and communication skills (Hmelo & Evensen, 2000; Tan, 2008). According to Hmelo-Silver (2004), students learn through facilitated problem solving using the PBL method. Students are able to master the knowledge learned through solving real problems because constructivist learning is transferable (Akçay, 2009). The notion that knowledge is being actively constructed by the learner necessitates SDL (Mok, Cheng, Leung, Shan, Moore, & Kennedy, 2007). Therefore, learning becomes an act of discovery as students examine the problem, research its background, analyze possible solutions, develop a proposal, and produce a final result (Maizam, Saleh, & Hadi, 2007). PBL is therefore deemed an effective approach to produce students who are able to discover and solve problems by teamwork in today's competitive global market.

Moreover, researchers have found that the interest in the applicability of PBL at the high school level has increased in recent years and PBL can be successfully applied in chemistry (Tarhan & Acar, 2007), where abstract concepts make this a tough subject. By using PBL, students have a chance to explore, conduct research, and discuss among themselves. Students play an important role in their own learning. As a result, their learning is the process of working toward the resolution of the given problem. PBL is a good approach in learning chemistry because it will enhance students' content knowledge and foster their interpersonal skills. The most important aspect in PBL is students' own responsibility in the learning process and, according to Gallow (n.d.), it is student-centered learning that produces learning opportunities that are most relevant to students.

## 3 Characteristics of PBL

Barrows (as cited in Beacham & Shambaugh, 2007) provides a teacher checklist with features of core characteristics to be designed into courses. These characteristics include the following:

1. Learning is student centered.
2. Learning is carried out in small groups.
3. A teacher is presented as a facilitator or guide.

4. Authentic problems are presented at the beginning of the course.
5. The problems encountered are used as tools to achieve the required knowledge and problem-solving skills necessary to solve the problem.
6. New information is acquired through SDL.
7. Learning is achieved by analyzing and solving representative problems.

PBL prepares students for life-long learning by engaging them in active learning, in which students are responsible for discovering facts and uncovering key concepts (Alessio, 2004). One of the characteristics of PBL that makes it different from other methods of learning is the problem design in PBL. In PBL, students are presented with a realistic problem without prior traditional lectures or presentations (Duch, Groh, & Allen, as cited in Alessio, 2004). A problem can be anything that raises questions germane to the subject matter and affords free inquiry by students (Barrows, 1986). In brief, PBL refers to a variety of approaches to instruction, which all have in common that much of the learning and instruction is anchored in concrete problems (Hmelo & Evensen, 2000). During the process of solving the problem, students develop knowledge of theory, practice, facts, concepts, and appropriate inquiry strategies related to the initial problem (Alessio, 2004). Preparing students to solve realistic problems by developing multiple skills is the essence of PBL.

To be successful in their careers, students will also need to be able to go through the process of presenting their solutions and continuously evaluating what they have achieved. First, small student groups comprised of 4–7 persons are formed. The concepts, learning aims, and duration of the subject matter are set. Then, students examine and recognize problems from distributed lists. The problems are real-world situations, complex and open ended, that will challenge higher-order thinking, creativity, and synthesis of knowledge (Steinemann, as cited in Awang & Ramly, 2008). When students engage in SDL through PBL, they regularly convene to share, evaluate, and critique each other's work during group meetings (Awang & Ramly, 2008). Students work in the small groups toward solutions and must collaborate and negotiate within their group to rule in and rule out viable solutions (Lambros, 2002). The group members work to evaluate all the information obtained through several sources such as the internet and reference books. Blumberg (2000) concluded that PBL students are active library users. The lecturer serves as a facilitator or guide during the PBL process. Toward the end, the guidance is progressively faded (Merrill, 2002) and students take the role of "facilitators" as they become expert in their topic.

When the solution is reached, the group presents their solution to other groups (Akınoğlu & Tandoğan, 2007). During the problem-solving and decision-making stages, group members deal with multiple and often conflicting goals and values, work with constraints, and determine the most appropriate action to take to accomplish the group's goals by creating functional relationships with each other (Awang & Ramly, 2008; Lambros, 2002).

Hmelo-Silver (2004) summarizes five goals for students in PBL: (1) constructing flexible knowledge, (2) developing effective problem-solving skills, (3) developing SDL skills, (4) becoming effective in collaboration skills, and (5) increasing in intrinsic motivation. In addition, she states that all of these goals of PBL are well suited to help students become active learners because PBL situates learning within real-world problems and makes students responsible for their learning. Therefore, more educators are becoming interested in applying PBL in their instruction because PBL emphasizes active, transferable learning and has potential to motivate students.

## 4 Methodology

The research design used in this study was the pretest-posttest control group design. The quasi-experimental design with nonequivalent groups was used. The pretest-posttest control group design in educational research involves an experimental and a control group both given a pretest and a posttest.

The sample was comprised of 1-year program biology science students (average age of 18 years) who were taking chemistry in semester II session year 2009/2010 in Penang Matriculation College in Malaysia. Each class consisted of about 25 students. A total of 65 science students took part in this study. The 65 students were divided into four classes. Two classes of students for a total of 32 students ($n=32$) were given the treatment of following the PBL tutorial. The other two classes of students ($n=33$) followed the non-PBL tutorial. The study was carried out over 5 weeks at the beginning of the second semester of 2009/2010 and “The effect of concentration on cell potentials” was the selected topic because it is a tough concept to be understood by students. The response rate was 39.88% in this study, as some of the participants did not sit for the post achievement test. The participants who completed both pretests and posttests were 21.50% male and 78.50% female. The majority of the students were Malay while only 6.20% were Chinese.

For the non-PBL group, the lecturers taught the same subject by using the traditional teacher-centered lecture format during lecture and tutorial while the experimental group was used the PBL techniques. The PBL group started 2 weeks before the non-PBL group so as to ensure that the PBL group students were learning and solving problems independently without attending the usual lecture on the subject such as in the non-PBL group. The objective was for students to be able to discuss the effect of concentration and temperature on cell potential on their own without lecturer’s assistance. The students had learned Le Chatelier’s principle in the subject “ionic equilibrium” during the first semester of session 2009/2010. Therefore, the students already had the prior knowledge to learn how concentration might affect cell potentials during second semester.

One pretest and one posttest were used in this study to test the understanding of students on cell potential in both the PBL group and non-PBL groups. The achievement test was in the form of written test that was adapted from Tarhan and Acar (2007) in their studies on using PBL in an eleventh grade chemistry class: “factors affecting cell potential.” Both questions in pretest and posttest used in the control group and the groups were exactly identical except for the figures and numbers.

A pilot study was conducted to ensure the reliability of the test administered in the actual research. The pilot study was carried out among 25 students and the reliability of pretest and posttest for academic achievement was found to be $r=0.735$ and $r=0.694$, respectively. According to Oosterhof (2001), a scale with a computed alpha of above 0.60 is acceptable for a classroom test where the instrument is considered to have an acceptable level of internal consistency. The maximum score for the test is 21 and the minimum is 0. The content validity for both tests and the rubric for marking were determined by three chemistry education expert lecturers.

A pretest was carried out among the experimental and control group to ensure that the students did not learn about factors affecting cell potential using Le Chatelier's principle (Tarhan & Acar, 2007). After attending the PBL tutorial or regular tutorial, the students would complete the posttest, which consisted of two constructed-response questions. The constructed-response form was chosen because it was a test with which students were familiar. The constructed-response questions are able to reduce the students' chances of getting correct answers through guessing (Tan, 2000). The content of the test consists of electrochemical cells, equilibrium, and the effect of concentration on cell potential.

In this study, the posttest was used to measure the understanding of Le Chatelier's principle in determining the cell potential of electrochemistry. The achievement test was titled "Electrochemistry: Cell Potential." The achievement test is in the form of a paper-and-pencil test. The achievement tests were administered directly to the PBL group and non-PBL group after they completed the lesson. The achievement test took about 20 min to be completed by the respondents. All the answers were evaluated by the researcher, three expert lecturers and the tutor. The scores given were compared and discussed until an agreement was reached among the researcher, expert lecturers and the tutor.

The posttest was given after the students completed the PBL tutorial for the PBL group. While, for the non-PBL group, students completed the achievement test after they attended lectures and regular tutorial. Both groups took this test at week 5.

## 5 Findings and Discussions

The result showed that there was no significant difference between the pretest of PBL group and non-group in achievement ($p=.650$) at $p<.05$. This verified that the pretest scores were not a potential confounding variable of the posttest in terms of academic achievement. The PBL group and non-PBL group respondents' background were very similar. According to Campbell and Stanley (1963), the more similar the groups as measured by pretest, the more effective the control is.

An achievement test, in the form of a written test, was adapted from Tarhan and Acar (2007) in their studies on using PBL to test the understanding of cell potential. The mean for the posttest for the PBL group was 12.94 and for the non-PBL group was 11.12. Results from the analysis of independent $t$-tests showed there was a statistical difference between the achievement test score for the PBL group

**Table 1** Means, standard deviation, and independent *t*-tests for the PBL and non-PBL group

| | Group | | |
|---|---|---|---|
| Posttest score | non-PBL | PBL | *p* |
| M | 11.12 | 12.94 | 0.045 |
| SD | 3.51 | 3.65 | |

Note: $p < 0.05$

($M = 12.94$, $SD = 3.65$) and the non-PBL group ($M = 11.12$, $SD = 3.51$); $t(63) = 2.05$, $p = .045$. The result showed that the respondents who attended the PBL tutorial significantly outperformed the non-PBL group tutorial subjects ($p < .05$). Refer to Table 1.

The result from independent *t*-tests showed that there was a statistically significant difference between the achievement test score in cell potential between the PBL group and non-PBL group. Students who attended the PBL tutorial had significantly higher scores on the achievement test for the cell potential topic compared with the students who did not attend the PBL tutorial. The study supports that PBL improves students' understanding of cell potential with higher scores on the achievement test compared with the non-PBL group of students. The result of this study is congruent with Tarhan and Acar's (2007) study on the effectiveness of PBL on eleventh grade students' understanding of the effects of temperature, concentration, and pressure on cell potential. The researchers concluded that PBL is effective in improving students' performance in electrochemistry.

From the performance of the participants in the PBL group, it is concluded that PBL is an effective constructivist method for learning about the effects of temperature and concentration on cell potential in a matriculation college chemistry class. During the discussion, some of the participants were able to relate the factors affecting cell potential in an electrochemical cell to Le Chatelier's principle, which they have learned during the first semester. As proposed by John Dewey (1916), students learn best by doing and by thinking through problems. The participants in the study needed to think about how concentration and temperature affect cell potential during the PBL tutorial. At the same time, they learned new content while solving presented problems. They incorporated the new knowledge on cell potential into Le Chatelier's principle, which they had learned earlier.

When students start to incorporate their new knowledge and skills, they exhibit the self-monitoring characteristics where they show commitment to construct meaning by assimilating and accommodating new concepts with previous knowledge (Garrison, 1997). The design and characteristics of the PBL tutorial therefore improve the construction of new knowledge using prior knowledge skills. This finding is also supported by Sungur, Tekkaya, and Geban (2006), as they also found that PBL can improve students' achievement as students in the experimental group appeared to be more proficient in the use and organization of relevant information, in constructing knowledge, and moving toward better conclusions. Mohamed and Abdul Kadir (2005) also found improvement in students' performance from 1999 to 2002 at the University of Malaya in Malaysia. Problem solving in the PBL instruction could encourage students to use their critical thinking to solve the problems in Penang Matriculation College.

Matriculation students were better prepared in solving cell potential problems from a short period of PBL instruction. The design of the PBL tutorial in the study was a short session for 5 weeks only. This short period of PBL tutorial on cell potential among matriculation students had yielded positive results. Kenney (2008) administered a one-shot session in examining the enhancement of library instruction at Roger Williams University. In that study, the short period of PBL had a significant impact on matriculation students' academic achievement in electrochemistry. PBL helped them explore and learn independently about the concept of electrochemistry more thoroughly because electrochemistry is the most difficult among the chemistry subjects to understand (Abdul Manaf & Subramaniam, 2004; Thompson & Soyibo, 2002). However, the guidance from the lecturers was still needed.

## 6 Conclusion and Implication

The results of the comparison between the PBL group and non-PBL group suggest that PBL is able to enhance students' academic achievement. Matriculation students could benefit from the PBL tutorial, which emphasizes working collaboratively and actively to construct knowledge in a continuous process of building and reshaping understanding of cell potential. This positive result of PBL indicates that curriculum designers in Matriculation Colleges may consider designing the chemistry curriculum by blending PBL into the curriculum in the early stages especially, requiring students to use PBL to solve real-life problems. As students become more familiar with PBL later on, curriculum designers can consider incorporating full PBL instruction in the chemistry curriculum.

Lecturers could look into the possibilities of incorporating PBL into their teaching gradually in order to promote critical thinking among students. When lecturers decide to take the role of facilitators and provide minimal guidance, students will have to take the initiative and effort to learn. At the same time, lecturers could also encourage students to be more critical in solving problems gradually. Lecturers in Matriculation College should consider using PBL as the sole instruction method or to support regular instruction to enhance students' performance.

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# Teaching Catalysis by Means of Enzymes and Microorganisms

**Peter Grunwald**

## 1 Introduction

The aim of this chapter is to demonstrate how it is possible to introduce students into the field of homogeneous and heterogeneous kinetics on the basis of experiments with the enzyme urease and with yeast cells. An additional advantage is that students learn fundamentals in kinetics as well as in biochemistry simultaneously, which may be looked at as an example of a time-saving teaching method. Among others, experiments will be put up for discussion, allowing for a simple immobilization of the biocatalysts (including the preparation of magnetic beads for easy separation of the catalyst from the reaction mixture) as a prerequisite for their reuse. The experiments stand representatively for the aims of industrial biotechnology or green chemistry with respect to low consumption of energy and chemicals, reduction of waste formation, and so on and provide teachers with the opportunity to include topics such as sustainable development, responsible care, and related ones into the discussion with their students.

## 2 Background and Justification

Catalysis, and biocatalysis in particular, are topics affecting all areas of everyday life. Life itself is impossible without biocatalysts (their dysfunction causes serious diseases with possibly fatal consequences). In ancient times, catalytic processes were used for brewing beer and baking bread. Since the nineteenth century, the chemical industry (which has no counterpart in physics or biology) has increasingly

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employed catalysts to improve the efficiency of production processes. Several simple experiments demonstrate the phenomenon of catalysis, the increase of a reaction rate by addition of small amounts of certain compounds, termed catalysts, as, for example, the decomposition of hydrogen peroxide – normally storable at room temperature for a long time – to water and oxygen that occurs spontaneously if a drop of bromine is added (e.g., Atkins, 1989):

$$2H_2O_{2(aq)} \xrightarrow{Br_2} 2H_2O_{(l)} + O_{2(g)}$$

Here, bromine acting as the catalyst together with the reactants are present in the same aggregation state, representing an example of a homogeneous catalyst or homogeneous catalysis. It should be mentioned that the above-given overall reaction does not allow conclusions with respect to the reaction mechanism; bromine undergoes changes in its oxidation state during its action on $H_2O_2$ but is not consumed, as can be shown by making up the balance of the different reaction steps. A similar effect is achieved when solid silver oxide is used instead of bromine. In this case, catalyst and reactants are present in different phases, which is called heterogeneous catalysis. This type of catalysis finds broad application in industrial processes. A famous example is the synthesis of ammonia

$$N_{2(g)} + 3H_{2(g)} \xrightarrow{Fe_{(s)}} 2NH_{3(g)}$$

with finely divided iron as heterogeneous catalyst promoting the $NH_3$ synthesis as detected by Fritz Haber in 1908 (Nobel Prize in Chemistry 1918) and scaled up in the following years by Carl Bosch (Nobel Prize in Chemistry 1931). Ammonia was first used mainly for fabrication of explosives ($NH_4NO_3$) but is today indispensable for the production of fertilizers, fibers, and plastics. The reaction mechanism of the catalytic synthesis of ammonia, where the metal catalyst enables an alternative pathway with a significantly reduced activation energy $E_A$ has been described by Ertl (1983) and Ertl, Lee, and Weiss (1982). Gerhard Ertl was awarded the Nobel Prize in Chemistry in 2007 for “his studies of chemical processes on solid surfaces.”

Catalysts, accelerating biochemical reactions, are the so-called enzymes or biomacromolecules with molecular weights in the range from about 10,000 to several million g/mol. They are built from amino acids and are synthesized by living organisms according to the traditional dogma of molecular biology “DNA → RNA → Protein.” Many enzymes are posttranslationally modified (glycosylation, phosphorylation, etc.) and require non-protein cofactors for developing catalytic activity. They possess a so-called active site where the substrate is converted to products. The active site consists of only a few amino acids, in many cases forming a catalytic triad of unique geometric shape. A substrate is recognized by an enzyme when it fits into the active site, a mechanism proposed already in 1894 by Emil Fischer (Nobel Prize in Chemistry, 1902) and known as the “lock and key theory.” Many decades later, this model was extended by the “induced-fit-theory” (Koshland, 1958), which is based on the assumption of a more flexible active site architecture.

Enzymes by nature are catalytically active at room temperature, which is why they are employed to an increasing degree in industrial processes where they replace traditional catalysts and contribute to lowering of greenhouse gas emissions. Furthermore, as only few – if any – additional chemicals are required, the amount of waste produced is reduced. Most enzymes are soluble in water and thus may be looked at as homogeneous catalysts. If biocatalysts are applied for industrial purposes they are often bound to the surface of water-insoluble carrier materials or entrapped within a porous carrier matrix, a procedure known as immobilization; it allows for the simple separation of the catalyst from the reaction mixture and for its reuse. Experiments with immobilized enzymes and cells provide an opportunity to teach the laws of heterogeneous catalysis (see below).

Examples of industrial (or white) biotechnology that meanwhile emerged as a promising alternative to traditional procedures for the production of chemicals and plastics are the production of vitamin B2 by BASF (Ludwigshafen, Germany), where the substitution of an eight-step chemical procedure by a fermentation process led to a reduction of $CO_2$ emission by 30% and of waste by 95%, or the fabrication of 7-aminocephalosporanic acid (Antranikian & Heiden, 2006); here, waste management made up 21% of the total production costs compared with the traditional chemical process but only 1% after its replacement by a biotechnology based one (for further examples see Grunwald, 2009; Sheldon, Arends, & Hanefeld, 2007). All together, industrial biotechnology fulfills many of the 12 principles of green chemistry formulated by Anastas and Warner (1998).

## 3 Chemistry Is Interdisciplinary

Questions related to the content of chemistry curricula are answered in part by the fact that chemistry is an interdisciplinary science. This is not an original statement, particularly when one considers how Emil Fischer (1907) worded this idea more than 100 years ago in his Faraday Lecture to the Chemical Society in a rather visionary way:

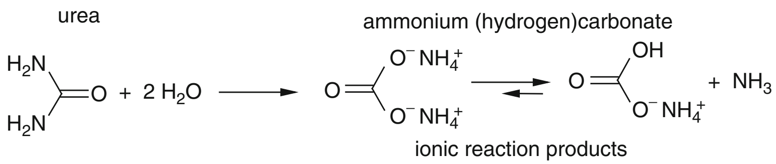
> The separation of chemistry from biology was necessary during the past century while experimental methods and theories were being elaborated; now that our science is provided with a powerful armoury of analytical and synthetic weapons, chemistry can once again renew the alliance with biology both to its own honor and to the advantage of biology (E. Fischer, 1907, quote on p. 1765).

This interdisciplinary character nowadays is of course not restricted to chemistry and biology but includes physics with new research fields resulting from an overlap, such as (bio)nanotechnology, which gains increasing importance in medicine and pharmacy, for example. Molecular biology together with biochemistry, analytics, and informatics have led to the rather new research fields of genomics and proteomics, which are not only of academic interest but have already found applications for biotechnology (Figeys, 2005). Examples are metagenomic and metaproteomoic analyses performed in connection with the use of lignocellulolytic microorganisms for the cost-effective production of biofuels from biomass (Tamaru & Doi, 2011). In view of this spiraling growth of knowledge with its many new possible applications of high general interest, education in chemistry/natural sciences must be accompanied by permanent revision, including the deletion of traditional topics in favor of new ones, with a certain focus on topics related to life sciences as recommended nearly 30 years ago by David Samuel (1984) in a lecture given at the 29th IUPAC congress in Cologne, Germany, 1983.

## 4 The Experiments – General Aspects

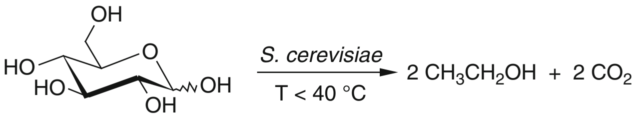
The experiments described here have been performed by students (chemistry, food chemistry, biochemistry, and future chemistry teacher students) within the kinetics part of a practical course in physical chemistry in their second semester. During the first semester they have to successfully pass a practical course in inorganic/general chemistry. Some of the experiments described here have been developed by chemistry teacher students during a 3-month lab at the end of their academic studies as part of their first examination.

As catalysts, the enzyme urease or yeast cells (*Saccharomyces cerevisiae*) are employed. Urease and its substrate urea both demonstrate for students some important milestones in science history. Urease was the first protein to be crystallized by the American chemist James Batcheller Sumner (1887–1955) in 1926; in 1946 he was awarded the Nobel Prize in Chemistry – together with John Howard Northrop and Wendell Meredith Stanley – for protein crystallization, which is an essential prerequisite for elucidation of protein structures by X-ray spectroscopy (Sumner, 1946). Urease catalyses the hydrolysis of urea according to the following equation:




Urea was synthesized in 1828 by Friedrich Wöhler from ammonium cyanate (Wöhler, 1828). This publication is of historical significance as it was the first time that an organic compound was obtained from an inorganic one and is sometimes looked at as the starting point of modern organic chemistry.

The yeast *Saccharomyces cerevisiae* is known from beer brewing and bread baking (baker's yeast) and belongs to the group of microorganisms that ferment glucose *via* pyruvate to ethanol and $CO_2$. This process, catalyzed by a series of different enzymes, is important as a means of gaining energy in the form of adenosine triphosphate (ATP). The overall reaction consisting of many enzyme-catalyzed steps may be written as:




## 5 Conductivity Measurements and the Activity of Biocatalysts

As already mentioned, rapid increase in knowledge requires, among others, time-saving teaching methods; proposals are summarized in the following tables. As can be seen from Table 1, the use of enzymes and cells as catalysts in a practical course in kinetics offers the opportunity to impart some basic knowledge in biochemistry as well, particularly the structure and function of enzymes, their kinetics, and inhibition. This holds similarly for fundamentals in electrochemistry if experimental results are obtained from conductivity measurements (see figures below).

In connection with the use of conductivity measurements for obtaining results, it is necessary to briefly introduce students to electrochemistry by discussing terms such as weak and strong electrolytes, conductivity κ (given in μS/cm), and its dependence on temperature and concentration, mobility of ions, transport numbers, and so on. Figure 1 schematically shows the change in conductivity as a function of time when urease is added to a urea solution. The slope of the straight line in μS/min may be used as a direct measure for the reaction rate (see also Grunwald, 1984; Hanns & Rey, 1971).

Figure 2 demonstrates how alcoholic fermentation may also be investigated by means of conductivity measurements.

For this, $CO_2$ developing from alcoholic fermentation is passed from the reaction vessel into a second vessel containing a potassium hydroxide solution and the conductivity electrode. According to the reaction

**Table 1** Topics that may be treated simultaneously

Enzymes and cells as catalysts

| Single aspects | Additional topics |
|---|---|
| *Enzymes and cells* | *Biochemical fundamentals* |
| Mild reaction conditions | Green Chemistry |
| Low energy consumption | |
| No additional chemicals | Industrial/White Biotechnology |
| Low waste production | Sustainable development |
| Cost-effective processes | Responsible care |
| *Conductivity measurements* | *Electrochemical fundamentals* |

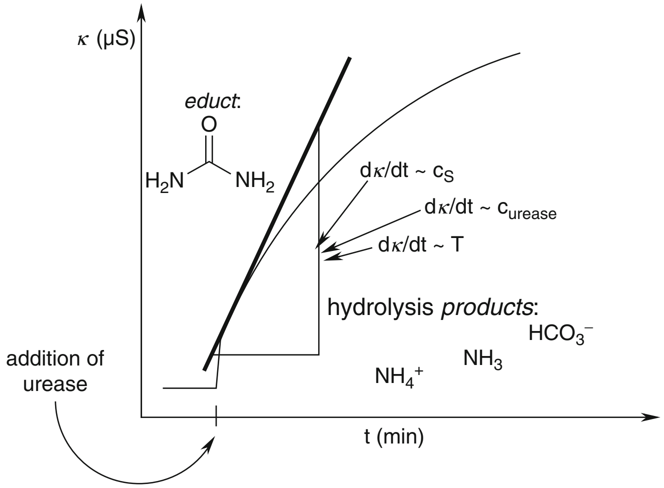



**Fig. 1** The electric conductivity of a freshly prepared urea solution is that of distilled water (~1 µS/cm). The addition of a urease solution results in a slight increase in conductivity due to the fact that urease dissolved in water conducts the current. The subsequent increase in activity results from hydrolysis of urea into ionic products. The slope (µS/min if the cell constant of the electrode is 1 $cm^{-1}$) of the straight line at the beginning of the reaction depends on the parameters listed in Table 2. As the amount of ammonia formed under these conditions is low, the reaction mixture must not be buffered

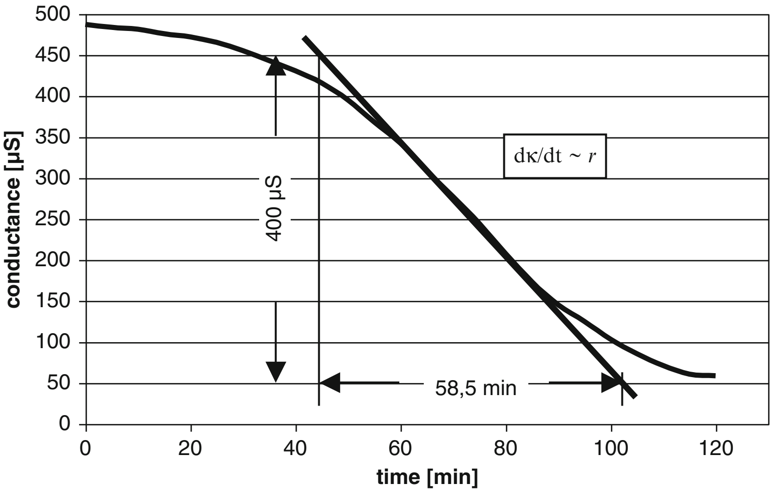



**Fig. 2** If $CO_2$ liberated during alcoholic fermentation is passed into a potassium hydroxide solution the conductivity of this solution decreases due to an exchange of highly mobile hydroxyl ions by hydrogen carbonate ions that have a significantly lower mobility

$$NaOH + CO_2 \longrightarrow NaHCO_3$$

$$u\,(OH^-): 20.64 \qquad u\,(HCO_3^-): 4.45$$

$$[u] = 10^{-8}\ m^2V^{-1}s^{-1}$$

the conductivity decreases because the electric mobility of the hydrogencarbonate ions formed is by a factor of about 5 less than that of the original hydroxide ions. Again, the period of constant decrease in conductivity can be taken as a measure for the biocatalyst's activity.

## 6 Experiments on Homogeneous Catalysis

A catalyst takes part in the reaction it catalyzes, thereby providing an alternative reaction pass, but is not consumed. The interaction of a substrate (S) with an enzyme (E) resulting in the formation of products (P) is often written in the following simplified way

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} E + P$$

The generation of the enzyme/substrate complex ES can be compared with an adsorption of the substrate molecule to the enzyme's active site (like the adsorption of nitrogen molecules on the iron catalyst as a prerequisite for weakening the strong triple bonds between the N atoms). The rate of the catalyzed reaction depends on the concentration of ES and hence can be written as

$$r = k_2 \cdot c_{ES}$$

an expression containing the unknown concentration of the enzyme/substrate complex for which an expression is obtained by the so-called steady-state approximation:

$$\left(\frac{dc_{ES}}{dT}\right)_T = 0 \cdots for \cdots c_E << c_S$$

The condition $c_E << c_S$ is normally fulfilled due to the low ratio of molecular weights of substrate to enzyme, which is the case with the urea/urease system 60.04–548.000 g/mol. Setting up the three rate equations where $c_{ES}$ is involved and considering that the concentration of the amount of free enzyme $c_E$ is given by the difference between the total enzyme concentration $c_{Eo}$ and that of $c_{ES}$ gives

$$c_{ES} = \frac{c_{Eo} \cdot c_S}{\frac{k_{-1} + k_2}{k_1}} \quad \text{and thus} \quad r = \frac{k_2 \cdot c_{Eo} \cdot c_S}{K_M + c_S}$$

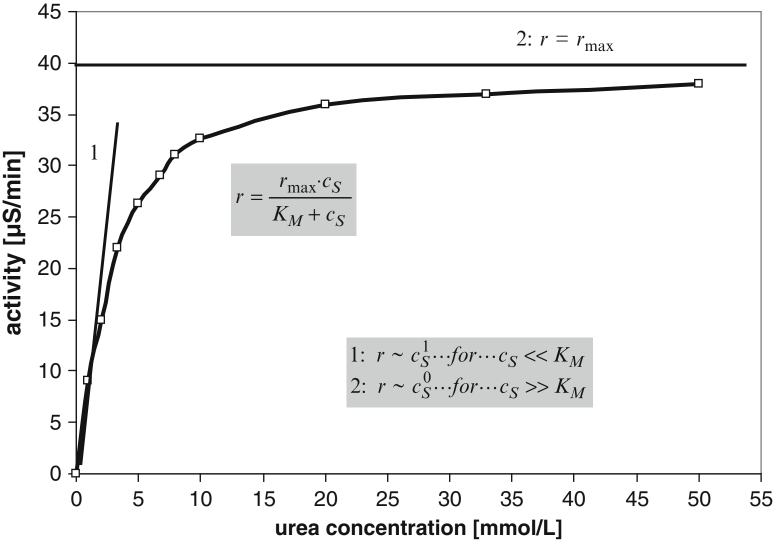



**Fig. 3** Plot of activity versus substrate concentration for the system urease/urea, determined by conductivity measurements at T = 25 °C

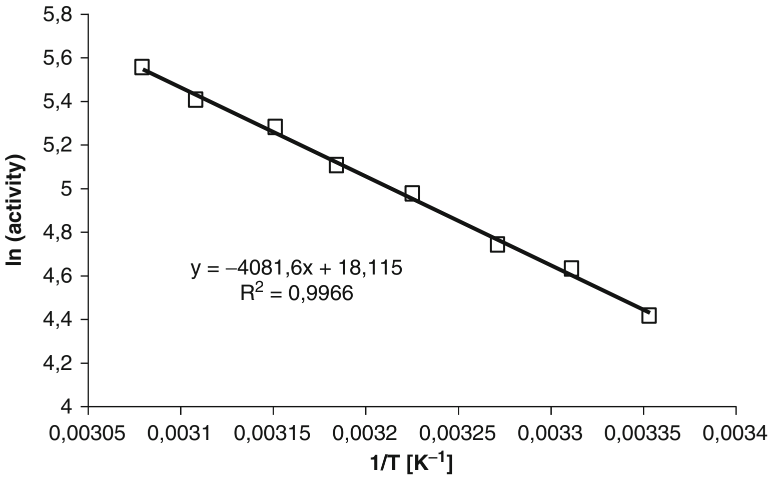



**Fig. 4** Temperature dependence of the urease-catalyzed urea hydrolysis between 298 and 325 K. The calculated activation energy $E_A$ is 34 kJ/mol. For the uncatalyzed reaction $E_A$ is about 130 kJ/mol, which means that urease effects a rate acceleration by a factor of $10^{15}$

In the obtained famous Michaelis-Menten equation with the Michaelis-constant $K_M$ (mol/L), the product of $k_2$ and $c_{Eo}$ is often written as the maximum reaction rate $r_{max}$:

$$r = \frac{r_{max} \cdot c_S}{K_M + c_S} \cdots or \cdots \frac{1}{r} = \frac{K_M}{r_{max}} \cdot \frac{1}{c_S} + \frac{1}{r_{max}}$$

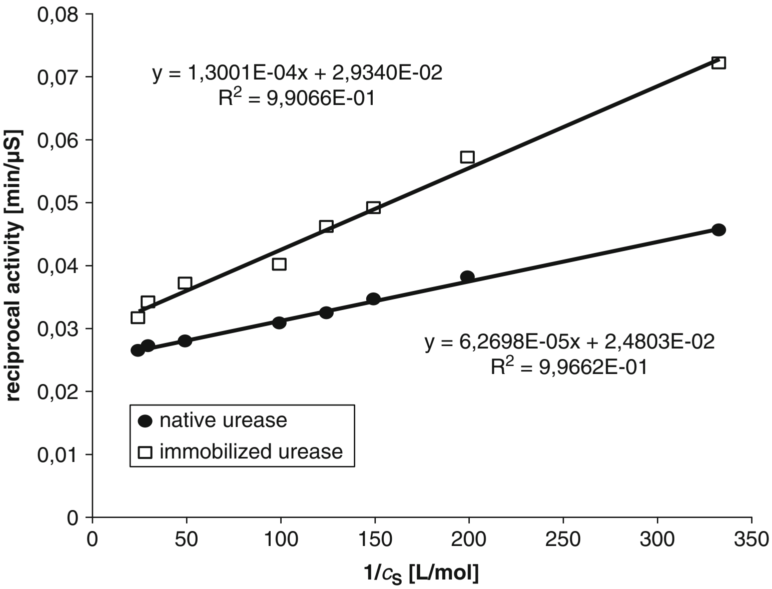



**Fig. 5** Determination of $K_M$ and $r_{max}$ for native ($K_M$=2.5 mmol, $r_{max}$=40.3 µS/min) urease and urease immobilized within Ca-alginate beads with a diameter of about 1 mm ($K_M$=4.4 mmol, $r_{max}$=34.1 µS/min). The determination of the activity of immobilized urease is somewhat problematic because small amounts of the enzyme may be lost during preparation of the samples; uniform experimental conditions must be maintained

$K_M$ is a characteristic of an enzyme, whereas $r_{max}$ depends on the purity of the enzyme preparation (number of active sites). As can be seen from the above equation and from Fig. 3, a plot of $r$ versus $c_S$ represents a rectangular hyperbola and a determination of $r_{max}$ would require very high substrate concentrations, beyond experimental feasibility.

Therefore, the experimental data are linearized according to methods named after Hanes, Eadie-Hofstee, and Lineweaver-Burk. The latter represents a double reciprocal plot with a slope of the straight line of $K_M/r_{max}$ and an ordinate intercept of $1/r_{max}$ as shown with the examples given in Fig. 5 (for the advantages and disadvantages of these methods see biochemistry textbooks or Bisswanger, 2004).

The temperature dependence of most enzyme-catalyzed reactions may be described by using the simple Arrhenius equation (Fig. 4). The reaction rate passes through a maximum before it goes down due to heat denaturation of the biocatalyst. With about 60 °C for urease (if the incubation time is kept low), this so-called temperature optimum is comparatively high.

Similarly, conductivity measurements may be used to show how the reaction rate depends on the catalyst concentration; the activity increases linearly with increasing enzyme supply, that is, the reaction rate is first order with respect to $c_E$.

# 7 Heterogeneous Catalysis

Enzymes and cells are often employed in an immobilized state, particularly when applied in production processes. Immobilization stands for a technique by which a catalyst is made water-insoluble, which is achieved by binding it to the surface of a water-insoluble carrier material or by entrapment within the porous matrix of a carrier. Immobilization has several general advantages, such as the reusability of the catalyst and its easy separation from the reaction mixture due to which the reaction products are not spoiled by proteins or cellular material, but there are also disadvantages, depending, among others, on the immobilization method (Table 3).

Other immobilization methods rely on ionic forces, complex binding, or encapsulation. Here, only the entrapment of urease and yeast cells within alginate is discussed, because this method is easy to perform by employing inexpensive starting materials. The entrapment within alginate is based on the following reaction termed "ionotropic gelation":

$$\underset{\text{(sol)}}{(\mathrm{Na^+})_2\text{-alginate}} + \mathrm{CaCl_2} \xrightarrow{\text{biocatalyst}} \underset{\text{(gel)}}{\text{Ca-alginate}} + \mathrm{Ca^{2+}}$$

The use of the polysaccharide chitosan for immobilization (Grunwald, 2006), which bears free amino groups, may be looked at as a mixture of entrapment and cross-linking insofar as, after mixing chitosan with the catalyst in question, the mixture is reacted with bifunctional reagents.

# 8 Experiments on Heterogeneous Catalysis

All reactions described in the previous section (see Table 2) may be performed with immobilized enzymes (or cells) as well (Table 3). For an evaluation, however, the laws of heterogeneous catalysis have to be considered, resulting from the fact that the obtained results are affected by diffusion phenomena leading to a mass transport

**Table 2** Detailed learning goals regarding the topic homogeneous catalysis/enzyme kinetics ($K_M$: Michaelis-Menten constant; $r_{(max)}$: [maximum] reaction rate; $E_A$: activation energy)

| Varied experimental parameter | Observation/calculated quantity |
|---|---|
| Substrate concentration $c_S$ | Determination of the characteristic parameters $K_M$ and $r_{max;}$ (T = const.); order of the reaction 1: $c_S << K_M$ and 0: $c_S >> K_M$ (Fig. 3). |
| Enzyme/catalyst concentration $c_E$ (T and $c_S$ = const.) | The reaction rate $r$ is of first order with respect to the catalyst/enzyme concentration: $r \sim c_E$.[1] |
| Temperature T(°C); $c_E$ and $c_S$ = const. | $r$ increases exponentially with T; a plot of ln$r$ versus 1/T (K$^{-1}$) allows to calculate $E_A$ (Fig. 4). |
| General goals | |
| Setting up rate equations; appropriate use of the underlying mathematical fundamentals | |

**Table 3** The main immobilization methods together with their advantages and disadvantages, and examples of carrier materials (Buchholz, Kasche, & Bornscheuer, 2005; Grunwald, 2009)

| Immobilization method | Advantage | Disadvantage | Carrier material |
|---|---|---|---|
| Adsorption | Low binding forces<br>High residual activity | Leakage of catalyst from the carrier surface | Mainly inorganic compounds ($Al_2O_3$, porous glass). |
| Covalent binding | No or only slight leakage | Mostly (considerable) activity loss due to the applied (rigid) chemistry | Organic/inorganic carrier materials with functionalized surfaces |
| Crosslinking | No additional carrier material needed | Activity loss possible | none |
| Entrapment | High catalytic activity after optimization | The method of choice for immobilization of whole cells; less suited for enzymes with low molecular weight | Naturally occurring polysaccharides (al-ginate, chitosan) or polymers such as polyvinyl alcohol |

limitation with the consequence of reduced catalytic activities, as shown in the following figure where activities of native urease and urease immobilized in Ca-alginate are compiled. Apart from an enhanced $K_M$-value, activation energies are reduced because $E_A$ for diffusion and thus for diffusion-controlled reactions is low.

For simplicity, mathematical treatment is often done for biocatalysts immobilized within a ball-shaped matrix. External diffusion limitation results from the so-called unstirred "Nernst layer" surrounding a bead in the reaction solution. Its thickness is reduced with increasing stirring rates so that external diffusion limitations may be neglected in case of rapid stirring. Internal diffusion caused by interaction between the carrier material and the substrate molecules and quantitatively described by the effective diffusion coefficient $D_e$ (Grunwald, 1989; Klein, Stock, & Vorlop, 1983) gives rise to substrate concentration gradients within the catalyst bead; for beads with a larger diameter the substrate concentration within the center of a bead may go down to zero so that the enzyme molecules (or microorganisms) there do not "see" any substrate. As a consequence the catalytic activity no longer increases linearly with increasing enzyme or cell loading as expected for the native counterparts. How the preparation conditions of an immobilized biocatalyst can be optimized is seen from the following equations:

$$r = \eta \frac{r_{\max} \cdot c_S}{K_M + c_S} \quad \text{and} \quad \eta = \frac{2}{d}\sqrt{\frac{K_M \cdot D_e}{r_{\max}}}$$

The Michaelis-Menten equation is "corrected" for simple ball-shaped biocatalysts by a factor $\eta$, termed efficiency. The efficiency and thus the reaction rate increases with the square root of $D_e$ promoted by a porous matrix, and is inversely proportional to the particle diameter $d$ (see Sect. 10). Reducing $d$ of alginate particles from 3 to 0.06 mm enhances the activity of immobilized urease by a factor of about 5 (Grunwald, 2000)

## 9 Conclusion

This chapter attempted to demonstrate that a traditional practical course in kinetics may serve to discuss topics beyond a simple treatment of single kinetic terms and laws. As shown here, the choice of biocatalysts offers the opportunity to simultaneously impart some fundamentals in biochemistry and if the experiments are carried out by conductivity measurements basic electrochemistry may be taught as well. To acquire this additional knowledge in connection with the main topic is of advantage not only because students know why they have to learn about these fundamentals but also because it stands for a time-saving teaching method bringing about free space for discussing further topic-related aspects with the students. These are recent developments in industrial biotechnology that contribute increasingly and significantly to environmentally friendly production processes. This way of teaching may be seen also as a challenge to orient contents more toward progress in research and to keep learning up-to-date, which at the same time means that lifelong learning is obligatory to professional teachers.

## 10 Experimental Section

### *10.1 Activity Measurements*

For measuring the catalytic activity of urease or yeast cells, a conductivity meter, a Pt double electrode, and a reaction vessel (50 mL) are required. The initial increase in activity is a direct measure of the reaction rate (Fig. 1). For determining the temperature dependence of $r$, the reaction vessel must be connected to a thermostat. In case of urease (e.g., U 1500 from Sigma) a solution containing 1 mg/mL should be used; 1 mL of this solution is added to 50 mL of an urea solution with a concentration of 0.01 mol/L for determining $E_A$ or concentrations varying between 0.001 and 0.1 mol/L for $K_M$. For experiments with baker's yeast, glucose concentrations between 0.04 and 0.4 mol/L and yeast quantities ranging from 20 to 400 mg/50 mL are well suited; in this case, the reaction vessel where $CO_2$ is generated from alcoholic fermentation is connected to a second vessel containing 0.1 M KOH and the Pt-electrode. Alternatively, the activity of yeast cells may also be determined volumetrically or photometrically by use of an enzymatic test kit, however it is rather expensive (Grunwald, 2000).

## *10.2 Immobilization*

Entrapment of biocatalysts is done in the following way: 200 mg sodium alginate is added in small portions under stirring to 9.8 – x mL distilled water that contains already x gram of Urease (0.001–0.05 g) or baker's yeast from the super market (0.2–2 g), respectively. The homogeneous rather viscous sol is then dropped by use of a one-way syringe into a stirred $CaCl_2$ solution. After 30 min the hardening process is complete; the beads are separated by filtration and rinsed three times each with 10 mL of distilled water. The diameter of the beads may be varied by employing canulas with different diameters; alternatively, a device may be used, described elsewhere (Grunwald, 2000).

Magnetic separation is a well-established method in diagnostic microbiology or bio-analytics. Magnetic alginate beads (see figure) containing the biocatalyst can be easily prepared by addition of the ferromagnetic magnetite (0.02–0.06 g) to the alginate/enzyme(yeast) sol.

Many additional experiments may be performed in the presence of different concentrations of heavy metal ion solutions ($CdCl_2$, $PbCl_2$, and others) in order to study their inhibitory effect on the enzyme urease, the toxic effect on living cells, or the capacity of yeast cells for metal bioadsorption/bioaccumulation, which may be of use in waste water treatment or noble metal recovery.

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# The Application of the SATL in Biochemistry

**Suzana B. Golemi**

Though newly introduced, global education has occupied a special place in the glossary of education. It prepares both teachers and students to have a broad view of problems and issues and think constructively about the future and their role in it. In this respect, we need to consider ourselves as global citizens and take all the responsibilities that accompany the phenomenon of globalization. At the same time, teachers must regard themselves as members of their community and country. The main characteristic of teaching in the framework of global education is the partnership between the teacher and the student, which finds itself expressed in the methods and numerous interactive techniques that constitutes its content. The teachers who continue to teach by employing traditional methods find it difficult to promote the active role of students in the classroom, see the relationship of their subject to others, and perceive the prospective of their teaching. The philosophy of global teaching integrates exactly these elements that the traditional method lacks. The focus of the philosophy of global education is the student and teaching.

Systemic Approach in Teaching and Learning (SATL) is a means of orienting and restructuring (Fahmy & Lagowski, 2003). It demands that teachers' information be oriented by the strategy of the map of concepts. This method contests the linear approach, which is currently widely popular. It is the teachers' responsibility to train their students to think systemically, a characteristic of globalism. In this way we can ensure effective teaching.

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# 1 Methodology

The method is applied at the University of Shkoder "Luigj Gurakuqi" (Albania) in the Faculty of Natural Sciences, at the Department of Biochemistry with the students of the first study degree (BA), in the subject of biochemistry.

SATL is a contemporary method of teaching and learning. In the beginning, it was difficult to apply this method because the students were used to the traditional linear methods. Then, we decided to prepare a seminar with the intention of presenting the systemic method.

The systemic method enables the professor to create a diagram based on one concept, starting with some basic knowledge that students are supposed to have prior to the beginning of the systemic method.

The professor is well aware of the concept structure that he/she will organize into close clusters as presented in Fig. 1. The uniqueness of this method is that the relationship between the concepts should be bi-directional.

For the handling of module "Metabolism of the organic substances" we will start with a simple diagram, which is important because thermodynamics also allows us to determine whether or not chemical processes and reactions occur spontaneously. Living cells and organisms represent an open system. An open system may exchange matter, energy, or both with the surroundings. Living cells and organisms are typically open systems that exchange matter (nutrients and waste products) and heat (from metabolism, for example) with their surroundings. If the outside source of energy stops, the cell processes tend to equilibrium; this leads to cell death (see Fig. 2).

The teaching strategy is itself systemic. The application of the method SATL (Systemic Approach in Teaching and Learning) involves the development of systemic diagram. Systematic teaching starts with the systematic diagram (DS1), passes through both intermediate diagrams (DS2), (DS3), and so on, and ends up with the systematic diagram (SDF). In the SDF diagram, all links between concepts, metabolic cycles, cell organs, and body organs are familiar and well clarified (Fahmy & El-Hashash, 1999) (see Fig. 3).

The module where the systemic approach was employed is presented by the systemic diagrams displayed in Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12.

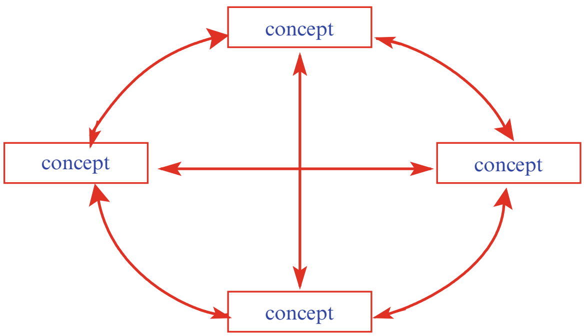



**Fig. 1** Systemic representation

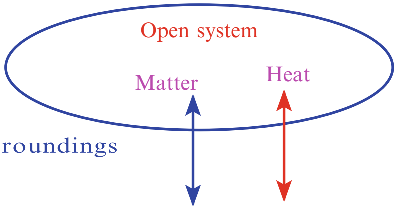



**Fig. 2** Systemic diagram displaying the exchange of matter with the environment

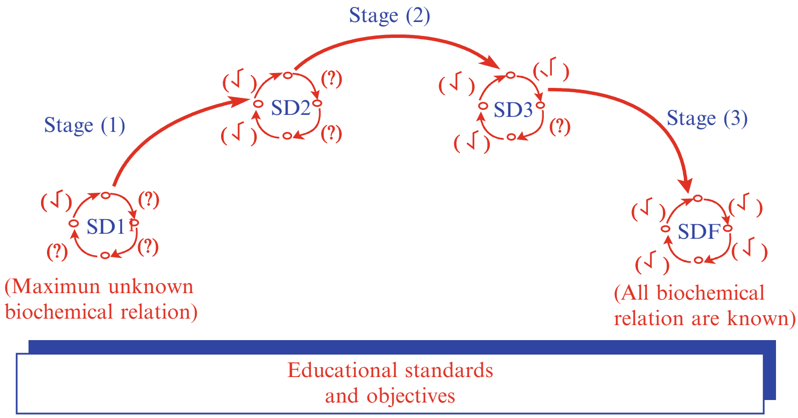



**Fig. 3** Systemic teaching strategy

In order to explain the concept of metabolism, the teacher, together with the student, creates the systematic diagram DS1. After that, the students will create the diagram DS2 based on the diagram DS1. In the DS1, the chemical bonds between the metabolic stages (1–9) are unknown; the students will learn that during the study of metabolism. After studying the metabolic processes that occur in the cell or organisms (catabolic pathways, anabolic pathways, cyclic pathways, metabolites), the students will apply it in the DS2 diagram. The SD2 diagram changes. These changes are displayed in the SDF diagram. In this way, we create all systematic diagrams (as displayed in Fig. 4).

Metabolism develops through a number of chemical transformations, in the course of which intermediary compositions are created (as displayed in Fig. 5). In general, biosynthetic pathways (including fuel storage) are referred to as anabolic pathways, that is, pathways that synthesize larger molecules from smaller components (Garret & Grishan, 1995). Catabolism pathways are those that break down larger molecules into smaller components.

The systematic diagram that explains the connections between the metabolic major fate of the glucose is displayed in Fig. 6. Glucose is the key food molecule for most organisms. It is central to all of metabolism and is the source of carbon for synthesis of most other compounds.

Many metabolites that are created in different cell organelles cannot pass from one organelle to another, but it is the shuttle mechanism makes this transportation

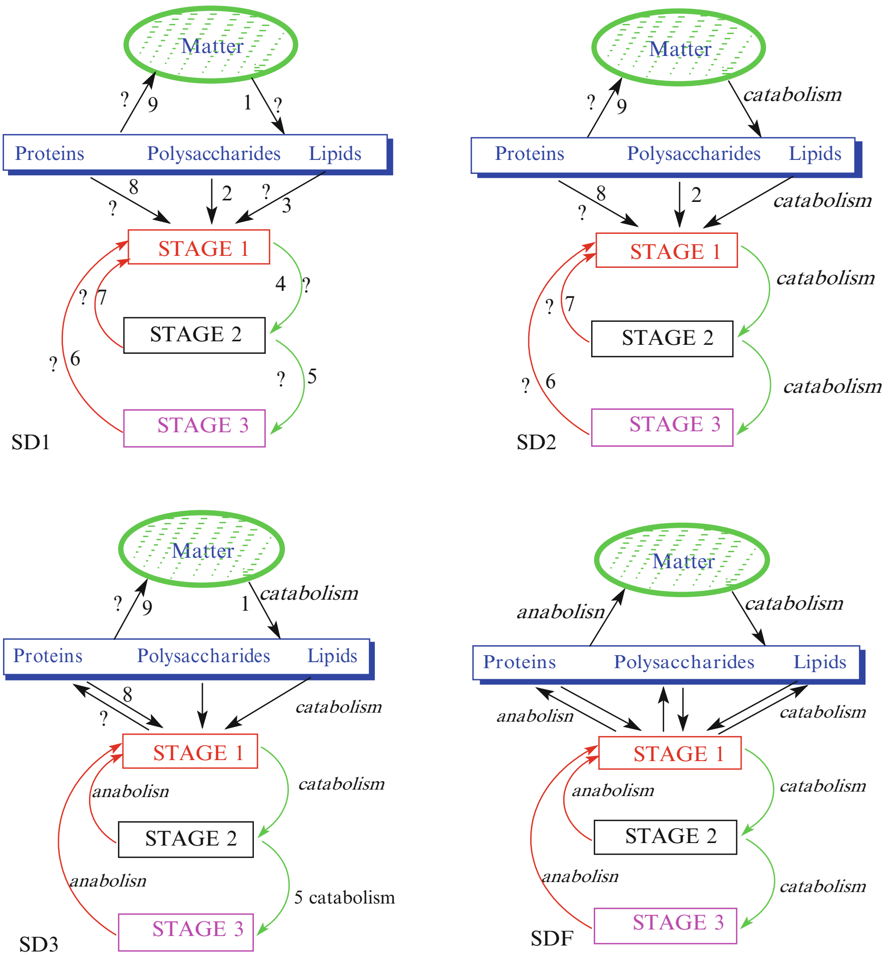



**Fig. 4** Systemic diagram on the stages of metabolism

possible. This mechanism is the malate-aspartate shuttle**.** Malate is transported across the inner mitochondrial membrane by a specific translocase, which exchanges malate for α-ketoglutarate (Collen, Marks, & Michaell, 2005). The newly formed axaloacetate cannot pass back through the inner mitochondrial membrane under physiologic conditions, so aspartate is used to return the oxaloacetate carbon skeleton to the cytosol (see Fig. 7).

In matrix, transamination reactions transfer an amino group to oxaloacetate to form aspartate, which is transported out to the cytosol (using an aspartate/glutamate exchange translocase) and converted back to oxaloacetate through another transamination reaction.

We can create the systemic diagram that shows the connection between the organs and metabolite processes that occur in different organs. The systemic diagram

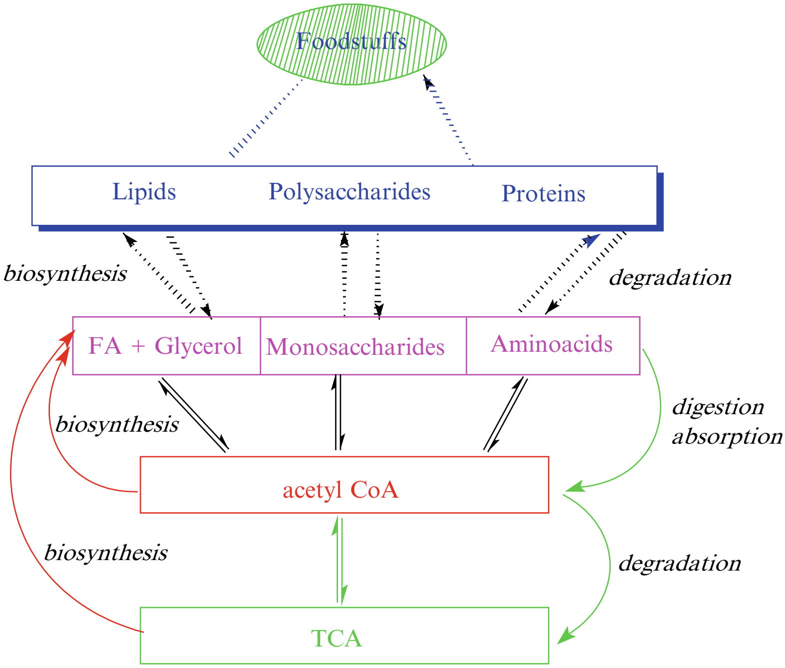
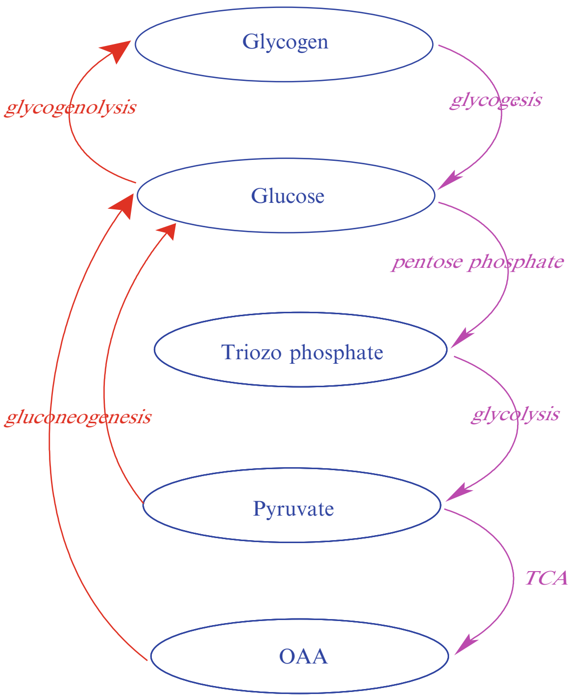



**Fig. 5** Systemic diagram on the metabolism of food substances in the organism (carbohydrates, lipids, proteins)

**Fig. 6** Systemic diagram displaying the link between metabolic routes of glucose



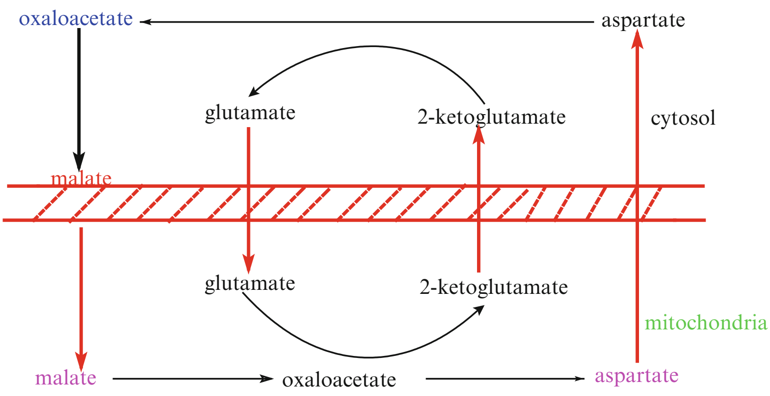



**Fig. 7** Systemic diagram displaying the relationship between cell organelles (mitochondria and cytosol)

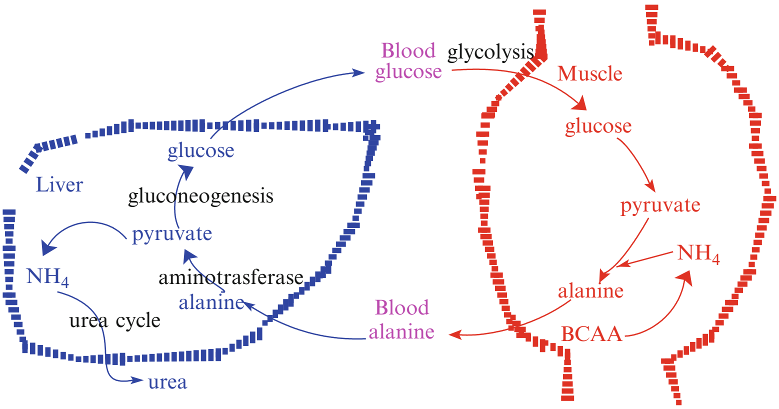
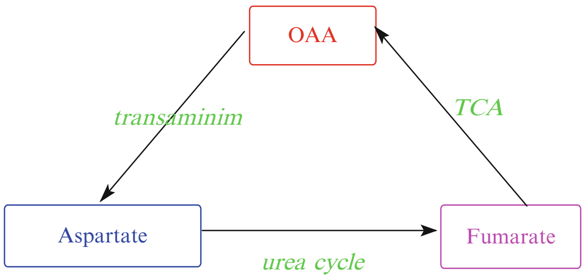



**Fig. 8** Systemic diagram displaying the relation between the liver and the muscles

displays the connection of the organs with each other (e.g., liver connects with the muscle through the blood, see Fig. 8) The nitrogen arising from the oxidation of BCAA in the skeletal muscle can be transferred back to the liver as alanine in the glucose-alanine cycle. The amino group of the BCAA (branched-chain amino acid) is first transferred to α-ketoglutarate to form glutamate and then transferred to pyruvate to form alanine by sequential transamination reactions (Alla, Conwan, & Stewart, 2004). The pyruvate arises principally from glucose via the glycolytic pathway. The alanine released from skeletal muscle is taken up principally by the liver, where the amino group is incorporated into urea, and the carbon skeleton can be converted back to glucose through gluconeogenesis. Aspartate, required for the operation of the cycle urea, synthesized from fumarate, a product of the urea, via the TCA cycle, followed by transamination, demonstrates the interrelation between cycles (urea and TCA) and transamination (see Fig. 9).

**Fig. 9** Systemic diagram displaying the relationship between cycles and metabolic pathways (OAA is oxaloacetate)



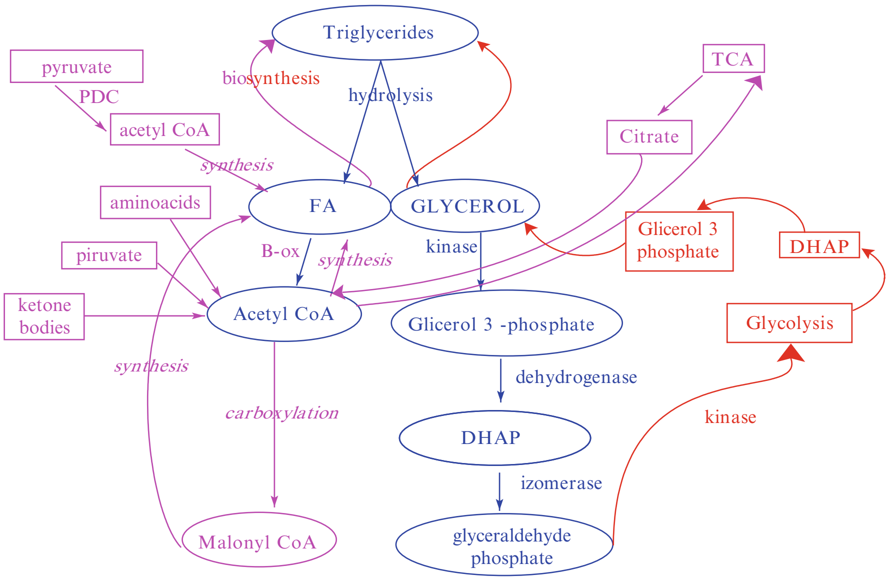




**Fig. 10** Systemic diagram on the metabolism of lipids (FA is fatty acids; DHAP is dihydroxyacetone phosphate; PDC is pyruvate dehydrogenese complex)

Acetil CoA has a major role in lipid metabolism, which is why we created the systemic diagram where the acetil CoA has a major role as well. Acetyl CoA can be formed by B-oxidation of fatty acids, decarboxylation of pyruvate, degradation of certain amino acids, converted ketone bodies, and intermediates of the TCA cycle (see Fig. 10).

Amino acids are building blocks for the synthesis of proteins and the source of carbon and nitrogen atoms for the synthesis of biomolecules. The anabolic reactions that produce amino acids have, as a starting point, the intermediates of the citric acids cycle that cross the mitochondrial membrane into cytosol (Kuchel & Gregory, 1988). Compared with the metabolism of carbohydrates and, lipids, the metabolism of amino acids is extremely complex (see Fig. 11).

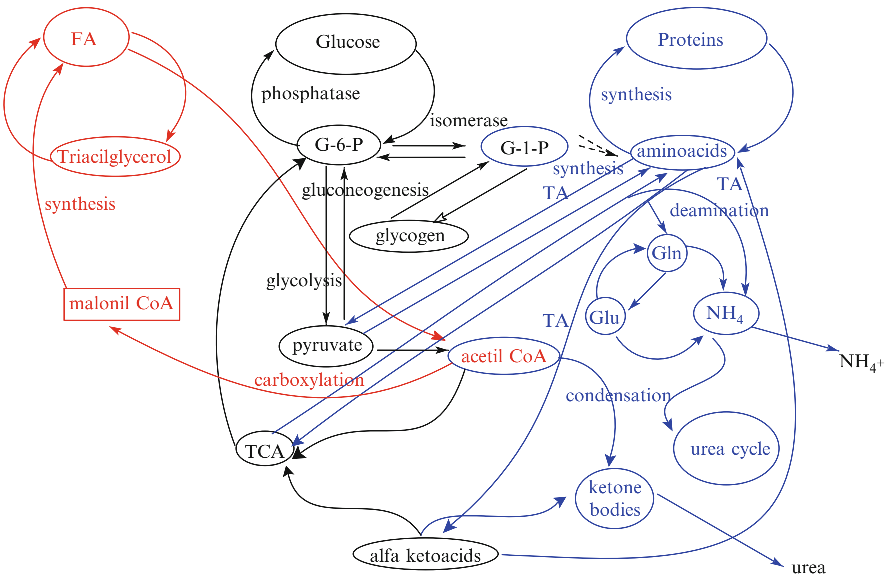



**Fig. 11** Systemic diagrams on the metabolism of proteins (Glu is glutamic acid; Gln is glutamina; TA is transaminase)

The citric acid cycle plays a central role in metabolism. Three main points can be considered in assigning a central role to the citric acid cycle. The first of these is the catabolism of carbohydrates, lipids, and proteins (as displayed in Fig. 12). The second is the function of the citric acid cycle in the anabolism of carbohydrates, lipids, and amino acids. The third and final point is the relationship between the individual metabolic pathway and the citric acid cycle (Norman & Iqbal, 2007).

## 2 Results

The systemic diagram shows that the food diet, mainly composed of carbohydrates, lipids, and proteins, dissolves and is absorbed. The organism is able to synthesize other compounds that the food diet does not contain in its cells. The components that the diet may or may not contain may be metabolized through four basic types of pathways:

- fuel oxidative pathways
- fuel storage pathways
- mobilization pathways, and
- detoxification

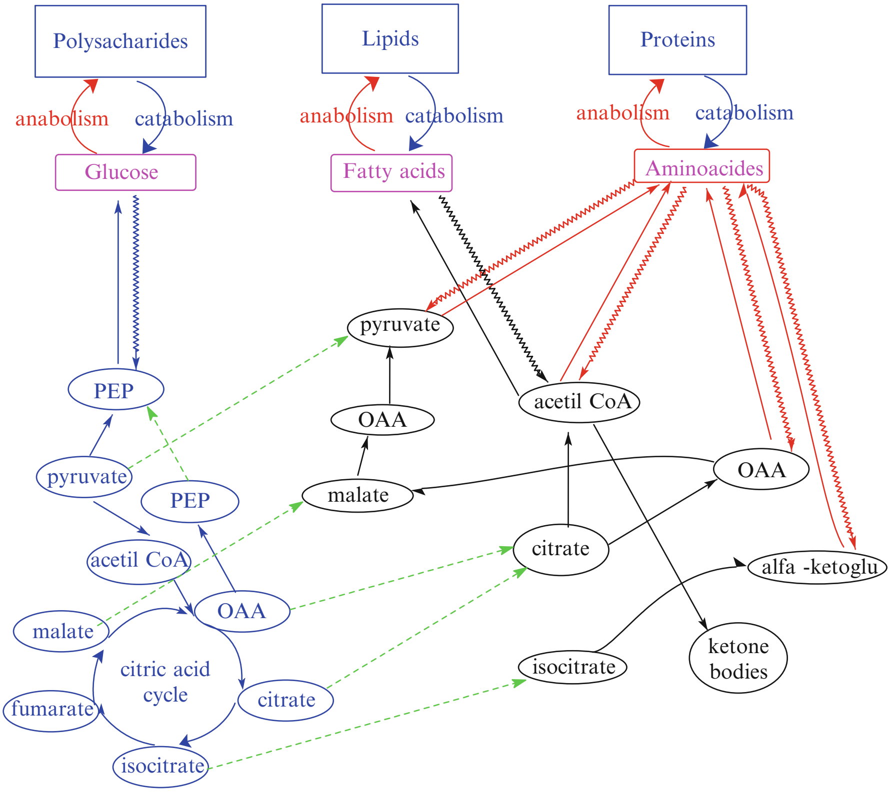



**Fig. 12** Systemic diagram displaying the relationship between carbohydrates, lipids, and proteins (PEP is phosphoenolpyruvate). The green dashed line denote connection of the organs with each other (Color figure online)

Fuel oxidative pathways convert fuel into energy and can be used for biosynthesis and mechanical work. However, what is the source of energy when we are not eating between meals and while we sleep? Organisms have other metabolic pathways that store fuel. The fuel that we store can be mobilized during periods when we are not eating or when we need increased energy for exercise. Metabolic transformations in organisms take place simultaneously, but their representation by means of special diagrams (Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11) is conditioned by didactic demands.

The communicating mechanisms and those that arrange the metabolic pathways constitute a unity of processes and phenomena. In this way, some amino acids produce acetyl CoA by means of the Krebs cycle, while others directly provide acetyl-CoA. The acetyl-CoA is transformed into carbohydrates, carbohydrates into lipids, PEP into carbohydrates, pyruvate into glucose, and so on.

These transformations are indivisible from each other, coordinated, and interrelated with each other. The entity of these processes is arranged by hormones (which will be the focus of another study).

## 3 Discussion and Conclusion

The systemic method brings a new vision to the education of biochemistry. Based on the result from the students, one may conclude that the application of the systemic method in teaching and learning biological chemistry is more successful compared with the traditional linear teaching. This method increases the participation of the students in class (e.g., when they participate to create the diagram).

With the application of this method students can:

- provide the most relations between concepts, metabolic processes, cell organelles, and the organs in which they develop through the systematic diagrams
- organize thinking in the process of systemic diagram completion
- complete difficult systematic diagrams through systemic thinking
- improve perception by increasing their observation skills
- learn through creation and not through reproduction; therefore, they could increase their creativity

By means of this method:

- empirical questions can be developed
- biochemical problems can be solved
- practice, as an important component for the study of biochemistry, can be carried out successfully
- students' performance can be assessed.

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# Part IV
# Curriculum and Assessment in Chemistry Education

**Mei-Hung Chiu**

The alignment among curriculum standards, instruction, assessment, and evaluation plays an important role in educational reform. The outcomes from assessment and evaluation shape effective and constructive instructional materials and programs from which teacher professional development should be implemented. Six chapters are included in this section. First, Ma, Fulmer, Liang, Chen, Li, and Li adopted Porter's method of analysis of textbooks to investigate the alignment of chemistry curriculum standards of junior high school and 9th graders' exit examinations in three cities in China. They found that as a result of a shift of curriculum standards from merely content-oriented to higher-order cognitive competence, a misalignment between standards and assessment was found. Second, Lin and Chiu used an alternative assessment format, the two-tier diagnostic instrument, to investigate secondary school students' conceptions of chemical equilibrium and acid/base. The results revealed that even high school students still did not possess a well-developed understanding of chemical equilibrium concepts and ionization. Misconceptions related to macroscopic, microscopic, and symbolic representation by the students were also found. These findings revealed that the students might be able to memorize factual information but were not able to provide high-quality explanations for scientific phenomena. The third chapter, by Burns and Frank, proposes an alternative assessment, learning logs, to evaluate the effectiveness of a college chemistry course. They found that, based upon qualitative analysis from learning logs, the instructor was able to reflect and improve his teaching in chemistry. Lay and Khoo investigated how the learning environment in schools influences students' learning in Malaysia. The results revealed that there is a significant difference in the perceptions of the tertiary chemistry learning environment between primary and secondary school pre-service chemistry teachers. The questionnaire they developed could be used

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for teacher professional development. The female students perceived their tertiary chemistry learning environment more favorably compared with male students, even though it did not reach the significance level. The fifth chapter, by Yang, Hsu, and Wang, assessed freshmen's chemistry competence at technology colleges. The results showed that the students had high motivation to pursue their advanced studies but were lacking in understanding regarding some chemistry concepts, namely, structures of atoms, molecules, and ions, which are microscopic concepts. This result is consistent with the research in the literature. Finally, Chen and Chiu investigated how chemistry teachers changed their views of cognitive apprenticeship for chemistry laboratory via working with science educators. They found that with a longitudinal collaboration between school teachers and researchers, conceptions of ideal teaching style should involve a cognitive apprenticeship approach. Therefore, perceptions of instructional strategies were changed in a constructive manner.

# An Alignment Analysis of Junior High School Chemistry Curriculum Standards and City-Wide Exit Exams in China

**Hongjia Ma, Gavin W. Fulmer, Ling L. Liang, Xian Chen, Xinlu Li, and Yuan Li**

## 1 Introduction

The most recent science education curriculum reform in China was initiated through the "Outline of Curriculum Reform of Basic Education" issued by the Ministry of Education (MoE) of the People's Republic of China in 2001 (Ministry of Education, 2001). At the junior high school level, according to the *Outline*, science might be taught using either separated subject-based curricula (i.e., physics, chemistry, and biology) or integrated science curriculum. The corresponding national curriculum standards and curriculum materials were also developed around the same time period. During 2001 and 2002, there were about 500 counties and regions participating in the experimental stage of the implementation of new curricula. By 2010, the new curriculum standards and corresponding curriculum materials had been implemented in more than 80% of the provinces and cities in China (Wang, 2002).

The national curriculum standards are intended to function as the basis of curriculum development, classroom instruction, and examinations (Ministry of

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Education, 2001). Whereas the new curriculum standards have been in effect for about 10 years, the following two key issues remain unresolved:

1. There is a mismatch between the teaching practices and the theories of learning and instruction underlying the new curriculum. In other words, teachers generally accept the underlying philosophy of the new curriculum and standards but continue to adopt traditional chemistry conceptual frameworks and teacher-centered instructional methods in classroom teaching.
2. There is a mismatch between the content and assessment of curriculum. Teachers tend to teach for the high-stakes exams. Content in the curriculum standards but not emphasized in the exams is likely to be neglected by teachers.

Therefore, to ensure the success of the standards-based science education reform, it is important to examine the fidelity of implementation of the new curriculum and standards. Given the exam-driven tradition of the Chinese K-12 education system, we decided to begin our fidelity research with an analysis of the alignment between the curriculum standards and the standardized exams.

## 2 Purpose of the Study

This study examines the alignment between the national chemistry curriculum standards (7–9) and the 2009 9th grade exit exams in Nanjing (NJ), Nantong (NT), and Yangzhou (YZ) cities. We will examine both content and cognitive demands as reflected in the curriculum standards and exit exams, and discuss the implications of the study at the end of this chapter.

## 3 Significance of the Study

As an attempt to examine the alignment between the 9th grade exit exams and the junior secondary school chemistry curriculum content standards in China, the current study is significant in several ways: First, the results of the study provide a reliable source of information for science educators, educational policymakers, and teachers to reflect upon learning, instruction, classroom assessment, and external evaluation issues. The alignment analysis may lead to further development and refinement of curriculum standards, textbooks, examinations, and classroom instruction as well. Second, this study will stimulate discourse on the fairness of educational assessment and evaluation systems. There are generally serious consequences associated with high-stakes, standardized exams. Regardless of the type of assessment used or how the assessment results are to be used, *validity* (i.e., the adequacy and appropriateness of the use of assessment tools) and *reliability* (i.e., the consistency of the assessment results) are two of the most essential characteristics (Linn & Miller, 2005). The alignment analysis will assist the improvement of assessment systems by providing new evidence of content validity of the assessment tools, in addition to the traditional reliability and difficulty indexes. Furthermore, although previous studies have reported results of the alignment analysis between the Chinese national physics curriculum guidelines and the provincial-level 12th grade exit exams (Liang & Yuan, 2008; Liu et al., 2009), no alignment research has been done at the junior secondary school level. The current study will contribute to the discourse on the establishment of a reasonable or desirable level of alignment for the standardized exams with certain unique characteristics of a combined norm-referenced and criterion-referenced nature.

# 4 Methods

In this section, we describe the general characteristics of the 9th grade exit exams, the content analysis of the curriculum content standards and the exams, and how the alignment indexes are produced.

## *4.1 Standardized 9th Grade Exams*

At the compulsory education stage in China, the junior high schools in most Chinese provinces carry out traditional disciplinary courses: biology, physics, and chemistry. Students take biology at 7th grade, physics from 8th to 9th grade, and chemistry at 9th grade. When students graduate at 9th grade, they should take the exit examination, including physics and chemistry (the biology examination was finished at the end of 8th grade).

Jiangsu is located on the eastern seaboard of China, which is more economically developed than other provinces of China. The three cities (NJ, NT, and YZ) in Jiangsu were selected because of their history of leadership in standardized testing and educational reforms in China. The findings of the study would have implications to other provinces adopting a standardized assessment system similar to Jiangsu.

The schools in Jiangsu province offer the traditional disciplinary courses. Students must take standardized exit exams before they graduate. We chose the chemistry exit examination in 2009 in Nanjing, Nantong, and Yangzhou cities within Jiangsu as our research samples.

In 2009, the contents of the mathematics and physics tests were both controlled by the Jiangsu province, while other test subjects and investigating subjects were organized by individual cities.

There are two main functions for the exit examination. On the one hand, the exit examination in Jiangsu province can assess whether the students have mastered the content required at the stage of junior high school. On the other hand, students' scores will determine which high school they can attend. Therefore, this is deemed as one of the most important examinations by students, parents, teachers, and principals of junior high schools.

### 4.2 Analysis of the Curriculum Content Standards and Exams

The fundamental goal of the new Chinese science curriculum standards is to develop scientific literacy for all students. All science curriculum standards share a common framework defined by three dimensions: knowledge and skills; processes and methods; and emotions, attitudes, and values.

The chemistry curriculum content standards consist of five themes, each of which includes several sub-themes. In addition, a number of benchmark statements are listed under the sub-themes.

To further classify the contents based on the cognitive demands, we used the revised Bloom's taxonomy (Anderson & Krathwohl, 2001), that is, remember, understand, apply, analyze, evaluate, and create, to represent the cognitive reasoning skills as described in the curriculum standards. For instance, the benchmark statement "students will know the sources and possible harm of some typical pollutants" was mapped into the content theme "Chemistry and Societal Development" because of its connection to social issues, and to the cognitive level "Remember" because the statement uses the verb "know." Table 1 presents the chemistry curriculum standards in two-dimensional matrices.

One chemistry education professor and two graduate students conducted the data analysis. The average inter-coder reliability was 0.891 for the curriculum content standards, and 0.613–0.799 for the exams, respectively. The final results were produced by resolving the disagreements through face-to-face discussions among the research team members. Tables 2, 3, 4 present the exams by theme and by cognitive level based on number of points.

### 4.3 Measurement of Alignment

In this study, we adopted the definition of alignment as "the degree of agreement between a state's content standards for a specific subject area and the assessment(s) used to measure student achievement of these standards" (Bhola, Impara, & Buckendahl, 2003, p. 21). The index of alignment was calculated using Porter's method (Porter, 2002). In Porter's model, in order to determine alignment between curriculum standards and tests, two tables are created (one for representing the curriculum standards and the other for exam). Each table is a two-dimensional matrix in which the rows represent content and columns represent levels of cognitive demand. Then an alignment index is produced by comparing the level of agreement in cell values of the two matrices, both of which were standardized by converting all cell values into proportions out of the grand total. The formula for calculating the Porter alignment index (P) is as follows:

$$\mathrm{P} = 1 - \frac{\sum_{i=1}^{n} |(Xi - Yi)|}{2}$$

**Table 1** Chemistry curriculum content standards by theme and by cognitive demand

| Theme | Sub-Theme | Remember | Understand | Apply | Analyze | Evaluate | Create | Subtotal |
|---|---|---|---|---|---|---|---|---|
| Scientific inquiry (SI) | A better under standing of scientific inquiry; improving the ability of scientific inquiry; learning about the basic skills and ability to conduct experiments | 5(0.06) | 3(0.03) | 7 (0.08) | 1(0.01) | 1(0.01) | 2(0.02) | 19(0.21) |
| Chemical substances around us (CSAU) | The atmosphere around the earth; water and common solution; metals and metallic minerals; common compounds in daily lives | 17(0.20) | 4(0.05) | 4(0.05) | 0(0.00) | 0(0.00) | 0(0.00) | 25(0.30) |
| Matter composition (MC) | Diversity of matter; particulate nature of matter; chemical elements; symbols of substance compositions | 8(0.09) | 5(0.06) | 2(0.02) | 1(0.01) | 0(0.00) | 0(0.00) | 16(0.18) |
| Chemical changes (CC) | Characteristics and classification of chemical changes; the law of conservation of mass | 4(0.05) | 4(0.05) | 1(0.01) | 0(0.00) | 1(0.01) | 0(0.00) | 10(0.12) |
| Chemistry and societal develop-ment (CSD) | The relation between chemistry and energy resources; the usage of natural resources; common synthetic materials; chemicals and human health; environment protection | 14(0.16) | 3(0.03) | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | 17(0.19) |
| Subtotal | | 48(0.56) | 19(0.22) | 14(0.16) | 2(0.02) | 2(0.02) | 2(0.02) | 87(1.00) |

Note: Number of content statements is reported. The values in parentheses are the proportion of points in the respective cell to the total number of statements coded

**Table 2** Chemistry exam by theme and by cognitive demand based on number of points in Nanjing City (NJ)

| Theme | Remember | Understand | Apply | Analyze | Evaluate | Create | Subtotal |
|---|---|---|---|---|---|---|---|
| SI | 3(0.04) | 3(0.04) | 1(0.01) | 0(0.00) | 0(0.00) | 2(0.03) | 9(0.11) |
| CSAU | 7(0.09) | 5(0.06) | 6(0.08) | 3(0.04) | 0(0.00) | 0(0.00) | 21(0.26) |
| MC | 4(0.05) | 11(0.14) | 5(0.06) | 0(0.00) | 0(0.00) | 0(0.00) | 20(0.25) |
| CC | 2(0.03) | 6(0.08) | 2(0.03) | 2(0.03) | 2(0.03) | 0(0.00) | 14(0.18) |
| CSD | 8(0.10) | 8(0.10) | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | 16(0.20) |
| Subtotal | 24(0.30) | 33(0.41) | 14(0.18) | 5(0.06) | 2(0.03) | 2(0.03) | 80(1.00) |

Note: Number of test points is reported. The values in parentheses are the proportion of points in the respective cell to the total number of statements coded

**Table 3** Chemistry exam by theme and by cognitive demand based on number of points in Nantong City (NT)

| Theme | Remember | Understand | Apply | Analyze | Evaluate | Create | Subtotal |
|---|---|---|---|---|---|---|---|
| SI | 6(0.060) | 4(0.040) | 2(0.020) | 0(0.000) | 0(0.000) | 0(0.000) | 12(0.120) |
| CSAU | 20(0.200) | 18.5(0.185) | 5(0.050) | 3(0.030) | 0(0.000) | 2(0.020) | 48.5(0.485) |
| MC | 1(0.010) | 11(0.110) | 4(0.040) | 0(0.000) | 0(0.000) | 0(0.000) | 16(0.160) |
| CC | 0(0.000) | 6.5(0.065) | 2(0.020) | 4(0.040) | 0(0.000) | 0(0.000) | 12.5(0.125) |
| CSD | 4(0.040) | 7(0.070) | 0(0.000) | 0(0.000) | 0(0.000) | 0(0.000) | 11(0.110) |
| Subtotal | 31(0.310) | 47(0.470) | 13(0.130) | 7(0.070) | 0(0.000) | 2(0.020) | 100(1.000) |

Note: Number of test points is reported. The values in parentheses are the proportion of points in the respective cell to the total number of statements coded

**Table 4** Chemistry exam by theme and by cognitive demand based on number of points in Yangzhou City (YZ)

| Theme | Remember | Understand | Apply | Analyze | Evaluate | Create | Subtotal |
|---|---|---|---|---|---|---|---|
| SI | 3(0.03) | 2(0.02) | 7(0.07) | 1(0.01) | 1(0.01) | 2(0.02) | 16(0.16) |
| CSAU | 10(0.10) | 21(0.21) | 0(0.00) | 2(0.02) | 0(0.00) | 0(0.00) | 33(0.33) |
| MC | 5(0.05) | 7(0.07) | 4(0.04) | 1(0.01) | 0(0.00) | 0(0.00) | 17(0.17) |
| CC | 2(0.02) | 9(0.09) | 4(0.04) | 8(0.08) | 0(0.00) | 0(0.00) | 23(0.23) |
| CSD | 5(0.05) | 6(0.06) | 0(0.00) | 0(0.00) | 0(0.00) | 0(0.00) | 11(0.11) |
| Subtotal | 25(0.25) | 45(0.45) | 15(0.15) | 12(0.12) | 1(0.01) | 2(0.02) | 100(1.00) |

Note: Number of test points is reported. The values in parentheses are the proportion of points in the respective cell to the total number of statements coded

In this equation, $n$ is the total number of cells and $i$ refers to a specific cell in each matrix, ranging from 1 to $n$. For example, for a 3×4 table, there are 12 cells, thus, $n = 12$. $X_i$ refers to the $i$th cell in Table X (e.g., the standardized exam matrix) and $Y_i$ refers to the corresponding cell in Table Y (e.g., the curriculum content standards matrix). Both $X_i$ and $Y_i$ are ratios with a value from 0 to 1. The sum of $X_1$ to $X_n$ is equal to 1, so is the sum of $Y_1$ to $Y_n$. The discrepancy between the $i$th cells of the test table and standard table can be calculated as $X_i - Y_i$. The total absolute discrepancy is then calculated by summing the absolute discrepancies over all cells. The values of this index range from 0 (indicating no alignment) to 1 (indicating perfect alignment). In the current study, the chemistry curriculum content standard and exam were represented in 5×6 matrices. In order to find the critical value of the alignment index, we followed Fulmer's (2011) method, using an algorithm in Microsoft Visual Basic for Applications to place the curriculum points and test points (100 each) into two tables randomly (five rows and six columns; see explanations in the next section) and calculated alignments between each pair of tables. This simulation algorithm was repeated for 20,000 iterations, and the alignment indices calculated each time. This process yielded a normal distribution with mean of 0.71 and standard deviation of 0.042, which was stable along all iterations. Therefore, we needed an alignment index of 0.78 for it to be statistically significant at the .05 level on the basis of the random sampling distribution from this algorithm (Fulmer, 2011).

## 5 Results

### *5.1 Alignment of the Chemistry Exam and the Curriculum Content Standards*

The Porter alignment index was 0.63 for both Nanjing City and Nantong City, and 0.61 for Yangzhou City. Compared with the aforementioned critical value (0.78) derived from the random sampling distribution as described in the methods section, the results suggested that the chemistry exam was not statistically significantly aligned with the chemistry curriculum content standards. The comparisons between the curriculum emphases and the content distribution in the exam are presented in the figures below.

Figure 1 presents the comparison between the curriculum emphasis and the test emphasis for NJ City. The two topographs, derived from Tables 1 and 2, show the relative emphasis levels ranging from "0–0.05 (or 0–5%)" to "0.15–0.2 (or 15–20%)"

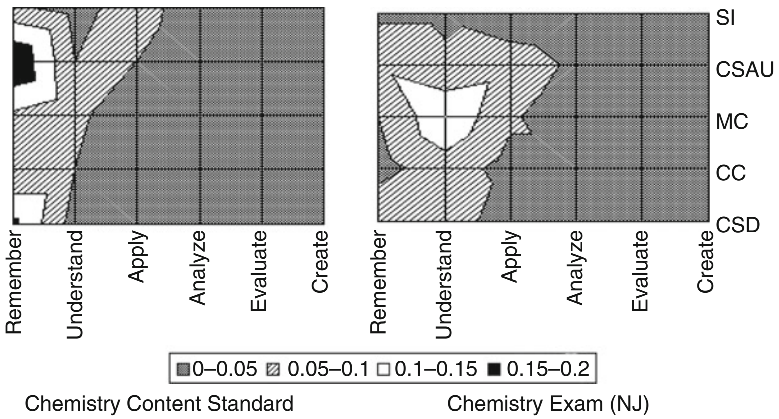


**Fig. 1** Topograph of comparison between the chemistry content standards and the exam by theme and by cognitive level (NJ)

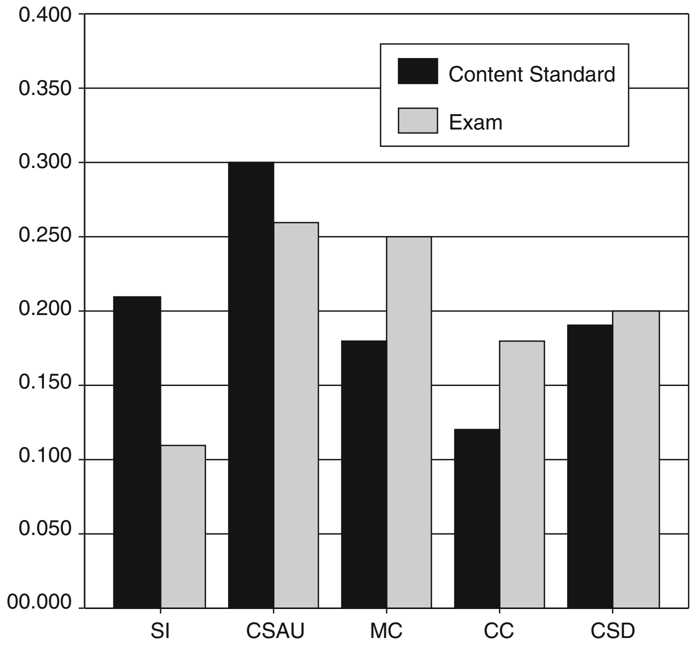


**Fig. 2** Comparison between the chemistry content standards and the exam by theme (NJ)

for the curriculum standards and from "0–0.05 (or 0–5%)" to "0.1–0.15 (or 10–15%)" for the exam. The black areas indicate the heaviest emphasis in both topographs. We can see that there are two black areas in the curriculum standard, one for the theme of CSD and cognitive level of Remember, and another for CSAU and Remember, but there is not a black area in the exam. Another discrepancy between the two topographs is an overall shift from curriculum to test toward higher cognitive skills by de-emphasizing Remember and emphasizing Understand for CSD, CC and MC. That is, the graphics "move right" from curriculum standard to exam. The dissimilarities between the shapes of the curriculum and the exam topographs indicate a lack of alignment between the two.

According to Figs. 1 and 2, the exam covered all of the themes described in the curriculum standards but the proportions are different for NJ City. For instance, the theme most emphasized in the curriculum standards is "Chemical Substance Around Us" (30%). In the exam, the theme of CSAU is also the most heavily weighted but with a slightly lower proportion (26%). The biggest discrepancy is found to be on the "scientific inquiry" theme, where the proportion is 21% in the curriculum standards but only 11% in the exam.

Compared with the curriculum standards, the analysis of the exam items indicates that there is a general shift toward higher cognitive demands for NJ City (Figs. 1 and 3). The greatest difference identified is the shift from the "Remember" level to the "Understand" level. In the content standards, about 56% of the content is required at the "Remember" level and 22% at the "Understand" level. In the exam, however, about 30% of points were devoted to the "Remember" and 41% of points were devoted to "Understand."

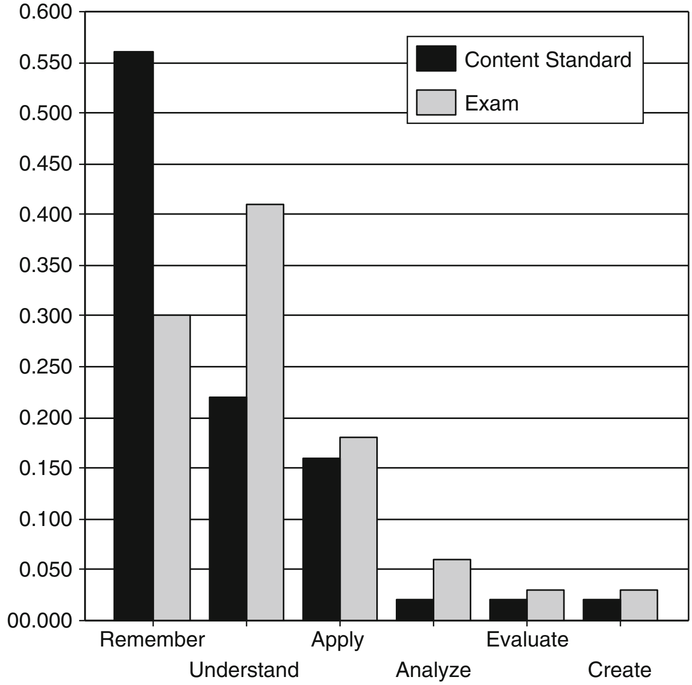


**Fig. 3** Comparison between chemistry content standards and exam by cognitive level (NJ)

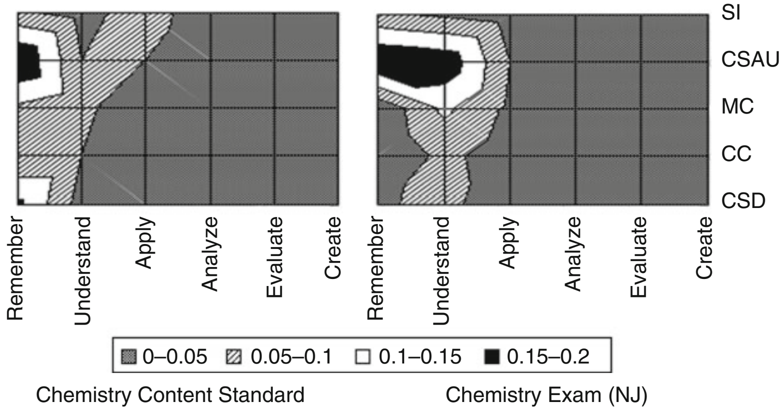


**Fig. 4** Topograph of comparison between the chemistry content standards and the exam by theme and by cognitive level (NT)

Figure 4 presents the comparison between the curriculum emphasis and the test emphasis for NT City.

The black areas indicate the heaviest emphasis both in the two topographs. We can see that both topographs have black areas, but in the curriculum standard there are two black areas, one for the theme of CSD and for cognitive level of Remember, and another for CSAU and Remember, whereas in the exam there is only one for

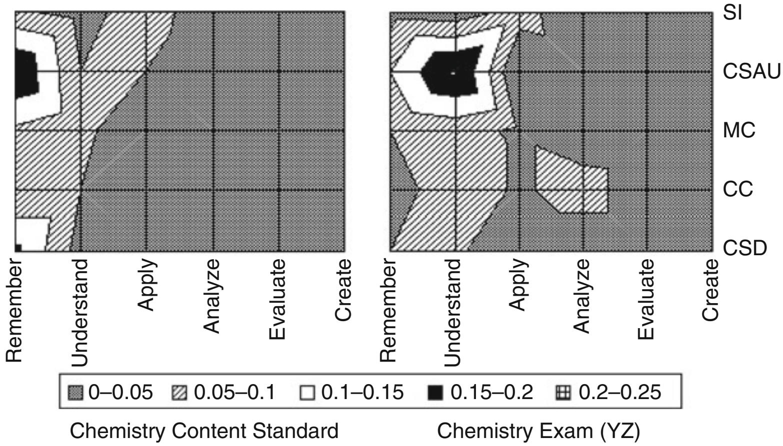


**Fig. 5** Topograph of comparison between the chemistry content standards and the exam by theme and by cognitive level (YZ)

CSAU and Remember, Understand. The white areas also show this dissimilarity. Another discrepancy between the two topographs is that an overall shift from curriculum to test toward higher cognitive skills by de-emphasizing Remember and emphasizing Understand for CSD, CC and MC. Overall, the two patterns of the curriculum emphasis and the test emphasis are different, indicating a lack of alignment between the two.

From Table 1 and Table 3, we can find that the exam covered all of the themes described in the curriculum standards, however, there exist some dissimilarities for NT City. For example, the curriculum standard most emphasizes "CSAU" (30%), as does the exam, but the proportion is higher (48.5%). It is also the biggest discrepancy between the curriculum standard and the exam.

Compared with Tables 1 and 3, we find that there is a shift from lower cognitive level toward higher level for NT City. For example, in the curriculum standard the proportion of Remember level is 56%, but in the exam the proportion is 31%. Meanwhile, in the curriculum standard the proportion of Understand level is 22%, and in the exam the proportion is 47%. We also can see there is a lack of "Evaluate" cognitive level in the exam.

Figure 5 presents the comparison between the curriculum emphasis and the test emphasis for YZ City. We can see some dissimilarities. In the exam there is a "window pane" area (ratio between 0.2 and 0.25), which is for the topic of CSAU and for the cognitive level of Understand. Again, we can see the graphics "move right" from curriculum standard to exam and the different numbers of black area. Overall, the two shapes of the curriculum emphasis and the test emphasis are different, indicating a lack of alignment between the two.

From Tables 1 and 4, we find that the exam covered all of the themes described in the curriculum standard, but there are some dissimilarities for YZ City.

For instance, the theme most emphasized in the curriculum standard is CSAU (30%); in the exam it is also the most heavily weighted but with a slightly higher proportion (33%). And the greatest discrepancy is about the theme CC, where the proportion is 12% in curriculum standard but 23% in the exam.

Comparing Tables 1 and 4, there is a shift from lower cognitive level Remember toward higher cognitive level Understand for YZ City. For example, in the curriculum standard the proportion of Remember level is 56%, but in the exam the proportion is 25%. Meanwhile, in the curriculum standard the proportion of Understand level is 22%, and in the exam the proportion is 45%. There is also a greater dissimilarity between Analyze cognitive level; in the curriculum standard the proportion of Analyze level is 2%, while in the exam the proportion is 12%.

## 6 Discussion

The results of the study revealed that there is a general lack of alignment between the national junior high school chemistry curriculum standards and the 9th grade level exit exams. Such misalignment was primarily due to two reasons: (1) there is an overall shift from curriculum standards to the exams toward higher cognitive demands by underemphasizing "Remember" and overemphasizing "Understand" and "Apply;" and (2) the curriculum themes or topics were disproportionally represented in the exams. These findings are consistent with what has been reported in the Chinese high school physics education studies (Liang & Yuan, 2008; Liu et al., 2009). In the following section, we will discuss some issues directly related to the results of the study.

First, the lack of alignment between the curriculum standards and the high-stakes tests may influence teaching in different ways. On the one hand, when the tests demand higher cognitive skills than the curriculum standards do, teachers will certainly focus on the development of students' higher-order thinking in instruction. This could be considered a positive effect. On the other hand, given the limited instructional time, while the teachers provide more classroom time for students to practice the problems similar to the nature of the test items to achieve higher test scores, other curriculum contents/skills less emphasized in the tests might be largely ignored, which will negatively impact the implementation of new standards-based curricula.

Second, although the validity of content standards is not addressed in this research project, the lack of alignment might prompt Chinese science educators to reexamine the validity of the curriculum standards based on empirical evidence. The results of the alignment studies will not be meaningful unless we are certain that the content standards are both theoretically and empirically sound.

Third, it has been generally agreed that the highest cognitive levels such as "Evaluate" and "Create" are hardly assessed through paper-and-pencil tests. They might be more appropriately addressed through performance-based practical tests. In fact, starting in 2010, practical lab-based tests have been integrated into the exit assessment system.

A "pass" or "fail" grade is assigned based on the student's performance and the grade are used as a reference for schools and related decision makers.

Fourth, the 9th grade exit exams serve two functions. On the one hand, the test results indicate how well the students have achieved the compulsory curriculum standards that emphasize scientific literacy for all. The exams therefore should be criteria-referenced. On the other hand, the students will be "selected" into the senior high schools based on their scores on the exit tests. The exams therefore should also be norm-referenced. Such unique features of the exams challenge us to think: If perfect alignment is not desirable in this case, then to what degree should the exit tests be aligned with the curriculum standards? This question will not be answered by statistics alone. Teachers and other stakeholders should also join in this conversation.

Finally, there are some limitations in our data analysis. For instance, the themes and sub-themes described in the curriculum standards are classified as general key concepts or contents. The amount of instructional coverage time devoted to each theme and/or sub-theme is different depending on the classified nature of the content. In our analysis, no weights on the instructional coverage time on each theme were assigned, which may have contributed to the findings of misalignment. We suggest that such weighting issues be considered in future analyses.

## 7 Implications and Recommendations

Alignment research can help science educators, teachers, and educational policymakers make informed decisions about effective teaching and student learning. As mentioned previously, classroom instruction has always been subject to high-stakes examination pressure in China. In other words, for any standards-based reform to be successful, the reforms of high-stakes assessment systems are most critical.

Alignment research also provides us a road map toward the establishment of a more valid assessment system by showing us where improvements are needed and how to achieve the goal of "fairness." For instance, through the alignment analysis in the current study, it was found that there is an overall shift from curriculum standards to the exams toward higher cognitive demands in all of the three cities. We therefore suggest that the alignment studies be routinely conducted as a way to monitor the quality of high-stakes exams. Furthermore, classroom instruction should be added to the alignment equation. Teachers should be provided with professional development on issues involving effective classroom instruction, paper-and-pencil tests, performance-based assessments, and so on. We believe that it is the concerted efforts of stakeholders (e.g., science educators, teachers, educational policymakers, test developers, etc.) that will determine the level of success of the new curriculum reform in China. We hope that the findings of this study will stimulate discourses on the advancement of science curricula, instruction, and assessment within the international science education community.

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# A National Survey of Students' Conceptions and Their Sources of Chemistry in Taiwan: Examples of Chemical Equilibrium and Acids/Bases

**Jing-Wen Lin and Mei-Hung Chiu**

## 1 Introduction

Constructivism claims that students' prior knowledge influences their future science learning. Therefore, it is valuable that teaching strategies accept students' pre-existing experiences or ideas as a starting point (Tsai & Chou, 2002). Since 1980, science educators have widely surveyed and categorized students' prior knowledge in various domains, known as "misconceptions" or "alternative conceptions." Some of these alternative conceptions have something in common all over the world, while others are unique and are influenced by specific elements of Taiwanese culture. However, due to a lack of systematic data, these commonalities and particularities are not fully known. Moreover, improving Taiwanese students' science learning must start by uncovering their learning difficulties. For this reason, it is important to build a basic database for Taiwanese students' conceptions. In this connection, the National Science Council in Taiwan conducted a large-scale integrated project, the National Science Concept Learning Study. This study took 4 years (from 2000 to 2003) to systematically investigate Taiwanese students' types, developmental trends, and sources of their alternative conceptions in chemistry, physics, and biology. This study, "An investigation of exploring mental models and causes of secondary school students' alternative conceptions in acids/bases, particle theory, and chemical equilibrium" (Chiu, 2004), is one of the sub-projects. For the sake of brevity, this chapter only analyzes and

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discusses the two essential topics, "chemical equilibrium" and "acids/bases" of the national survey in 2003. The research questions examined in this chapter are:

1. What are the developmental tendencies of Taiwanese high school students' concepts on chemical equilibrium and acids/bases?
2. What are Taiwanese high school students' main alternative conception types on chemical equilibrium and acids/bases?
3. What are the sources that influence students' learning related to chemical equilibrium and acids/bases?

## 2 Theoretical Framework

### *2.1 Students' Ideas on Chemical Equilibrium*

Chemical equilibrium is the core concept of chemistry, and it is difficult for students to learn (Gussarksy & Gorodetsky, 1990; van Driel, 2002). The key point of this concept is the characteristic of bidirectional and dynamic reaction. However, in the teaching process, this characteristic is usually displayed by macro and visible phenomena, such as examples, color changes, solids precipitation, or heat generation. Consequently, these representations often make students misunderstand that a chemical reaction is a uni-directional reaction with a terminal point (Andersson, 1990). Moreover, even though students can recognize the dynamic process of a chemical reaction, they usually believe a forward and a reverse reaction would take place by turns (van Driel, de Vos, Verloop, & Dekkers, 1998). In Chiu, Chou, and Liu's (2002) study, they indicate further that students might believe a forward reaction would terminate before a reverse one.

The conception of chemical equilibrium is related to the macro, micro, and symbolic levels. Because scientific and everyday language can be different, students also have difficultly transforming these representations (Pedrosa & Dias, 2000). Bergquist and Heikkinen (1990) point out that students might be influenced by the representation of chemical equations and misunderstand reactants and products are separate with no interaction. Other common alternative conceptions include misapplying Le Chatelier's principle with the concentration of reactants and products as equal in equilibrium (Huddle & Pillay, 1996).

### *2.2 Students' Ideas on Acids/Bases*

How do students conceptualize these important concepts? Besides the Scientific Model, Lin and Chiu (2007) categorize middle school students' alternative framework of acids/bases into three mental models. They are the "Phenomenon Model," the "Character-Symbol Model," and the "Inference Model." The characteristic of the Phenomenon Model is that students view acids as substances with specific attributes and macroscopic characteristics. It is known that students who adhere to the Phenomenon Model are affected greatly by diverse daily experiences such as students' sense of taste (Nakhleh & Krajcik, 1994; Toplis, 1998). But Lin and Chiu point out that these daily experiences today have broadened to TV media. The characteristic of the Character-Symbol Model is that students perceive acids as substances that contain particular chemicals. So, students could use specific words, symbols, or names of functional groups as criteria. In Schmidt's (1991) study, he also suggests that some terms, such as "neutralization," act as hidden persuaders that mislead students to form misconceptions. Therefore, teachers should notice the language in teaching. They should help students to discuss the limitations of these "hidden persuaders" and the differences between the Character-Symbol Model and Scientific Model. As to the Inference Model, this is characterized by students inaccurately linking some fragmentary scientific concepts. Take the topic of "neutralization," for instance, the neutralization reaction produces salt, and then salt hydrolysis affects the acidity or basicity of a solution. However, students link these scientific concepts incorrectly, and they usually use the quantity or concentration of $[H+]$ or $[OH-]$ as the main criterion to decide the acidity or basicity of a solution.

### *2.3 Two-Tier Diagnostic Instrument*

With regard to the methods for exploring students' alternative conceptions, Wandersee, Mintzes, and Novak (1994) found more than 14 types in a review of the literature. Among them, interviewing is one of the most commonly used methods for identifying students' existing conceptions. Although an interview is quite valuable, teachers cannot implement them readily due to their often heavy teaching load, limited time, and the necessary additional training. Another commonly used method is a multiple choice test, a kind of pencil-and-paper test for easy quantification. With large numbers of participants, researchers could compare students' and scientists' differences. This method is quite suitable for summative assessment (Treagust, 1995; Wandersee et al., 1994). With regard to the development of a two-tier diagnostic instrument, this instrument combines the advantages of an interview with the benefits of traditional multiple choice tests. Besides, it improves upon their drawbacks. Treagust (1995) claimed this tool had great potential to unlock students' alternative conceptions and then provide instant feedback. It is an efficient tool to assist teachers capturing students' ideas in a limited time. However, it should be noted that this instrument uncovers students' existing conceptions rather than providing summative assessment. Its results highlight students' current knowledge rather than a comparison with science knowledge. Peterson, Treagust, and Garnett (1989) point out that only students whose correct answer combinations include both the first (declarative knowledge or phenomenon) and the second (reasons) tiers demonstrate true understanding. Otherwise, their conceptions are misconceptions. This way, students could not choose a correct combination simply by guessing. Therefore, this method is superior to the traditional one. On the other hand, if the percentage of any incorrect combination is higher than 20%, it indicates this alternative conception type is quite representative. With a more cautious attitude, we used 15% as a benchmark to select students' alternative conceptions in this study.

For diagnosing students' alternative conceptions effectively, developing a two-tier diagnostic instrument includes several conscientious procedures. For example, collecting students' ideas by open questionnaire or interview, creating a concept map as well as propositions, examining and revising test items repeatedly, and building reliability and validity. This procedure takes considerable time and effort. However, it is expected that teachers could apply this instrument for assessment and instruction. With this instrument, teachers could collect the students' most popular ideas in a short time and improve their instruction. The aim of the National Science Concept Learning Study was to collect students' alternative concepts by type and developmental tendency to build a basic database of students' preconceptions; therefore, it adopts a two-tier diagnostic instrument to attain this aim.

## 3 Methodology

### *3.1 Participants*

This study involved 6,989 junior and 2,934 senior high school students in Taiwan. These students were selected based on the stratified sampling method that was adopted from the TIMSS (e.g., location, school size). The three booklets cover wide ranges of chemistry concepts, such as gas particles, acids/bases, chemical equilibrium, electric current, categorization of matter, and organic compounds. Details can be found in Chiu (2007). Students were randomly assigned to take one of the three booklets for each grade level. The details are shown in Table 1.

### *3.2 Instrument*

The instrument this study adopted was a two-tier diagnostic instrument from the national survey. Its developmental procedure followed the format that Treagust (1988, 1995) proposed and then modified it for local use as described in Chiu (2007).

**Table 1** Participants in each grade level and each booklet

| Booklets | Senior high school (HC) (11$^{th}$ grade) | Junior high school (SC) (8$^{th}$, 9$^{th}$ grades) | Total |
|---|---|---|---|
| A | 998 | 2,390 | 3,388 |
| B | 991 | 2,350 | 3,341 |
| C | 945 | 2,249 | 3,194 |
| Total | 2,934 | 6,989 | 9,923 |

**Table 2** The corresponding items and their content in each booklet

| Topic | Code | Corresponding Number | Number of Students | Content |
|---|---|---|---|---|
| Chemical Equilibrium | E1 | HC-ABC-02<br>SC-ABC-03 | 2,934<br>6,989 | The **dynamic equilibrium** concept which solids **continuously dissolve** and **precipitate** in a saturated solution. |
| | E2 | HC-A-10<br>SC-A-11 | 998<br>2,390 | **Phase transition** between both ice and water in an adiabatic condition. |
| | E3 | HC-B-09<br>SC-B-11 | 991<br>2,350 | **Temperature** effects on the **endothermic** and **exothermic reaction rates**. |
| | E4 | HC-B-10<br>SC-C-10 | 991<br>2,249 | The **dynamic equilibrium** concepts which solids **continuously dissolve** and **precipitate** in a saturated solution. |
| | E5 | HC-C-11<br>SC-C-11 | 945<br>2,249 | Gases do not influence the reaction process as they do not participate in the reaction. |
| Acids/Bases | A1 | HC-ABC-04<br>SC-ABC-04 | 2,934<br>6,989 | The relationship between the **air pressure** and the **pH change** caused by dissolving gas in a solution. |
| | A2 | HC-C-13<br>SC-C-12 | 945<br>2,249 | Weak electrolyte particles dissociate from molecules to ions and **randomly** and **dynamically distribute** in water. |

Note: HC and SC present senior high and junior high school chemistry, respectively; A, B, C present three different booklets

It includes concept maps and propositional statements to interview students and so on. There were three booklets (i.e., A, B, C), each including 18 items. To compare the developmental tendency on chemical equilibrium and acids/bases between junior and senior high school students, we designed five and two corresponding items on chemical equilibrium and acids/bases, respectively. Sample items and students' responses are shown in Appendix A. The item numbers and key concepts are shown in Table 2.

### 3.3 Data Analysis

The analysis was conducted in two parts. First, we focused on analyzing students' conception types and tendencies on chemical equilibrium and acids/bases in the national survey. This part of the analysis mainly focused on the items whose two-tier answer combination were greater than 15%. And then, we analyzed percentages in each response type and adopted a *t* test to analyze percentages of each item in junior and senior high school students. Second, we analyzed students' responses in interview data, field notes, and classroom observations in order to infer the sources of students' ideas.

# 4 Research Results

## *4.1 Developmental Tendencies of Students' Conceptions*

Figure 1 shows students' correct percentages of responses for the first tier of five chemical equilibrium and two acids/bases items. All together, students had higher correctness in items E4, E5, and A1. All of their percentages were greater than 50%. It shows students have good understanding on the conceptions of "the concentration of solids is constant in a saturated solution," "noble gases do not influence the reaction process," and the macro phenomenon of "the relationship between the air pressure and the gas dissolution."

Comparing students' correctness between the first and the second tiers further, the results show the correct percentages of the second tier about E4, E5, and A2 are less than half of the first tier in junior high school. Owing to the lack of equilibrium properties about dynamic, random, and micro-scope, students' correctness of the second tier dropped sharply in E4 and E5. In the case of A2, their answers showed they do not understand what an electrolyte nor are they familiar with the proper nouns *particles*, *ions*, and *molecules* or the mechanism in their microscope.

If we compare the correctness of the first tier between junior and senior high school students (Fig. 1), except E2, senior high school students have better understanding than junior high school students and reveal a significant difference ($p < .01$). Particularly, the senior high school students' performance in E1, A1, and A2 are most outstanding. These situations imply senior high school students are more conscious of macro phenomena chemical equilibrium as well as acids/bases than junior high school students. Also, they are more knowledgeable about the properties of "weak electrolytes," "molecules," and "ions." If we compare the second tier further, senior high school students still out-perform junior high school students in all items except E2 (Fig. 2), but the best performance items are changed

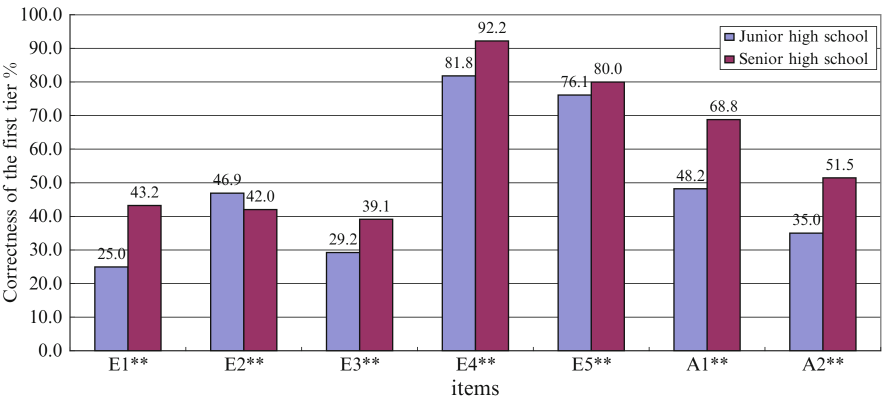


**Fig. 1** Students' correctness of the first tier (Note: ** $p < .01$)

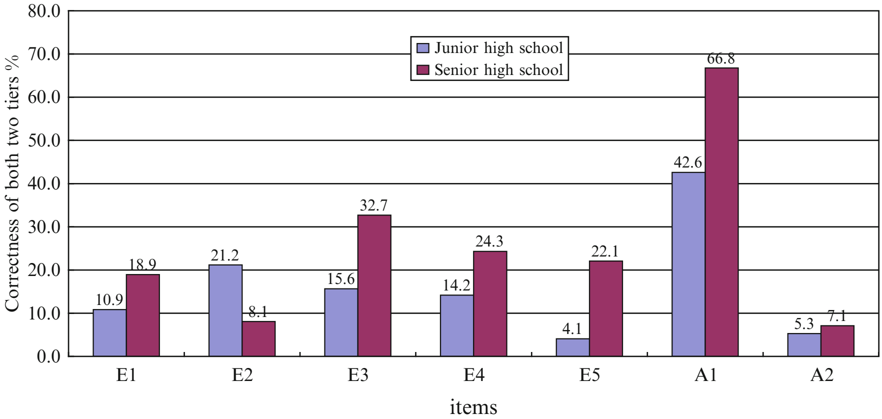


**Fig. 2** Students' correctness of both tiers

to E3, E5, and A1. The results also show senior high school students have advanced understanding of "increasing temperature speeds up both forward and reverse reactions in the endothermic and exothermic reaction," "gases do not influence the reaction process as they do not participate in the reaction," and "the relationship between the air pressure and the pH change caused by dissolving gas in a solution." With regard to E2, we conjecture that this is because some scientific language might mislead students' answer decisions, such as "specific heat." Both grade level students do not comprehend an adiabatic system well, and senior high school students are more familiar with the term "specific heat" without real understanding. This situation influences senior high school students' answer choosing strategy.

## *4.2 Types, Developmental Tendencies, and Sources of Alternative Conceptions*

According to the suggestion of Peterson et al. (1989), if any percentage of an answer combination of two tiers is higher than 20%, it indicates this type is representative of an alternative conception, and needs more attention from educators. However, with a more careful attitude, we decided to consider all combinations whose percentage is greater than 15%. Table 3 is our analysis about the types and percentages of alternative conception on chemical equilibrium and acids/bases.

### 4.2.1 Solids Continuously Dissolve and Precipitate in a Saturated Solution

There are three important alternative conceptions in this type (see Table 3). No matter whether junior high or senior high school student, most of them understand the

**Table 3** The typical types and percentages of students' alternative conception

| Types of alternative conception | Percentages % | |
|---|---|---|
| | Junior | Senior |
| A. Solids **continuously dissolve** and **precipitate** in a **saturated** solution | | |
| 1. In a saturated solution, all the vacant spaces between molecules are filled up, so the **shape** of the solid cannot change anymore. | 55.7 | 42.6 |
| 2. In a saturated solution, all the vacant spaces between molecules are filled up, so the **concentration** of the solution cannot change anymore | 54.8 | 59.5 |
| 3. All the vacant spaces between molecules are **filled by water**, so the solid collapses but not dissolves. | 2.6 | 18.8 |
| B. Phase transition between 0°C ice and water in an adiabatic condition | | |
| It needs heat to melt ice. The temperature degrees of ice and water are equal, so heat cannot be conducted to melt ice. | 34.0 | 22.9 |
| C. The temperature effect on the **endothermic** and **exothermic** reaction rates | | |
| 1. **An exothermic reaction releases heat**. If the temperature increases, the heat cannot be released easily, so the exothermic reaction rate decreases. | 16.4 | 21.0 |
| 2. **An exothermic reaction doesn't need heat**, so the increasing temperature doesn't influence the reaction rate. | 17.0 | 14.2 |
| D. The gas not participate in a reaction does not influence the reaction process | | |
| Noble gas does not influence products for not participating in the reaction. | 44.1 | 47.0 |
| E. Gas particles dissolve in a solvent | | |
| When carbon dioxide was pressed to dissolve in water, the more the pressure, the less the solubility of the gas. | 20.6 | 7.0 |
| F. Distribution of particles in an electrolyte solution | | |
| 1. Positive and negative ions attract each other to integrate into molecules again. | 19.4 | 9.2 |
| 2. Weak electrolytes only **partially** dissociate. | 12.5 | 33.9 |

concentration of a saturated solution is constant. However, due to lack of the learning experience and careful observation, they easily link the conceptions of the shape of a solute to the concentration, and infer the shape of a solute is also unchangeable. If we explore the reasons further, most students think that is because there is no vacant space for a solid in a saturated solution. Others believe although the solution is saturated, water can still drill through the vacant space of a solid to collapse it. We presume this is an intermediate model that is constrained by "solids dissolving" and "the concentration of a saturated solution is constant."

After comparing junior and senior high school students' performance, we found the latter are more knowledgeable about "a saturated solution" and "the concentration of a saturated solution is constant." However, these conceptions imply a static and constant mechanism to reinforce students' everyday intuition that "the vacant spaces are filled up, so the concentration of a solution is constant." That is the possible reason for the percentage of this type in senior high school students being slightly higher than for junior high school students (junior: 54.8%; senior: 59.5%). Besides, senior high school students have more observation experience with dissolution, so they have better understanding of the changeable shape of a solid in a saturated solution. However, due to lack of dynamic equilibrium conception that particles move dynamically, continuously, and randomly, these students think all the vacant spaces between solid molecules are filled by water and collapse to change their shapes.

### 4.2.2 Phase Transition Between 0°C Ice and 0°C Water in an Adiabatic Condition

This type is similar to the previous type. Students who held this type believe there is no heat transmission between the 0°C ice and 0°C water in an adiabatic system. Therefore, the ice shape is unchangeable. The percentage of junior high school students adhering to this concept was 34.0%, and drops to 22.9% after instruction.

### 4.2.3 The Temperature Effect on the Endothermic and Exothermic Reaction Rates

Usually, students "know" increasing temperature speeds up a forward and a reverse reaction rate. *However, the correctness of endothermic reaction is better than exothermic one.* The reason might be lack of real understanding of dynamic equilibrium in a micro context. Besides, Le Chatelier's principle is one of the key topics in senior high school. Adopting the static equilibrium and net effect viewpoint to teach Le Chatelier's principle might lead senior high school students to misapply it and enforce the alternative conception of "An exothermic reaction releases heat. If the temperature increases, the heat cannot be released easily, so the exothermic reaction rate decreases." That is the reason that the percentage of this alternative concept in senior high school students (21.0%) is higher than for junior high students (16.4%).

### 4.2.4 The Gas Not Participate in a Reaction Does Not Influence the Reaction Process

Students usually understand that a gas that does not participate in a reaction does not influence the products and the reaction process. However, this understanding also constrains in a net effect view with static state. The percentages of this type in junior high and senior high school students are quite similar (junior: 44.1%; senior 47.0%).

### 4.2.5 Gas Particles Dissolve in a Solvent

Why do students hold the alternative conceptions of the relationship between pressure and gas dissolution? The reason might be students' lack of understanding of the relationship between gas particles and pressure. Most students who chose this reason believe that "the more the pressure, the less the gas solubility." Fortunately, the percentage of this type decreased from 20.6% in junior high school to 7.0% in senior high school.

### 4.2.6 Distribution of Particles in an Electrolyte Solution

Students lack an understanding on the distribution of weak electrolytes after dissociation in water. This concept can be further divided into two subcategories. In the first type, students believe that the ionic conductivity of weak electrolytes is opposite after dissociated in water, and thus is attracted to form molecules in water (junior: 19.4%; senior: 9.2%). In the second one, students only understand weak electrolytes can be partly dissociated and neglect this process. If we compare the tendency between junior and senior high school students, junior high school students' mistakes result from unclear understanding of particles, while senior high school students have already developed an electrolyte concept. Consequently, senior high school students have better correctness in the first tier but still select incorrect answers in the second tier.

## 5 Conclusions and Implications

This study adopted the two-tier diagnostic instrument from the national survey and analyzed the two important topics, chemical equilibrium and acids/bases. Six representative alternative conceptions are identified. The results show except "phase transition between 0°C ice and 0°C water in an adiabatic condition," senior high school students have better understanding than junior high school students. Students' responses to the two-tier diagnostic instrument and interview data show senior high school students are more familiar than juniors with some science concepts and proper nouns, such as "specific heat," "saturated solution," and "weak electrolyte." Moreover, they are more conscious of some macro phenomena. Nevertheless, both senior and junior high school students lack understanding of the dynamic and random mechanism in chemical equilibrium and acids/bases ionization. Therefore, the correctness of these items is lower than others. With regard to the sources of these alternative conceptions, the results indicate the main difficulty is the transformation of macro, micro, and symbolic levels. This difficulty also arouses much researchers' attention (e.g., Pedrosa & Dias, 2000; van Driel, 2002). However, our study provides more detail about large-scale, across-grade survey data. It is helpful for examining and designing the related instruction about macro with micro interaction.

To sum up, a well-designed two-tier diagnostic instrument is helpful for science educators to understand how popular these known alternative conceptions are. Science textbook editors and teachers could design relevant curriculum that considers most students' pre-conceptions under such limited teaching time. It is the most effective method to revise students' alternative conceptions, while others simply convey some science knowledge with proper nouns (Treagust, 1995). However, it deserves to be mentioned that the aim of a two-tier diagnostic instrument is neither to identify students' alternative conceptions nor find their sources. Therefore, we have to conduct a further study to explore these important issues. Only with a clear understanding about students' alternative conceptions and their sources can related instruction yield twice the result with half the effort. Furthermore, our research results reveal the teaching about chemical equilibrium and acids/bases in Taiwan still focuses heavily on the static statements of science concepts and macro phenomena. The introduction of the micro and dynamic mechanism is not a new issue in science education. However, its teaching is usually isolated to the related science concepts context. For this reason, we suggest the instruction of these two topics should integrate particle viewpoint to explain these micro mechanisms for avoiding these important alternative conceptions.

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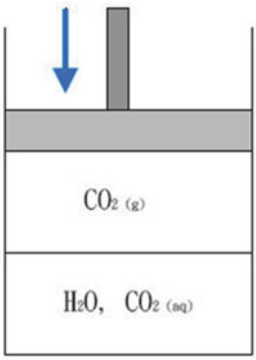
## Appendix A: The Selective Item with Students' Responses of Acids/Bases

1-1. At the temperature of 25 °C, carbon dioxide ($CO_2$) with a certain number of moles is put into an enclosed container with 100 mL of pure water and then press down the covering piston, the pH value of the solution will ________

1. Increase.




2. Decrease.
3. Remain unchanged.

---------------------------------------------------------------

1-2. Following 1-1, the reason for your answer is that:

A. As the pressure increases, the solubility of gas decreases; and since the carbon dioxide doesn't easily dissolve in water, the $CO_2$ in the water will be released, which increase the pH value of the solution.

B. The pressure increases so does the solubility of gas. The carbon dioxide dissolved in water produces more carbonic acid so that the pH value decreases.
C. The solubility of gases has nothing to do with the pressure. So the solubility of carbon dioxide does not change under different pressure.
D. At the same temperature, and the number of gas molecules remains fixed, the number of ions dissolved in the water remains the same.
E. The gas itself is hard to dissolve in water so the solubility of the two has nothing to do with the pressure and should be the same.

**Students' responses**

| | Reason | | | | | |
|---|---|---|---|---|---|---|
| Choice on first tier | A | B | C | D | E | Total |
| 1 | 20.6 | 4.0 | 1.0 | 0.8 | 0.3 | 26.7 |
| 2 | 2.0 | 42.6[a,b] | 2.1 | 1.0 | 0.6 | 48.2 |
| 3 | 1.0 | 1.2 | 12.1 | 4.6 | 5.9 | 24.8 |

[a]correct answer
[b]highest percentage of students' choice

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# The Use of Electronic Media for Chemical Education Research

**Francis Burns and David Frank**

## 1 History and Purpose of Study

In the summer of 2007, I listened to a paper presented by Byers (2007), who used learning logs in his chemistry course. He required his students to write their reflections within a bound notebook. When I implemented learning logs in my own classes the following fall, paper journals were used to record log entries. However, I quickly realized that too much time would be required to read and evaluate learning logs due to the large number of students (more than 90) in each of my undergraduate courses. I changed the assignment format to an electronic one, and found that this way I could manage a large set of learning logs. Based upon anecdotal evidence, it seemed that the learning log assignment was helping my students to learn. There is ample literature (Baggetun & Wasson, 2006; Buehl, 1996; Chesbro, 2006; Laffey, Musser, & Tupper, 1998; Roberts & Tayeh, 2007) that supports the use of student journals or learning logs in education.

I proposed and ran my first investigation of learning logs in the spring of 2008. Alas, my results did not provide any conclusive answers with regards to the effects of learning logs on student outcomes. As I reviewed learning logs and other writing assignments, some students voiced enthusiastic support of the assignment. Other students were "lukewarm" or even hostile to learning logs. Finally, test statistics and student grades did not provide any evidence of a link between learning logs and student performance.

Whether the use of learning logs changed my students' behavior, reading the logs did change my approach to teaching. Learning logs provided me with detailed

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information regarding learning from the students' perspective. Student logs typically contained large amounts of information. Students were also willing to give their opinions and feelings – both positive and negative. I found that learning logs were useful for both developing my craft as a teacher and investigating pedagogically relevant questions.

For several years, I taught a one-semester survey course of general chemistry (*CHEM 114, Introduction to General Chemistry*). Some of my students also would elect to simultaneously participate in the *Structured Learning Assistance (SLA)* program. The SLA program was designed to increase the number of students who pass some of the most challenging courses, including CHEM 114. To achieve this outcome, the program provided students with extra instructional assistance, as well as provided workshops in academic skills, such as study skills. SLA students tended to perform better in my chemistry courses than non-SLA students.

What happened in the SLA sections? I have realized that learning is an inherently reflective process. The perspective of SLA students was critical to understanding the effect of the workshop upon their learning. Learning logs provided this information through a systematic coding process of the text. Hopefully, the process of answering this question will illustrate the utility of online learning logs as a tool for teacher development and educational research.

## 2 Literature Review

With the development of the Internet, computer-mediated communication (CMC) has become widely available for educational purposes: email (Collette & Richer, 1999), discussion boards (Moni, Moni, Poronnik, & Lluka, 2007), listserv (Piburn & Middleton, 1997), and web logs (Martindale & Wiley, 2005). Different CMC tools offer varying levels of privacy, ease in communication between students and instructors, and organizations. In a computer-assisted design (CAD) course, Collette and Richer (1999) integrated email into the course structure as an instructional method. The instructor-to-student interactions occurred at multiple levels: tutorial, metacognitive, and "life." Tutorial interactions focused on learning objectives. Metacognitive communications focused on "learning how to learn." "Life" level messages focused on student motivation. "What does this learning mean to the student?" In lieu of email, a large section biology course used discussion boards to foster student-to-student interactions through assigned groups, which engaged in extensive peer evaluation (Moni et al., 2007). Web logs have also been used as an instructional tool. A small group of doctoral students maintained personal blogs (web logs) as a course requirement (Xie & Sharma, 2004). Unlike many other CMC tools, blogs have a distinctly public quality. Student postings are generally open for public review and comment – even if the "public" is limited to the course participants.

Both science and science education courses have made extensive use of both student journaling and CMC resources, frequently combining them for purposes of

**Table 1** In CHEM 114, students in SLA sections had higher performance than students in non-SLA sections

| | |
|---|---|
| Median of student grade averages: | |
| SLA sections: | 83.6% |
| Non-SLA sections | 76.7% |
| Percentage of students earning C- or better | |
| SLA sections: | 79% |
| Non-SLA sections | 71% |
| Percentage of students failing (F) | |
| SLA sections: | 4% |
| Non-SLA sections | 11% |

student reflection. According to the literature, researchers generally concluded that student journaling positively affected students cognitively and affectively. Grumbacher (1987) found that "learning logs" were an effective tool for high school physics. She stated that her students' logs improved their problem-solving ability, integrated experience and theory, and improved her students' enjoyment of physics. At the University of Queensland, biology professors discovered that online discussions were an effective tool for the first-year course. Students found their student-to-student interactions to be both valuable and interesting. Although the authors didn't compare their course to a traditional biology course, they noted that the students maintained a high standard for the writing portion of the course, including the online discussions (Moni et al., 2007).

The Structured Learning Assistance (SLA) program was established in 1993 at Ferris State University (http://www.ferris.edu/sla/homepage.htm). It was designed to increase the number of students passing "gateway" courses, such as chemistry, mathematics, and economics. Currently, the SLA program teaches study skills and learning methods within these content areas, as well as content review. Most of the "gateway" courses have both SLA and non-SLA sections. Students *choose* to enroll in an SLA-designated section. As a result, students self-select for participation in the SLA program. For example, CHEM 114 (Spring 2010) had six non-SLA sections (normal) and two SLA sections. Each section had approximately 22 students. In addition to their normal class meetings, students in SLA sections meet twice per week for one and a half hours with a SLA facilitator, who is normally an advanced undergraduate student. Course professors monitor the progress of the SLA meetings, serve as mentors, and retain ultimate control over the SLA activities. For CHEM 114 (Spring, 2010) all SLA students were required to attend the SLA sessions until after the first semester test. Students passing the first test with 87% or better were no longer required to attend the twice weekly SLA sessions; otherwise, students received an automatic failing grade in the course if they had four or more unexcused absences from SLA sessions. Table 1 illustrates the differences in SLA and non-SLA students. As in prior semesters, CHEM 114 students participating in the SLA program had better overall performance than non-SLA students as a whole.

# 3 Methodology

## *3.1 Participants*

At Ferris State University, students pursuing allied health or technical degrees are required to complete a one-semester survey course of general chemistry (CHEM 114), which consists of 3 h of lecture and one 2-h laboratory session per week. Students elect to participate in the SLA program by enrolling in SLA-designated course sections. These students also receive an *extra* 3 h of instruction per week led by an SLA facilitator. In the spring of 2010, a large cohort of students enrolled in CHEM 114: two sections were designated as "SLA" and six sections retained their normal structure. As the lecturer for this large multi-sectional course, I organized the material, testing, and laboratory syllabus. I also taught five of the laboratory sections. Another instructor taught the laboratory portion of the SLA sections, and still another instructor taught a sixth non-SLA laboratory section. Other than the extra instructional time, the different sections were treated the same, completing equivalent assignments and examinations.

During the last week of class, I asked my students if they would be willing to let me use their individual logs as part of my study. Although all students were required to maintain a learning log as part of their coursework for CHEM 114, student participation in my research project was voluntary. Student permission was obtained through a written consent form. Of the CHEM 114 students, 77.6% ($n=125$) elected to participate in my learning log research project. Within this large group of students, a smaller group of SLA students consented to participate ($n=35$); 58.3% of SLA students chose to participate in the study, and 89.1% of the non-SLA students chose to participate. Participating students were assigned a random number for identification purposes.

# 4 Materials

During the semester, students used a course website, which was established at http://OpenChemistry.us. Moodle (version 1.9.6) served as the software, which is open source and available for free at http://Moodle.org. Students used this website to submit their writing assignments.

During data analysis, I used MAXQDA 10 software (http://maxqda.com), which is commercial text analysis software. The software permits straightforward coding, aggregation of coded data, and data manipulation.

## *4.1 Procedures*

Although students were not required to participate in this study, all of the enrolled students were required to electronically submit weekly learning logs as part of their normal coursework. Each entry consisted of a summary of the week's work, as well as a reflection upon the work. Students summarized lecture, laboratory, online homework, and SLA (if applicable). Students reflected upon the week's work, such by posing questions related to chemistry or the course, any problems or issues, connections between lecture and anything else, and/or feelings concerning chemistry or course. Students needed to summarize the week's work in two to three paragraphs each week, covering the above material in some fashion. No other requirements were imposed in order to increase the palatability of the assignment, as well as permit individual perspectives to be expressed.

Students recorded their learning log entries at http://OpenChemistry.us. The learning log assignment was set up in an online text format, which permitted students to write weekly log entries. When I evaluated the assignments, students would receive immediate feedback through email notification. I used email to provide guidance for improvement in assignment, as well as their general course success. After the semester ended, pertinent student logs were downloaded; personal identification information was removed, and then logs were saved as a Microsoft Word document.

At this point, I made a series of decisions regarding the qualitative analysis of student learning logs. First, I focused on the learning logs from SLA students because I wanted to identify potential factors affecting their success. Second, I printed off sample learning logs: two from "A" students, two from "C" students, and two from "F" students. Using these documents, I developed codes to identify SLA activities and student reflections. In addition, I wrote an operational definition for each code (Appendix 1).

After developing a set of codes, I loaded the SLA files into the MAXQDA 10 program and then coded them. First, I coded all text passages that referred to SLA and then isolated these passages from the rest of the learning log passages. Second, I coded these SLA passages using the codes and sub-codes listed in Appendix 1. Finally, I isolated and counted the number of coded statements. In addition, I counted the number of words using Microsoft Word.

## 5 Results

I found that almost all of my students were frequently candid in their electronic communication and writing assignments. As a result, I learned to be dispassionate while reading learning logs because some students made very critical statements regarding chemistry or the course, including the instructors. I also learned to value these statements because they provided a "window" to what some students *really* think or believe.

Based upon previous work, I had anticipated information "overload" (Burns, Frank, Kerr, & Stanislav, 2008). Past online writing assignments and electronic communication generated a glut of information. The current study collected 489,500 words from all of the participating students. When I started my qualitative analysis, I quickly focused on the question, "What is happening in the SLA sections?" As a result, I decided to limit qualitative analysis to learning logs of SLA students, which reduced the amount of information to less than 30% of the total amount of available information (143,195 words).

Despite this reduction, I still had a very large amount of text to read and analyze. Both SLA and non-SLA students attended the same lectures and completed the same laboratory activities. The major difference between the SLA and non-SLA students was the two extra instructional sessions each week. As a result, I focused on text passages that reported information related to the SLA sessions. I should mention that SLA students with an overall course average of an 87% (B+) were excused from SLA attendance. These students were not required to attend, but some students chose to attend nonetheless. For simplicity, I did not distinguish passages from students with voluntary attendance from students with compulsory attendance.

By focusing on passages related to SLA sessions, I reduced text analysis to 432 passages or 23,572 words, which was quite manageable. As summarized in Table 2, I reviewed these passages and coded individual statements as related to either SLA Activities (65%) or Student Reflections (40%). I recognize that the total exceeds 100%, but sometimes statements overlapped between a particular activity and a student's reflection upon that activity. The bulk of the statements provided summary information. This may be related to the design of the assignment in which I specifically required students to summarize their SLA sessions, if they were not excused from the sessions. Students were also expected to reflect upon the week's work, but I did not specifically require them to reflect upon their SLA sessions.

During each SLA instructional session, different learning activities occurred. For example, the SLA facilitator frequently reviewed content from lecture. This activity normally involved the entire class. Other activities may have involved small groups or individuals. Most SLA sessions had a variety of activities, but most students summarized only one or two activities. Occasionally, most of the students would comment on a specific activity. For example, "Chemical Jeopardy" was played only once, but most of the class commented favorably on the class game. In contrast, a workshop that focused on study skills also received many comments in student logs, but most of these comments were not favorable. Still other activities were frequently included in SLA sessions but *not* reported by students. For example, students assessed their outside learning activities on a weekly basis as a separate activity during SLA sessions, but this activity was rarely mentioned by students in their logs. In the end, student entries reflected their personal perspectives and values. The students reported the activities that they liked (valued) or disliked.

Although content review was present at almost all sessions, students reported more frequently on either "Formative Evaluation" or "Question & Answer" activities. Formative evaluation activities were limited to self-assessment, such as a pretest or "warm-up" questions, which were a set of content questions to be worked on by students at the beginning of class. Question and answer activities ranged from the involvement of the entire class to small groups to one-on-one tutoring. These activities were probably the most memorable of the many activities in SLA.

Although students tended to focus on their summary of SLA activities, they also reflected upon them. I found that students tended to make value judgments of activities.

**Table 2** SLA students reported an array of learning activities and reflections in their learning logs

| Codes | Number of passages/ statements | Number of words | Percentage of SLA passages (%) |
|---|---|---|---|
| 1. SLA passages | 432 | 23,572 | |
| 2. SLA Activities | 660 | 15,349 | 65.1 |
| 2.1. Review Content | 109 | 2,345 | 9.9 |
| 2.2. Metacognitive Activities | 62 | 1,620 | 6.9 |
| 2.3. Formative Evaluation | 147 | 2,892 | 12.3 |
| 2.4. Question & Answer Activities[a] | 114 | 2,907 | 12.3 |
| 2.4.1. Entire class involved in activity | 34 | 433 | 1.8 |
| 2.4.2. Small groups | 26 | 681 | 2.9 |
| 2.4.3. Individual | 18 | 953 | 4.0 |
| 2.4.4. Not specified by student | 36 | 840 | 3.6 |
| 2.5. Peer tutoring | 7 | 127 | 0.5 |
| 2.6. Work on homework/ handouts | 121 | 2,277 | 9.7 |
| 2.7. Workshop Activities | 54 | 2,107 | 8.9 |
| 2.8. Game Activities | 19 | 360 | 1.5 |
| 2.9. Other | 27 | 714 | 3.0 |
| 3. Student Reflections | 420 | 9,476 | 40.2 |
| 3.1. Feelings | 59 | 2,002 | 8.5 |
| 3.2. Value Judgments | 194 | 4,257 | 18.1 |
| 3.3. Problems/Issues | 56 | 2,315 | 9.8 |
| 3.4. Successes | 68 | 1,832 | 7.8 |
| 3.5. Review | 3 | 55 | 0.2 |
| 3.6. Plan of Action | 19 | 418 | 1.8 |
| 3.7. Other | 21 | 720 | 3.1 |

[a]The numbers in each subsection under 2.4 add up to the totals shown across from 2.4

Most often, students reported that a particular activity helped them learn chemistry or found it to be useful or something similar. Occasionally, students voiced that a particular activity was pointless. Based upon this information, I believe that students tended to assess the value of particular activities. If a particular activity was considered valuable, they reported it. The most and least valued activities were probably the most memorable ones.

## 6 Conclusions and Implications

My results illustrate that online learning logs can be an effective tool for gathering information for educational research and educators. Combined with candid reporting by students, instructors and education researchers have a powerful tool for collecting important information. However, these individuals can be easily overwhelmed by too much information. Educators and/or researchers need to consider carefully both the structure of the assignment as well as the technology used to collect the learning logs. In this study, I provided specific directions that students needed to provide a summary of SLA activities. As a result, they provided this information on a regular basis. I would have been interested in comparing the study habits of SLA and non-SLA students, but I did not structure the assignment to capture this information. Only a few students provided any of this information related to their study habits.

I found that students readily provided both positive and negative information regarding chemistry, the course, and even me. This is valuable information, but it can be upsetting. Teachers and/or researchers must read students' entries with respect and objectivity.

So what might be taking place in SLA sections that influences their classroom performance? SLA students receive up to an *extra* 3 h of structured learning activities each week. More importantly, these 3 h are pedagogically rich with regard to the mix of activities. Through their learning logs, the students themselves identified (both by repetition and by stating which activities they liked or disliked) the activities that they perceived to be more or less effective. If I could structure my large lecture hall to mimic the much smaller SLA environment, then the differences between SLA sections and non-SLA sections might be less.

My analysis of SLA learning logs provided me with insights into the activities that students value. Chemistry students highly value the following activities: Formative Evaluations and Question & Answer sessions. I am revising my teaching to integrate formative assessment into lecture (in progress), and reinforcing the importance of asking questions during lecture. I am also encouraging my students to form study groups, work with tutors, and meet with me during my office hours. Overall, this learning log project has caused me to rethink what I do in the classroom and will continue to influence my teaching in the future.

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## Appendix 1

### *Codes & Subcodes with Their Operational Definitions Used for SLA Passages*

1. SLA Activities – Anything *done* in SLA (as recalled by a student and/or deemed relevant)
   - 1.1. Review Content
   - 1.2. Metacognitive Activities

- 1.2.1. Self-Assessment Tests/Surveys (e.g., Procrastination Survey)
- 1.2.2. Weekly Assessment of Learning Activities – Each student lists (checks off) the activities performed during the prior week and the time spent on the individual activities and as a total.
- 1.2.3. “Warm-up” learning log activity – students spend 5–10 min writing a summary of the week’s work
- 1.2.4. Assessment activities related to testing
  - 1.2.4.1. Prior to receiving test results (e.g., reviewing overall effort made by the student)
  - 1.2.4.2. After receiving test results (e.g., going over mistakes made on tests)

1.3. Formative Evaluation
- 1.3.1. “Warm-up” questions – Problems assigned at the beginning of the class for students to work on an individual basis.
- 1.3.2. Pretests and/or old tests – question sets given to students for self-assessment

1.4. Question & Answer Activities – coded according to type of interactions
- 1.4.1. Entire class involved in activity (e.g., answers posted on board and discussed as a class)
- 1.4.2. Small groups
- 1.4.3. Individual (between student and SLA instructor and/or tutor OR with another SLA student)

1.5. Peer tutoring – student describes her or his activities as a peer tutor

1.6. Work on homework/handouts
- 1.6.1. Textbook problems
- 1.6.2. Best Choice problems
- 1.6.3. Problem sets generated by SLA

1.7. Workshop Activities –programs/small group activities with a specific learning outcome
- 1.7.1. Learning Styles Workshop
- 1.7.2. Textbook/study skills workshop
- 1.7.3. Problem Solving Workshop – specific activity developed by Professor Burns, which focused on problem solving skills. SLA students worked in small groups with tutors from Honors Program (and SLA instructors) and solved a series of problems on a worksheet.

1.8. Game Activities (e.g., Bingo and Jeopardy)

1.9. Other
- 1.9.1. To be used only if other categories do not apply
- 1.9.2. After coding, all of the “SLA Activities – Other” will be collected and reviewed as a set.

2. Student Reflections
- 2.1. Feelings – use of feeling words, such as “I was bored with last night’s activities” or “I am confused by significant figure rules.”
- 2.2. Value Judgments

    - 2.2.1. I like (or dislike) balancing equations
    - 2.2.2. States something is useful (or useless)
    - 2.2.3. Judges an outcome as successful or otherwise
  - 2.3. Problems/Issues
    - 2.3.1. Conceptual problems, such as having stating difficulty with balancing charges.
    - 2.3.2. Issues, such as students not talking in lecture.
  - 2.4. Successes
    - 2.4.1. "Measurable" success, such as a reporting specific test scores or laboratory outcome
    - 2.4.2. "Immeasurable" success, such as "I understand Lewis Structures better due to Hanna."
  - 2.5. Review – connected concept(s) with prior exposures, such as in "I covered this material in high school"
  - 2.6. Plan of Action – a statement of either the need for a particular action (e.g., I need to work on more practice problems) or the intention to engage in a particular action (e.g., I plan to work on more practice problems).
  - 2.7. Other – used when the student is reflecting upon material in some fashion, but does not appear to fall into the above categories.
    - 2.7.1. To be used only if other categories do not apply
    - 2.7.2. After coding, all of the "Student Reflections – Other" will be collected and reviewed as a set.

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# Investigation of Tertiary Chemistry Learning Environment in Sabah, Malaysia

**Yoon-Fah Lay and Chwee-Hoon Khoo**

## 1 Background of the Study

Over the last four decades, researchers in many countries have shown increasing interest in the conceptualization, assessment, and investigation of students' perceptions of psychosocial dimensions of their classroom environment. A considerable amount of work on the assessment and investigation of the classroom environment in schools was conducted. These include studies on the associations between students' perception of interpersonal teacher behavior and learning outcomes in primary mathematics classrooms (Goh & Fraser, 1996) and environment-attitude associations in secondary science classrooms (Wong & Fraser, 1995). In relation to this, the Harvard Project Physics of Walberg (Welch & Walberg, 1972) in the United States and studies by Fraser (1981, 1986) in Australia are educationally noteworthy. Interest in the study of learning environments becomes more prominent when there was evidence that learning outcomes and students' attitudes towards learning were closely linked to the classroom environment. Studies were conducted to determine the degree of importance of classroom environment in the teaching-learning process. The nature of the classroom environment and psychosocial interactions can make a difference in how students learn and achieve their goals (McRobbie, Roth, & Lucas, 1997).

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# 2 The Study

## *2.1 Problem Statement*

Research conducted over the past 40 years has shown the quality of the classroom environment in schools to be a significant determinant of student learning (Fraser, 1994, 1998). That is, students learn better when they perceive the classroom environment positively. Numerous research studies have shown that students' perception of the classroom environment account for appreciable amounts of variance in learning outcomes, often beyond that attributable to background student characteristics. In the Malaysian context, despite limited efforts in other educational areas, study of the learning environment is a crucial dimension of education. However, pre-service teachers' perceptions of their learning environments have not been explored. Primary and secondary pre-service chemistry teachers' perceptions of their chemistry learning environment formed the subject of this investigation. Because of the deficient understanding of students' perceptions of the tertiary chemistry learning environment, this proposed study aimed to gauge the perceptions of tertiary chemistry learning environments among primary and secondary school pre-service chemistry teachers and to determine whether there is a significant difference in their perceptions based on gender and types of schools taught.

## *2.2 Objectives of the Study*

This study attempts to achieve the following objectives:

1. to provide validation data for the 'College and University Classroom Environment Inventory' (CUCEI) when used in Sabah;
2. to gauge the perceptions of tertiary chemistry learning environments among primary and secondary school pre-service chemistry teachers in Sabah;
3. to determine whether there is a significant difference in students' perceptions of tertiary chemistry learning environments based on their gender and types of schools taught.

## *2.3 Research Questions*

This study attempts to answer the following questions:

1. Is CUCEI a reliable and valid instrument to measure students' perceptions of tertiary chemistry learning environments especially in the context of Sabah?
2. What are the perceptions of tertiary chemistry learning environments among primary and secondary school pre-service chemistry teachers in Sabah?

3. Is there a significant difference in students' perceptions of tertiary chemistry learning environments based on gender and types of schools taught?

## 2.4 Research Hypotheses

Two hypotheses to be tested in this study are:

1. There is no significant difference in the perceptions of tertiary chemistry learning environment between male and female pre-service chemistry teachers in Sabah.
2. There is no significant difference in the perceptions of tertiary chemistry learning environment between primary and secondary pre-service chemistry teachers in Sabah.

## 2.5 Definition of Terms

### 2.5.1 Learning Environment

Classroom learning environment refers to a space or a place where learners and teachers interact with each other and use a variety of tools and information resources in their pursuit of learning activities (Wilson, 1996). In this study, seven essential aspects of the tertiary chemistry learning environment studied are Student Cohesiveness, Individualization, Innovation, Involvement, Personalization, Satisfaction, and Task Orientation.

1. Students Cohesiveness
   Extent to which pre-service chemistry teachers know, help, and are friendly towards each other.
2. Individualization
   Extent to which pre-service chemistry teachers are allowed to make decisions and are treated differently according to ability, interest, and rate of working.
3. Innovation
   Extent to which the instructor (lecturer) plans new, unusual class activities, teaching techniques, and assignments.
4. Involvement
   Extent to which pre-service chemistry teachers participate actively and attentively in class discussions and activities.
5. Personalization
   Emphasis on opportunities for individual pre-service chemistry teacher to interact with the instructor and express concern for pre-service chemistry teachers' personal welfare.
6. Satisfaction
   Extent of enjoyment of classes.
7. Task Orientation
   Extent to which class activities are clear and well organized.

# 3 Methodology

## *3.1 Research Design*

This was a non-experimental quantitative study. Non-experimental research is a systematic empirical inquiry in which the researcher does not have direct control of independent variables because their manifestations have already occurred or because they are inherently not manipulable. Hence, inferences about relations among variables are made, without direct intervention, from concomitant variation of independent and dependent variables (Johnson & Christensen, 2000). In this study, sample survey method was used to collect data. The CUCEI developed by Fraser, Treagust, Williamson, and Tobin (1987) was used to gauge students' perceptions of tertiary chemistry learning environments (i.e., Personalization, Involvement, Student Cohesiveness, Satisfaction, Task Orientation, Innovation, and Individualization).

## *3.2 Research Samples and Sampling Method*

A group of primary and secondary pre-service chemistry teachers were selected, by using a cluster random sampling technique, from the Teacher Education Institute – Kent Campus and School of Education and Social Development, Universiti Malaysia Sabah. In relation to this, Universiti Malaysia Sabah is one of the public higher education institutions responsible for the training of pre-service secondary science teachers whereas Teacher Education Institute – Kent Campus is one of the teacher education institutions responsible for the training of pre-service primary science teachers in Malaysia. These student-teachers are trained to teach in different school contexts as primary and secondary school science teachers respectively. The CUCEI instrument was administered to these selected pre-service primary and secondary chemistry teachers to gauge their perceptions of tertiary chemistry learning environments. The distribution of pre-service chemistry teachers according to gender and types of schools taught is illustrated in Table 1.

**Table 1** Distribution of pre-service chemistry teachers according to gender and types of schools taught

| | N | % |
|---|---|---|
| Gender | | |
| Male | 25 | 34.7 |
| Female | 47 | 65.3 |
| Types of schools taught | | |
| Primary | 35 | 46.7 |
| Secondary | 40 | 53.3 |

### 3.3 Instrumentation

In this study, students' perceptions of tertiary chemistry learning environment were measured by using the "College and University Classroom Environment Inventory" (CUCEI) specially developed by Fraser et al. (1987). The CUCEI was developed to assess the perceptions of the psychosocial environment in university and college classrooms. Originally, the CUCEI was developed for use with small groups of about 30 students in seminars and tutorials in higher education classrooms (Fraser & Treagust, 1986; Fraser, Treagust, & Dennis, 1986). The final form of the CUCEI contains seven scales: Personalization, Involvement, Student Cohesiveness, Satisfaction, Task Orientation, Innovation, and Individualization. Each scale contains seven items, making a total of 49 items in all. There are four responses provided for each item, namely "Strongly Agree" (SA), "Agree" (A), "Disagree" (D), and "Strongly Disagree" (SD). Validation of the CUCEI conducted by Fraser and Treagust (1986) yielded scale alpha reliabilities ranging from .70 to .90.

### 3.4 Data Collection Procedures

Before administering the CUCEI instrument, formal permission from the related authorities was sought and obtained. The College and University Classroom Environment Inventory (CUCEI) was personally administered by the researchers. Students were gathered in the lecture hall and the instrument was administered to the students concurrently. The students were informed about the nature of the instrument and how the instrument should be answered. Each student was asked to read a statement pertaining to the tertiary chemistry learning environment and then indicate his or her degree of agreement or disagreement with the statement (i.e., Strongly Agree, Agree, Disagree, or Strongly Disagree).

### 3.5 Data Analysis Procedures

Each item in the CUCEI instrument was responded to on a 4-point Likert scale with four alternative responses: "Strongly Agree" (SA), "Agree" (A), "Disagree" (D), and "Strongly Disagree" (SD). All 49 Likert-type items were classified into two groups: Positive or negative items. For each of the positive Likert items, students' responses were assigned with numbers ranging from one to four (from "Strongly Disagree = 1" to "Strongly Agree = 4"). The scores were assigned in a reverse order for each negative Likert item (from "Strongly Disagree = 4" to "Strongly Agree = 1"). The higher the student scores on the CUCEI, the more positive the student's perceptions of the tertiary chemistry learning environment.

Descriptive statistics were used to describe the perceptions of tertiary chemistry learning environments among pre-service chemistry teachers at the teacher education institutions in the state of Sabah, Malaysia. Among the descriptive statistics used were percentages, mean, standard deviation, and range. On the other hand, as an effort to ensure all the quantitative data were drawn from a normally distributed population, graphical measures such as histogram, stem-and-leaf plot, normal Q-Q plot, and detrended normal Q-Q plot were plotted for each of the variables studied. Furthermore, numerical measures such as skewness and kurtosis were used to identify any deviations from normal distributions (Hair, Anderson, Tatham, & Black, 1998; Miles & Shevlin, 2001). After the assumptions of using parametric techniques in analyzing quantitative data were met, independent sample *t*-test was used to test the stated null hypotheses at a predetermined significance level, alpha = .05. Independent sample *t*-test was used to determine whether there is a significant difference in the perceptions of tertiary chemistry learning environments between male and female pre-service chemistry teachers. The same statistical test was also used to ascertain the significant difference in students' perceptions of tertiary chemistry learning environment based on types of schools taught.

# 4 Research Findings and Discussion

## *4.1 Reliability and Validation of the CUCEI Instrument*

The collected data were analyzed to test the internal consistency of the CUCEI scales. It was found that the Cronbach Alpha reliabilities ranged from .56 (Innovation) to .87 (Satisfaction) except for the "Individualization" subscale, which showed a low reliability of .295. Overall, the Cronbach Alpha reliability of the CUCEI instrument was found to be at a high of .914 (Table 2). These figures were comparable to the results reported by Fraser et al. (1987). Hence, these findings support the cross-cultural validity of the classroom environment scales when used for the first time in the context of Sabah. Each scale in the CUCEI was found to display satisfactory internal consistency reliability.

**Table 2** Cronbach's alpha reliability of the CUCEI

| Subscales | Item no. | Cronbach's alpha reliability |
|---|---|---|
| Personalization | 1, 8, 15, 22, 29*, 36*, 43* | .768 |
| Involvement | 2*, 9, 16*, 23, 30*, 37, 44* | .631 |
| Student cohesiveness | 3*, 10, 17, 24*, 31*, 38, 45* | .769 |
| Satisfaction | 4, 11*, 18, 25*, 32*, 39, 46 | .872 |
| Task orientation | 5, 12, 19*, 26*, 33, 40*, 47 | .681 |
| Innovation | 6*, 13*, 20, 27, 34*, 41, 48* | .560 |
| Individualization | 7*, 14, 21, 28, 35, 42*, 49* | .295 |
| Overall | | .914 |

*denotes negative item

**Table 3** Discriminant validity of the CUCEI

| | P | I | SC | S | TO | I | I | MC |
|---|---|---|---|---|---|---|---|---|
| Personalization | – | .719 | .192 | .761 | .663 | .526 | .392 | .54 |
| Involvement | .719 | – | .381 | .633 | .581 | .491 | .382 | .53 |
| Student cohesiveness | .192 | .381 | – | .252 | .268 | .013 | .141 | .21 |
| Satisfaction | .761 | .633 | .252 | – | .705 | .637 | .418 | .57 |
| Task orientation | .663 | .581 | .268 | .705 | – | .486 | .311 | .50 |
| Innovation | .526 | .491 | .013 | .637 | .486 | – | .480 | .44 |
| Individualization | .392 | .382 | .141 | .418 | .311 | .480 | – | .35 |

**Table 4** Mean and standard deviation of pre-service chemistry teachers' perceptions of the tertiary chemistry learning environment according to the CUCEI subscales

| Subscales | No. of Items | *N* | *M* | *SD* | Range |
|---|---|---|---|---|---|
| Personalization | 7 | 73 | 20.44 | 3.366 | 11–28 |
| Involvement | 7 | 74 | 18.93 | 2.446 | 12–24 |
| Student cohesiveness | 7 | 75 | 22.92 | 3.208 | 13–28 |
| Satisfaction | 7 | 74 | 20.07 | 3.908 | 7–28 |
| Task orientation | 7 | 67 | 19.57 | 2.846 | 10–24 |
| Innovation | 7 | 71 | 16.73 | 2.767 | 7–21 |
| Individualization | 7 | 72 | 18.54 | 2.142 | 13–24 |
| Overall | 49 | 62 | 137.73 | 15.557 | 91–171 |

The discriminant validity is described as the extent to which a scale measures a unique dimension not covered by the other scales in the instrument. Table 3 indicates that the mean correlations of the scales in the CUCEI ranged from .21 to .57. Based on the values, the CUCEI appears to measure somewhat overlapping aspects of the classroom environment, but distinctions between each scale, across all seven dimensions, in the instrument are evident.

### *4.2 Pre-service Chemistry Teachers' Perceptions of the Tertiary Chemistry Learning Environment*

Table 4 shows the mean and standard deviation of pre-service chemistry teachers' perceptions of the tertiary chemistry learning environment (overall and for each of the seven subscales, respectively).

As shown in Table 4, the overall mean value of students' perceptions of the tertiary chemistry learning environment ($M = 137.73$, $SD = 15.557$) revealed that students perceived the chemistry learning environment at the tertiary level as positive. This finding is important for it implies that these pre-service chemistry teachers, having experienced positive chemistry learning environments at the university and the teacher education institute, would be more inclined to establishing positive chemistry learning environments in their own classrooms to enhance their students' learning. This definitely would reinforce the need to create a positive chemistry learning environment as emphasized in the teacher education programs.

In relation to this, pre-service chemistry teachers' perceptions of the tertiary chemistry learning environment in descending order are "Student Cohesiveness" ($M = 22.92$, $SD = 3.208$), "Personalization" ($M = 20.44$, $SD = 3.366$), "Satisfaction" ($M = 20.07$, $SD = 3.908$), "Task Orientation" ($M = 19.57$, $SD = 2.846$), "Involvement" ($M = 18.93$, $SD = 2.446$), "Individualization" ($M = 18.54$, $SD = 2.142$), and "Innovation" ($M = 16.73$, $SD = 2.767$). Pre-service chemistry teachers perceived that they know, help, and are friendly towards each other. They also perceived that opportunities for individual pre-service chemistry teachers to interact with instructors who expressed concern for their personal welfare were abundant. They enjoyed the chemistry learning environment experienced at the tertiary level. However, they perceived that the instructors are not innovative with regards to lesson plans, class activities, teaching techniques, and assignments in conducting chemistry-related courses.

### *4.3 Mean Difference in the Perceptions of Tertiary Chemistry Learning Environments Between Male and Female Pre-service Chemistry Teachers*

The first null hypothesis was tested by using the Independent sample *t*-test at a specified significance level, alpha = .05. As shown in Table 5, independent sample *t*-test results showed that there is no significant difference in the perceptions of tertiary chemistry learning environment between male and female pre-service chemistry teachers ($t = -1.484$, $p = .143$). Hence, this finding failed to reject the first null hypothesis. Generally, female students perceived their tertiary chemistry learning environment more favorably as compared to their male counterparts. However, the mean differences were not statistically significant except for the subscale of 'Individualization'. Female students perceived that they are allowed to make decisions and are treated differently according to their ability, interest, and rate of working.

This research finding is supported by previous research on gender differences in classroom environment perceptions. Myint and Goh (2001), in a study to investigate gender differences in graduate teacher trainees' perceptions of their learning environments, found that out of seven scales, only "Student Cohesiveness" was significantly different. Female graduate teacher trainees perceived that, within their classroom environment, they knew each other well and maintained good friendships among themselves. This also appeared to corroborate with similar findings on gender differences in the classrooms. For example, in a study by Goh and Fraser (1997), they found that at the primary school level, the girls in Singapore generally viewed their classroom environments more favorably than boys. In Fisher and Rickards' study (1998), statistically significant gender differences were detected in students' responses to classroom environment scales. They found that females perceived their teachers in a more positive way than did males.

**Table 5** Mean difference in the perceptions of tertiary chemistry learning environments based on students' gender

| Subscales | Gender | *N* | *M* | *SD* | Mean difference | Effect size | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|---|---|
| Personalization | Male | 19 | 20.16 | 3.804 | −.533 | −.15 | −.539 | 59 | .592 |
| | Female | 42 | 20.69 | 3.468 | | | | | |
| Involvement | Male | 19 | 18.47 | 2.894 | −.717 | −.29 | −1.031 | 59 | .307 |
| | Female | 42 | 19.19 | 2.329 | | | | | |
| Student cohesiveness | Male | 19 | 22.47 | 3.405 | −1.026 | −.32 | −1.226 | 59 | .225 |
| | Female | 42 | 23.50 | 2.848 | | | | | |
| Satisfaction | Male | 19 | 19.16 | 5.156 | −1.461 | −.37 | −1.120 | 26.105 | .273 |
| | Female | 42 | 20.62 | 3.568 | | | | | |
| Task orientation | Male | 19 | 19.26 | 3.462 | −.594 | −.21 | −.729 | 59 | .469 |
| | Female | 42 | 19.86 | 2.692 | | | | | |
| Innovation | Male | 19 | 16.42 | 3.501 | −.269 | −.10 | −.299 | 27.622 | .767 |
| | Female | 42 | 16.69 | 2.636 | | | | | |
| Individualization | Male | 19 | 17.42 | 2.244 | −1.769 | −.82 | −3.019 | 59 | .004* |
| | Female | 42 | 19.19 | 2.063 | | | | | |
| Overall | Male | 19 | 133.37 | 18.467 | −6.370 | −.41 | −1.484 | 59 | .143 |
| | Female | 42 | 139.74 | 14.047 | | | | | |

*$p < .05$; The effect size is the mean difference divided by the pooled standard deviation

Research on gender differences in classroom environment perceptions was also conducted in various countries (Fisher, Fraser, & Rickards, 1997; Fisher, Rickards, Goh, & Wong, 1997; Fraser, Giddings, & McRobbie, 1995; Henderson, Fisher, & Fraser, 2000; Wong & Fraser, 1997). Overall, these studies have shown that girls generally hold more favorable perceptions of their classroom learning environments than boys in the same classes. These studies serve to inform teachers about the different learning needs of boys and girls. With this knowledge, teachers are likely to be guided in creating a more supportive environment for teaching and learning for both boys and girls. The considerable work (e.g., Ferguson & Fraser, 1996; Rickards, Fisher, & Fraser, 1997; Suarez, Pias, Membiela, & Dapfa, 1998) carried out with respect to gender and science education shows that male and female students perceive their learning environment differently. In general, girls tend to perceive their learning environment just as favorably if not more favorably than boys. This finding further supports previous related research (Fraser & McRobbie, 1995; Lawrenz, 1987; Rickards & Fisher, 1997; Wong & Fraser, 1997) in science laboratory learning environments.

### *4.4 Mean Difference in the Perceptions of Tertiary Chemistry Learning Environments Between Primary and Secondary School Pre-service Chemistry Teachers*

The second null hypothesis was tested by using the independent sample *t*-test at a specified significance level, alpha = .05. As shown in Table 6, independent sample *t*-test results showed that there is a significant difference in the perceptions of the tertiary chemistry learning environment between primary and secondary school pre-service chemistry teachers ($t = 2.813$, $p = .007$). Hence, this finding rejected the second null hypothesis successfully. Generally, primary school pre-service chemistry teachers perceived their tertiary chemistry learning environment more favorably as compared to their counterparts. Statistically significant mean differences were found in the Personalization, Involvement, Task Orientation, and Innovation subscales.

## 5 Conclusion

The results of this study indicate that the CUCEI is a reliable and valid instrument to use to gain a better picture of the chemistry learning environment and the perceived learning needs of chemistry students at the tertiary level in the state of Sabah, Malaysia. Measuring the learning environment with an appropriate tool will help lecturers examine their chemistry classes and improve the chemistry learning environment so all students may reach their full potential. It will be an advantage for lecturers to use this instrument in finding out the nature of their chemistry classrooms. Such information can then be used with other sources of data to be made

**Table 6** Mean difference in pre-service chemistry teachers' perceptions of tertiary chemistry learning environments based on types of schools taught

| Subscales | Types of schools taught | *N* | *M* | *SD* | *Mean difference* | *Effect size* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|---|---|
| Personalization | Primary | 26 | 22.19 | 2.885 | 2.887 | .86 | 3.457 | 60 | .001* |
| | Secondary | 36 | 19.31 | 3.497 | | | | | |
| Involvement | Primary | 26 | 19.81 | 2.498 | 1.447 | .59 | 2.333 | 60 | .023* |
| | Secondary | 36 | 18.36 | 2.344 | | | | | |
| Student cohesiveness | Primary | 26 | 22.88 | 2.643 | −.449 | −.14 | −.572 | 60 | .569 |
| | Secondary | 36 | 23.33 | 3.304 | | | | | |
| Satisfaction | Primary | 26 | 21.23 | 3.592 | 1.814 | .46 | 1.745 | 60 | .086 |
| | Secondary | 36 | 19.42 | 4.332 | | | | | |
| Task orientation | Primary | 26 | 20.77 | 2.160 | 1.880 | .66 | 2.627 | 60 | .011* |
| | Secondary | 36 | 18.89 | 3.151 | | | | | |
| Innovation | Primary | 26 | 18.23 | 2.065 | 2.786 | 1.01 | 4.249 | 60 | <.0005* |
| | Secondary | 36 | 15.44 | 2.843 | | | | | |
| Individualization | Primary | 26 | 18.81 | 2.593 | .308 | .14 | .530 | 60 | .598 |
| | Secondary | 36 | 18.50 | 1.978 | | | | | |
| Overall | Primary | 26 | 143.92 | 12.329 | 10.673 | .69 | 2.813 | 60 | .007* |
| | Secondary | 36 | 133.25 | 16.250 | | | | | |

*$p < .05$

aware of the changing needs of the chemistry classroom environment. This study also provided support for the fact that university and teacher education institute lecturers need to take gender differences into consideration when planning and designing chemistry curriculum for students at the tertiary level.

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# The Evaluation of Chemistry Competence for Freshmen at Technology Colleges in Taiwan

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## 1 Introduction

The purpose of this study is to evaluate the competence level in chemistry of freshmen at technology colleges in Taiwan. Chemistry is one of the core subjects in the field of engineering at technology colleges. Most professional courses in the Department of Engineering require chemistry as a prerequisite. All students are required to take a chemistry course in the first year of college. Chemistry competence for freshmen will affect their professional learning in the future, so understanding effective teaching and learning in chemistry is essential. The evaluation of chemistry competence for freshmen at technology colleges is thus an important subject.

The economic development of Taiwan relies heavily on science and technology, especially in the field of information technology (IT). The IT industry is in need of scientists and technicians at all levels. Most scientists and technicians graduate from a technology college. The effectiveness of teaching and learning at these technology schools will affect students' careers. Therefore, it is critical to probe the learning situation of students at technology colleges.

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In general, the ability level of students in private technology colleges is weaker than that of students in public colleges in Taiwan. Most students choose public schools for their advanced studies because public schools have high-quality teachers and equipment, as well as more resources than private schools. Moreover, the tuition and fees are lower in public schools than in private schools. As a result, private colleges become the second choice for most vocational high school students that plan to go to college. No research has examined gender difference in chemistry at the technology college level in Taiwan.

In this study, we created an evaluation instrument and assessed the chemistry competence for freshmen at technology colleges in Taiwan. We also examined the difference in chemistry competence between public and private technology colleges, as well as between male and female students. More importantly, we provide references for preparing remedial materials in chemistry for technology college students.

There are two limitations of this study. First, this study did not probe the chemistry teaching and learning in vocational high schools in Taiwan as our focus is on the competence of chemistry for college students. Second, this study is limited to the technology college freshmen in the Departments of Engineering and Science in Taiwan.

## 2 Literature Review

Chemistry is an important subject in engineering related departments at technology colleges. Sirhan (2007) pointed out that chemistry is often considered an important but difficult course, as chemistry topics are related to material structure. For many students, it is a complex subject. Sirhan believes that understanding how students learn can help chemistry teachers design effective teaching strategies.

Suaalii and Bhattacharya (2007) suggested that the purpose of chemical education is to help students develop a set of abstract concepts for a deeper understanding of chemistry. Fensham (1988), Zoller (1990), and Taber (2002) found that the abstract nature of chemistry learning is difficult, and thus a very high level of learning skills in chemistry becomes necessary. In fact, chemistry has been identified as an abstract and complicated as well as difficult subject.

Treagust, Chittleborough, and Mamiala (2003) found that students are unable to explain or to understand the phenomenon behind some chemical concepts. Many scholars (Çalýk, Ayas, & Ebenezer, 2005; Coll & Treagust, 2001; Nicoll, 2001; Taber, 2002) have pointed out that the *chemical abstract concept* is important because if students have the chemical abstract concepts without adequate absorption or understanding, the future chemical or other scientific concept or theory will be difficult for them to understand. Chinn and Malhorta (2002) also emphasized that the subject of chemistry is highly conceptual. Although chemical learning can be accomplished through repeated recitation, researchers have found that students often hold erroneous concepts (Bodner, 1991; Johnstone, 1984). Therefore, Schmidt (1997) suggested that students' learning of chemical concepts be presented as logical links between patterns.

Suaalii and Bhattacharya (2007) analyzed the related literature and found that students' chemical errors and learning difficulties in chemistry have been accelerating. If students hold faulty conceptions about chemical phenomena then their future learning is jeopardized as they build upon this faulty knowledge. Hence, how to clarify students' misconceptions becomes an important issue in the field of chemistry.

Regarding learning difficulties in chemistry, McCarthy and Widanski (2009) indicated that chemistry-evaluation anxiety was rated by participants as the worst type of chemistry anxiety. Because chemistry is perceived as a difficult course of study by the public, students may have predetermined negative attitudes about chemistry. Lou, Yan, and Wen (2004) surveyed high school chemistry and biology teachers from seven counties in southern Taiwan and found that 58% of the course contents cause learning difficulties for students. Johnstone, MacDonald, and Webb (1977) found that students have particular difficulty in the mole, chemical composition, chemical equations, organic chemistry, condensation reaction, and hydrolysis reaction. Overall, the literature concludes that chemistry is not an easy subject for students.

Another difficulty in learning chemistry is related to language and communication skills. Cassels and Johnstone (1985) pointed out the difficulties of language, including unfamiliarity with terminology, general misunderstanding, and use of familiar words whose meanings have been changed in the chemical field. Gabel (1999) indicated that students' difficulty learning chemistry is not necessarily a problem for the discipline itself, but for the language they use to illustrate the interdisciplinary approach. Hence, helping students understand the language of chemistry is a responsibility of chemistry teachers.

Barbera, Adams, Wieman, and Perkins (2008) found that a student's achievement expectation and self-concept correlated closely with achievement in chemistry. Students' beliefs can affect how they learn new information; in turn, students' experiences can shape their beliefs. Biggs (1999) concluded that the factor most affecting student learning of chemistry is student motivation. Therefore, determining how to increase students' motivation to learn is a challenge for chemistry teachers.

Sirhan (2007) stressed that the learning of chemistry varies according to the individual student. He further proposed that teachers should rethink students' misconceptions about chemistry. Teachers can use some strategies such as group discussion, dialogue, and exchange of ideas since different students may need different teaching strategies to learn optimally. Resnick (1987) found that when students encounter issues related to daily life, they will easily overcome learning difficulties. Song and Black (1991) suggested that some scientific knowledge that is useful for student's life is necessary for students. Therefore, in order to overcome the obstacles of students' learning, identifying and assessing student's misconceptions are crucial. Also, those aspects of chemistry that can be related to students' daily lives may be more readily understood by students and should be a focus of chemistry teachers.

If a teacher only wants to finish teaching the subject and content, the teacher has not reached his/her responsibility as a chemistry teacher. Turkish scholars Husamettin, Asli, Cngiz, and Durak (2006) found that the results of chemical achievement tests were higher for students going through computer analysis of chemistry than students taught using traditional methods. Bilgin and Geban (2006) indicated that the achievement of cooperative learning is superior to the traditional teaching of chemistry. Teachers' rethinking of their instruction becomes necessary to enhance teaching effectiveness in chemistry courses.

Regarding the differences between males and females, Clifton, Perry, Roberts, and Peter (2008) found no difference in academic achievement at the college level between males and females. According to some studies, female undergraduate students perform comparably to males in science courses (Adelman, 1991; Glynn, Taasoobshirazi, & Brickman, 2007). However, Felder, Felder, Mauney, Hamrin, and Dietz (1995) found that male students outperform females in science courses. Females receive lower grades than males in college-level science classrooms (Taasoobshirazi & Carr, 2008).

Females are able to attain similar grades as males in the classroom but not on science achievement tests. Possible explanations include differences in teacher support, parental support, motivation, enrollment patterns, and hands-on experience (Desouza & Czemiak, 2002; Enman & Lupart, 2000; Greene & DeBacker, 2004; Mattern & Schau, 2002; Shin & McGee, 2002; Taasoobshirazi & Carr, 2008). In sum, the findings comparing male and female performance in science are not consistent in the literature.

## 3 Methodology

### *3.1 Instrumentation*

We analyzed four versions of vocational school level chemistry textbooks to create test questions for freshmen at technology colleges. Twenty-two chemistry teachers in the chemical engineering department at various vocational schools across northern, central, and southern Taiwan, as well as five chemistry professors in the chemical engineering department at technology colleges were sampled to complete two rounds of Delphi survey on the test questions created earlier. Sixty final questions were selected. The first 18 questions are related to natural materials (Contents of Chapter 1). The next 17 questions are about energies in life (Contents of Chapter 2), while the following 18 questions are related to materials in life (Contents of Chapter 3). The last seven questions are related to industrial chemistry (Contents of Chapter 4).

To establish expert validity, those selected questions were reviewed and modified by eight chemistry professors at technology colleges. Difficulty analysis was also used. To establish reliability, 120 students sampled from a technology college answered those 60 questions. The overall Cronbach's Alpha coefficient is 0.837, suggesting that those questions are highly reliable.

### *3.2 Participants*

In October 2009, researchers sampled 25 classes at six technology colleges in the departments of science and engineering across northern, central, and southern Taiwan to assess their chemistry competence using those 60 questions. The subjects include 238 (including 46 females and 192 males) public and 756 (including 164 females and 592 males) private technology college students.

### *3.3 Evaluation Process*

This researcher called the chair of chemical engineering related departments to ask for their assistance beforehand. We sent the test questions along with a cover letter to those department chairs using prepaid envelops. The cover letter described the evaluation process in detail.

### *3.4 Data Analysis*

*T*-test was used to examine the difference in chemistry competence between freshmen in public and private technology colleges, as well as between male and female students.

## 4 Findings and Discussion

### *4.1 Evaluations of Chemistry Competence According to Chemistry Ability Indicators*

According to the chemistry ability indicators that were developed by Tai et al. (2010), the chemistry competence for freshmen at technology colleges is strong in the fields of interpreting information from the periodic table; understanding chemicals needed in daily life; and understanding gases and soils in nature. (Please see Table 1 for the mean of questions related to the chemistry ability indicators.) The periodic table is taught to students at the junior high level and so is well memorized come college. The finding that understanding chemicals needed in daily life is strong for students is similar to the study of Resnick (1987), which showed that course material related to daily life will be more easily understood by students and associated with fewer misconceptions.

**Table 1** Mean of questions related to chemistry ability indicators

| | | |
|---|---|---|
| I | Properly distinguishing matters | 0.44 |
| II | Abilities to understand atoms, molecules, and atomic structure | 0.38 |
| III | Abilities to understand water | 0.40 |
| IV | Abilities to understand gases and soils in nature | 0.52 |
| V | Abilities to understand the properties of solutions | 0.41 |
| VI | Knowledge of the types of energy resources | 0.50 |
| VII | Abilities to understand the principles of chemical reactions | 0.49 |
| VII | Abilities to understand batteries | 0.48 |
| IX | Abilities to interpret information from periodic table | 0.57 |
| X | Understanding chemicals needed in daily life | 0.55 |
| XI | Understanding general material chemistry | 0.45 |
| XII | Understanding general medical chemistry | 0.39 |
| XIII | Understanding modern chemical industries | 0.50 |

The chemistry competence for freshmen at technology colleges is weak in the fields of understanding structures of atoms, molecules, and ions; understanding properties of water molecules and solutions; distinguishing matter; and the application of medical chemistry. Structures of atoms, molecules, and ions are abstract concepts that will be difficult to understand if students do not have adequate absorption or understanding of the foundation upon which these abstractions are based (Çalýk et al., 2005; Coll & Treagust, 2001; Nicoll, 2001; Taber, 2002).

### *4.2 Analysis of Chemistry Competence Based on Topics Taught at Vocational High School*

The difference between public and private colleges is significant for all but the last chapter that includes seven questions related to industrial chemistry. From Table 2, it is clear that most of the means of the public technology college students are higher than those of the private college students. Since the public technology college students' ability level is better than that of the private students in general, it is not surprising that the difference between public and private colleges is significant in three areas. The reason that the means of the two groups in the last chapter that includes seven questions related to industrial chemistry are lower than the other three chapters is probably due to the lack of teaching and learning in vocational high in this field.

No significant difference is observed between male and female students from Table 3. The number of female students who study in technology colleges in the fields of science and engineering is much smaller than that of male students in Taiwan. However, most of the females in the departments of science and engineering at technology colleges have strong motivation to pursue their advanced studies. It is not surprising that females perform as well as males in chemistry competence. This finding is similar to Felder et al. (1995) and Taasoobshirazi and Carr's (2008) study.

**Table 2** Significant difference in freshmen chemistry ability evaluation between public and private technology college students

| Contents | Mean of public | Mean of private | t | df | Sig. (2 tailed) |
|---|---|---|---|---|---|
| Natural materials | 0.6039 | 0.5402 | −5.552 | 992 | 0.000 |
| Energies in life | 0.5618 | 0.4944 | −4.296 | 992 | 0.000 |
| Materials in life | 0.5044 | 0.4538 | −3.861 | 992 | 0.000 |
| Industrial chemistry | 0.4031 | 0.4118 | 0.701 | 992 | 0.484 |

**Table 3** Significant difference in freshmen chemistry ability evaluation between male and female students

| Contents | Mean of male students | Mean of female students | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|
| Natural materials | 0.5545 | 0.5648 | 0.863 | 992 | 0.388 |
| Energies in life | 0.5182 | 0.4983 | −1.262 | 992 | 0.207 |
| Materials in life | 0.4661 | 0.4884 | 1.748 | 992 | 0.081 |
| Industrial chemistry | 0.4094 | 0.4354 | 1.852 | 992 | 0.064 |

**Table 4** Significant difference in freshmen chemistry ability evaluation between male and female students in public technological colleges

| Contents | Mean of male students | Mean of female students | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|
| Natural materials | 0.6244 | 0.5833 | −1.398 | 236 | 0.163 |
| Energies in life | 0.5858 | 0.5038 | −2.036 | 236 | 0.043 |
| Materials in life | 0.5220 | 0.4746 | −1.432 | 236 | 0.154 |
| Industrial chemistry | 0.4100 | 0.4348 | 0.807 | 236 | 0.420 |

No significant difference is observed between male and female students in public technology colleges, except for the chapter two that includes 17 questions related to energies in life, as shown in Table 4. The reason that these two groups have significant difference in energies in life is unknown and thus requires further study in the future.

No significant difference between male and female students in private technology colleges is found for all but the third chapter, which includes 18 questions related to materials in life, as shown in Table 5. It is interesting that these two groups have significance in materials in life, in which female students usually perform better than male students.

## 5 Conclusions and Implications

The chemistry competence for freshmen at technology colleges is strong in the fields of interpreting information from the periodic table, understanding chemicals needed in daily life, and understanding gases and soils in nature. The chemistry competence for freshmen at technology colleges is weak in the fields of understanding

**Table 5** Significant difference in freshmen chemistry ability evaluation between male and female students in private technology colleges

| Contents | Mean of male students | Mean of female students | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|
| Natural materials | 0.5318 | 0.5596 | 2.259 | 754 | 0.024 |
| Energies in life | 0.4962 | 0.4968 | 0.034 | 754 | 0.973 |
| Materials in life | 0.4480 | 0.4922 | 3.343 | 754 | 0.001 |
| Industrial chemistry | 0.4093 | 0.4355 | 1.671 | 754 | 0.095 |

structures of atoms, molecules, and ions; understanding properties of water molecules and solutions; distinguishing matter; and the application of medical chemistry.

It is important to know the cause and effect of the weak part of the chemistry competence for freshmen. In addition, faculty members who teach chemistry at the technology college level need strategies to support student learning in the areas in which students are weakest.

The difference between public and private colleges is significant for natural materials, energies in daily life and materials in life except industrial chemistry. No significant difference is observed between male and female students in general. When comparing the difference between males and females in both public and private colleges, there is a significant difference in multiple areas. It would be interesting to know the reasons of these differences.

From this study, remedial materials to support the weak areas of chemistry competence for freshmen at technology colleges need to be created to enhance their chemistry learning. Developing a learning assessment system as well as investigating reasons for learning barriers and gender differences requires further study in the future.

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# Changes in Teachers' Views of Cognitive Apprenticeship for Situated Learning in Developing a Chemistry Laboratory Course

**Hui-Jung Chen and Mei-Hung Chiu**

## 1 Introduction

Situated learning has recently been used in science education for considering learning is participation in social practices. Through authentic practices, students can have interactions with the learning environment and develop meaningful learning. The context and content are inseparable from the reasoning process. The situated learning approach has been used to develop an instructional model of cognitive apprenticeship proposed by Brown, Collins, and Duguid (1989). Many of researchers and teachers exploring and applying the model of cognitive apprenticeship have accepted that this model can facilitate students' learning through embedded activities in social contexts with appropriation of a shared cognitive process (Collins, Brown, & Newman, 1989; Glazer & Hannafin, 2006; Hendricks, 2001; Hennessy, 1993; Jarvela, 1995). However, investigation is needed into teachers' views about cognitive apprenticeship and how teachers' views affect CA implementation. This study investigated the changes in five experienced chemistry teachers' perceptions of cognitive apprenticeship during their development of a new chemistry laboratory course over 2 years in a senior high school in Taiwan. The findings of this study are expected to help us understand the dynamic changes in teachers' perceptions on cognitive apprenticeship and design useful professional development programs for improving teachers' pedagogical content knowledge.

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## 2 Theoretical Background

Cognitive apprenticeship (CA) is a model of learning based on situated learning theory (Brown et al., 1989; Renick, Levine, & Zeitz, 1991). It is believed that learning can be facilitated through arrangement in socially shared activities and a social interaction context through a series of activities. It is a model of instruction that makes thinking visible in order to help students (Collins, Brown, & Holum, 1991; Collins, 2006; Dennen, 2004). In this model teachers act as experts by teaching strategies and scaffolding for thinking and solving problems.

In order to apply cognitive apprenticeship to classroom instruction, the learning environment has to be changed to externalize experts' internal thoughts and to guide learners to experience this process and solve problems. There are four dimensions that constitute the learning environment of the cognitive apprenticeship model: content, method, sequencing, and sociology (Collins et al., 1991). Each dimension is composed of a set of unique characteristics. For the content dimension, there are four types of experts' strategic knowledge, including domain knowledge, heuristic strategies, control strategies, and learning strategies. *Domain knowledge* includes the concepts and procedural knowledge needed within a particular subject matter. *Heuristic strategies* are the effective approaches experts use for accomplishing tasks. *Control strategies* include monitoring, diagnostic, and remedial components that help experts make use of meta-cognition for accomplishing the task. *Learning strategies* are for learning the above three types of knowledge and strategies.

Second, the learning environments require appropriate methods to promote the development of expertise. There are six teaching methods for implementing the cognitive apprenticeship: modeling, coaching, scaffolding and fading, articulation, reflection, and exploration. For *modeling* methods, teachers demonstrate a task and let students observe. Then teachers *coach* students how to do the task with more help. And teachers provided less help by *scaffolding and then fading* to let students performed tasks independently gradually. Finally, students are encouraged to *articulate* their thinking by verbalizing what they have done. Throughout the process, students are enabled to compare their results with those of other students and make reflections. Finally teachers invite students to make the explorations by themselves by solving other problems.

Third, cognitive apprenticeship provides three principles to guide the *sequencing* of learning activities: increasing complexity, increasing diversity, and global before local skills. *Increasing complexity* refers to the design a series of tasks from simple to more complicated. *Increasing diversity* means providing a sequence of tasks from one condition to various conditions in order to help students learn to distinguish which condition they should apply. They can solve the problem under different conditions. Or it can be referred to carrying out, first a low-level task, and then a higher-level task. *Global before local skills* refers to letting students construct a clear conception of one skill and then extend this to more skills. It will help students concentrate on one task, and then, the global structure of the whole series of tasks.

Fourth, sociology of the cognitive apprenticeship environment means to create the socially interactive environment to facilitate students' learning. It includes five characteristics: *situated learning, culture of expert practice, intrinsic motivation, cooperation*, and *competition*. It fosters students' learning in carrying out tasks or solving problems in an environment close to the real situation. This fourth dimension helps promote students' motivation by putting students together to experience authentic practices, by having active interaction with experts, and by promoting cooperation and competition with other students.

Cognitive apprenticeship has been used in classroom applications to foster student learning. It was applied for teaching causal reasoning by Hendricks (2001), who found that situated instruction can increase immediate learning. The students in the CA situated instruction group had better understanding of the concept of causality than the students in the abstracted instruction group. It was also implemented in a situation for teaching difficult chemistry concepts, such as chemical equilibrium (Chiu, Chou, & Liu, 2002). Chiu et al.'s study revealed that the CA group significantly outperformed the non-CA group by being capable of constructing the mental models of chemical equilibrium in the micro-world. Besides, cognitive apprenticeship methods can be integrated with technologically rich learning environments. For example, Jarvela's (1995) study, demonstrated that learning can be facilitated in a social interaction context. Furthermore, the cognitive apprenticeship model can provide a useful framework for professional development of teachers. For example, Dickey (2008) applied the cognitive apprenticeship model in a web-based course for pre-service teacher education. Dickey's study showed that the use of cognitive apprenticeship methods fostered an understanding of integrating technology for teaching and learning. In particular, four methods can foster the learning of skill knowledge: modeling, coaching, scaffolding, and exploration. Glazer and Hannafin (2006) also used the cognitive apprenticeship model to promote professional development by helping teachers learn and implement new teaching skills and strategies across a community of teachers.

Teachers' knowledge of cognitive apprenticeship is important in designing and conducting a meaningful instruction that helps students learn science. However, studies of teachers' views of cognitive apprenticeship have seldom been reported. This study aimed at promoting the development of teachers' understanding of cognitive apprenticeship over a time span of 2 years. The research question in this study was: What are the patterns of changes in the perceptions of cognitive apprenticeship among five teachers and for each individual teacher?

## 3 Methods

The study was conducted within the context of developing a new chemistry laboratory curriculum in a senior high school ranking in the top 1% in Taiwan. The participants were five experienced chemistry teachers with an average teaching experience of 13.4 years. In order to develop the course, they participated in workshops and

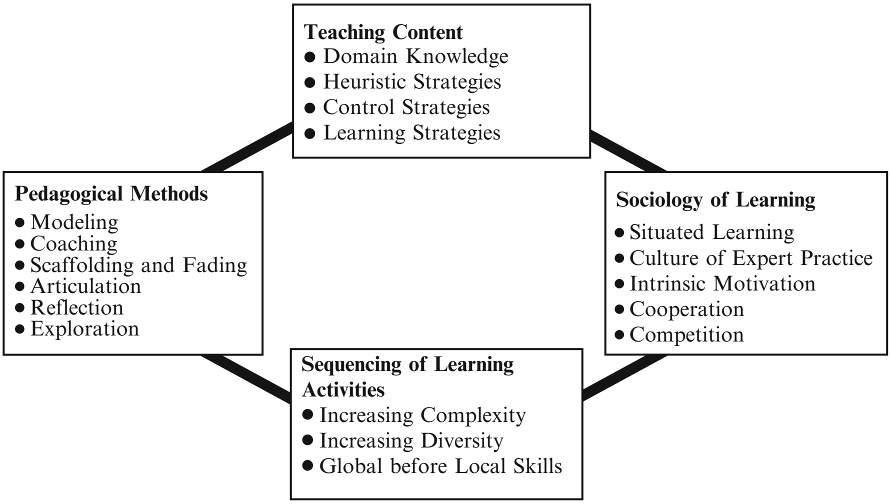


**Fig. 1** Four dimensions and their related characteristics in a cognitive apprenticeship learning environment (Collins et al., 1991)

group discussions (2 h every 2 weeks; 20 times in total). They reported the progress of the curriculum development and reflected on as well as discussed their findings in the meetings.

Data collection consisted of questionnaire surveys, semi-structured interviews, and analyses of documents and field-notes of the group discussions. The questionnaires, originally designed by Lin, Chiu, and Liu (2007), were based on the study by Collins et al. (1991) and the cognitive apprenticeship learning environment included four dimensions: teaching content, pedagogical methods, sociology of learning, and sequencing of learning activities (see Fig. 1). For teaching content, it included four kinds of knowledge: domain knowledge, heuristic strategies, control strategies, and learning strategies. It included six pedagogical methods: modeling, coaching, scaffolding and fading, articulation, reflection, and exploration. Sociology of learning includes five indicators: situated learning, culture of expert practice, intrinsic motivation, cooperation, and competition. Sequencing of learning activities included three indicators: increasing complexity, increasing diversity, and global before local skills. These characteristics were applied to designing for questionnaire (38 questions) and interview questions (6 questions) for studying teachers' views of the importance and the frequency of applying cognitive apprenticeship in the course across a time span of 2 years (from August 2007 to June 2009). The questionnaires used two scales: *importance* and *frequency of use of CA*. The importance scale was scored by teachers as 2, 1, 0, −1 and −2 respectively for options *very important, important*, *neutral, unimportant*, and *not at all important*. The frequency scale was also scored from 2 to −2, respectively, for options *always, often, sometimes, rarely*, and *never.*

# 4 Results

The following sections report the changes in teachers' views of cognitive apprenticeship as indicated by a comparison of the change in the mean scores in the questionnaire responses of five teachers, and a comparison of the change for each individual teacher.

## *4.1 Changes in Views of Cognitive Apprenticeship Among Teachers*

The results of teachers' views of the cognitive apprenticeship learning environment are organized by a two-dimensional diagram, in which the values on X and Y axes stand for the scores of two questionnaire scales: importance and frequency of use of CA, respectively. The mean questionnaire scores of the changes in the five teachers' views of the cognitive apprenticeship learning environment are presented in Fig. 2. The results revealed that the five teachers considered *sequencing of learning* as the most important and most often used strategy in the cognitive apprenticeship learning environment both before (October, 2007) and after the course development (April, 2009), especially sequencing related to the perspective of *increasing complexity of tasks*. They considered *sociology of learning* as the least important strategy in cognitive apprenticeship before course development, but their consideration

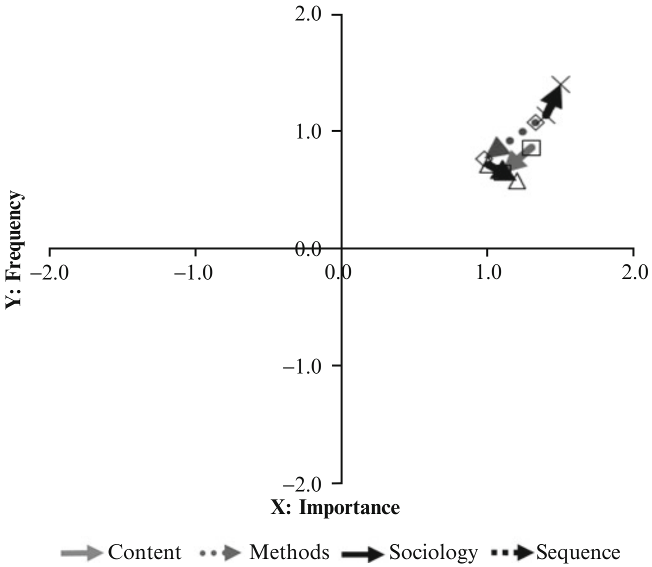


**Fig. 2** Changes in teachers' views of cognitive apprenticeship (questionnaire mean scores)

shifted to *teaching content* after course development. On the other hand, the five teachers considered *sociology* as the least used dimension in cognitive apprenticeship in 2007 but their views changed to considering both *sociology* and *methods* as the least used dimensions in 2009, especially the *competition* characteristic (in sociology dimension) and *reflections* characteristic (in method dimension).

### 4.2 Changes in Views of Cognitive Apprenticeship in the Individual Teachers

The results of the comparison of the changes in individual teachers' views are shown in Fig. 3. The changes in the five teachers' views were quite different. Three teachers, shown by the longer arrows in Fig. 3, demonstrated bigger amplitude of change in their views. The figure also shows that two teachers, CT2 and CT3, had changed more in all four CA dimensions than the other three teachers over the 2 years (2007–2009). On the other hand, teacher CT1 only changed a little over the same period. However, it is interesting to find that teachers CT3 and CT5 changed in a more negative direction, while teachers CT2 and CT4 changed in a more positive direction. For example, the two teachers (CT2 and CT4), who were directly involved in course instruction, both changed their views of the two scales (frequency and importance) of sociology from unimportant to important. While for the other three teachers (CT1, CT3, and CT5), who were involved in design and group discussion only, their view—that social perspective was the least important and seldom used strategy—remained unchanged. This finding suggests that both understanding theories and applying theories to teaching practices are important to teachers' professional development.

## 5 Discussion

The following sections discuss the results from two perspectives: how classroom enactment can affect teachers' views of cognitive apprenticeship and comparison of teachers' views of cognitive apprenticeship from this study with the relevant literature.

### 5.1 Classroom Enactment and Teachers' Views of Cognitive Apprenticeship

According to the above results, implementing the new instructional strategies with cognitive apprenticeship framework in classroom practices can affect teachers'

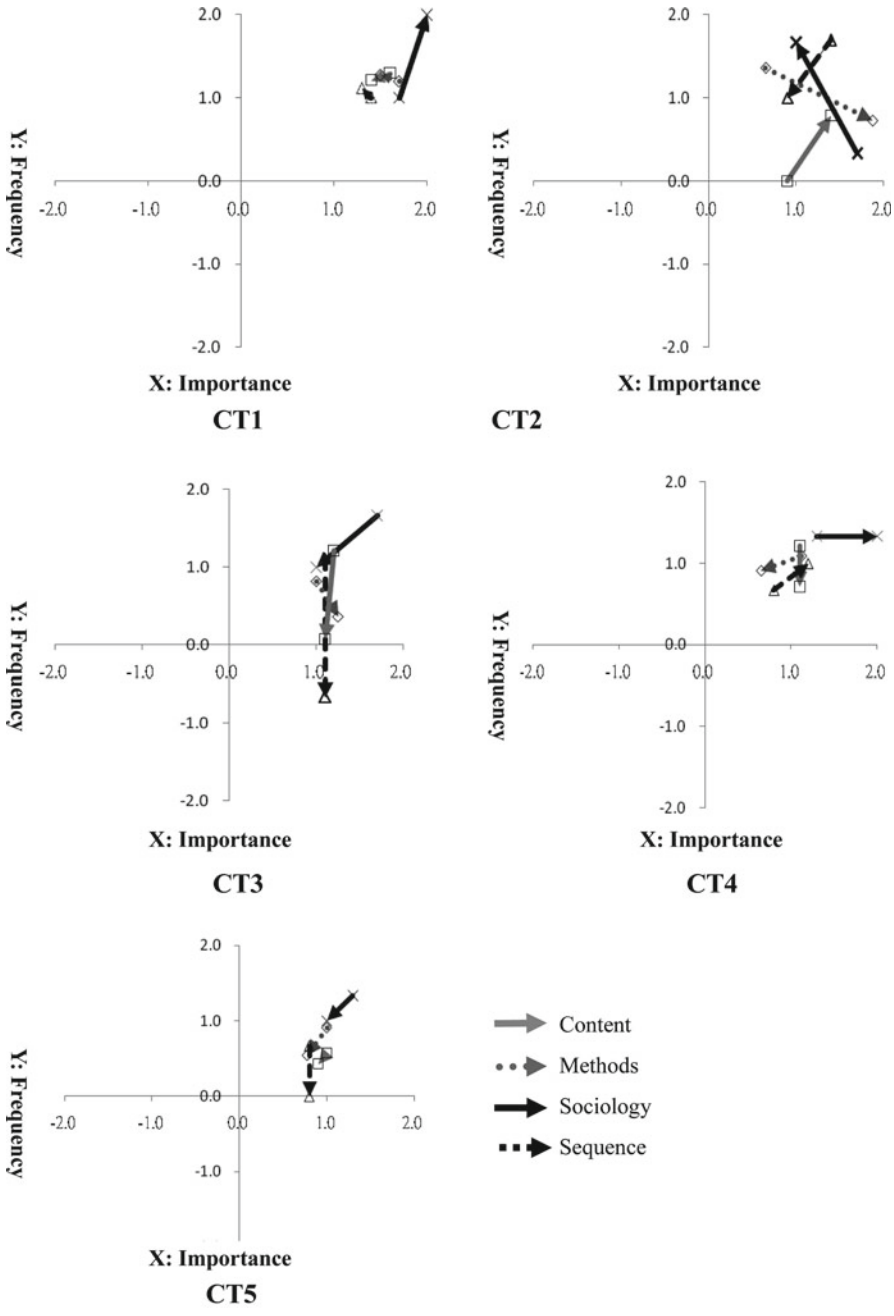


**Fig. 3** Changes in views of cognitive apprenticeship for individual teachers (questionnaire scores)

views of cognitive apprenticeship. In the beginning of the course development, all five teachers revealed that, although they had not heard of the term *cognitive apprenticeship*, they could describe its meaning literally in their own words. Teacher CT2 said in the interview:

> I have heard about "apprenticeship" but not "cognitive apprenticeship". However, I think the latter is very close to the former in meaning. The cognitive apprenticeship approach can be applied to a small class with less than 20 students. Like traditional apprenticeship, teachers show students how to carry on the task, and then students learn the skill and do the task on their own.

After the 2-year development and implementation of the new course, it is interesting to find that teaching practices can affect teachers' views of cognitive apprenticeship. Comparing the results of questionnaires and interviews, it was found that the teachers (CT2 and CT4), who were engaged in classroom practices, had applied the cognitive apprenticeship framework to develop instructional strategies to facilitate student learning, especially the sociology of learning dimension.

According to the definition of cognitive apprenticeship, the sociology dimension includes five characteristics: situated environment, culture of expert practice, intrinsic motivation, cooperation, and competition. The results of questionnaire responses showed that teachers CT2 and CT4 increased the frequency of applying social dimension strategies from 0.1 to 1.4 and from 0.7 to 1.0, respectively. On the other hand, the classroom observations also showed that teachers CT2 and CT4 embedded the CA strategies into classroom enactment. For example, teacher CT4 encouraged students to discuss the experimental results with others and asked students to make evaluations about other students' work. In the interview, teacher CT4 said he designed those social activities to let students observe how other students perform the experiment and make reflections throughout the activities. On the other hand, the teachers who were not involved in teaching practices and participating in group discussion showed different opinions of cognitive apprenticeship. As the results of the questionnaire responses showed, teachers CT3 and CT5 considered the social dimension strategies as unimportant in the classroom enactment. Their scores for this dimension were −0.7 and 0 after the 2-year course development and implementation in June 2009.

## 5.2 Comparison of Teachers' Views of Cognitive Apprenticeship in this Study with Literature

The cognitive apprenticeship environment for situated learning is composed of four dimensions: content, methods, sociology, and sequence (Brown et al., 1989; Collins et al., 1991). A review of empirical studies that applied cognitive apprenticeship in classrooms showed that the effective teaching method for applying cognitive apprentice is scaffolding and modeling followed by learners' reflections (Dennen, 2004). Making reflections is important for the method dimension of cognitive apprenticeship. Parker and Hess (2001) found that the experimental group of student teachers who experienced a well-designed class discussion and made reflections on the activities outperformed the control group without reflections. Bean and Patel (2002) found that the in-service teachers who were asked to keep weekly journals integrated their personal beliefs about reading concepts throughout the process of making reflections. Reflections therefore play an important role in the method dimension of cognitive apprenticeship. However, in this study, the five teachers considered themselves only applying "sometimes (0.4)" the reflection method in the classroom according to the questionnaire responses. The two teachers, CT3 and CT5, who were not involved in teaching practices but participated in group discussion only, considered making reflections was only "seldom (0)" applied in the instructional strategies. On the other hand, teacher CT2, who enacted cognitive apprenticeship in the classroom, changed his views on the frequency of applying reflections strategies in the classroom from "seldom (−1)" to "quite often (0.5)."

It is emphasized in the literature that the social dimension includes the situated learning environment within the CA framework. As Brown et al. (1989) mentioned, the central issue is to develop cognitive and meta-cognitive skills through participation in authentic learning experiences. Embedding learning activities in a social context can promote students' higher-order thinking skills. The social context includes cooperation and competition among students, as well as learning interactions between teacher and students. In this study, the five teachers considered themselves "not quite often" using the social interaction skills in their teaching strategies with CA. Even though the teachers had developed and implemented the new course, they still kept their views unchanged 2 years later, from 0.7 (sometimes) in October of 2007 to 0.6 (sometimes) in April of 2009. The scores of two sub-dimensions, situated learning and competition in particular, were lower than those of other sub-dimensions. For example, teacher CT3 considered "competition" was "seldom" used and "cooperation" never used in the classroom with cognitive apprenticeship in 2009. However, teacher CT2 showed progress he had made during the 2 years. He changed his view of applying social interaction skills to classroom practices from 0.1 (sometimes) to 1.4 (often). From the above, it is apparent that teachers need help to clarify what cognitive apprenticeship is and to apply it in their classrooms in order to bridge theories and teaching practices. Teachers need to be encouraged to apply CA strategies in the classroom enactment and improve their pedagogical content knowledge as proposed by Shulman (1986).

## 6 Conclusions and Implications

In the cognitive apprenticeship model, a teacher initially leads students toward learning a new task or solving a problem and gradually learners develop their own ability to do new tasks or solve new problems by themselves. However, learning how to use new instructional strategies such as cognitive apprenticeship is a challenge for teachers. Participation in professional development workshops in cognitive apprenticeship is not enough for teachers. It is important for teachers to implement the cognitive apprenticeship strategies in a real classroom context, make reflections from teaching experiences, and then improve their pedagogical content knowledge. In this study, the real context was the development of a CA-based course. Throughout enactment in the classroom, teachers interacted with students, made reflections, and modified their teaching strategies of implementing cognitive apprenticeship. Teachers constructed their own perceptions of cognitive apprenticeship and also reflected upon them during group discussions. Through this back and forth process, teachers modified their own opinions. Improvement of teachers' understanding of cognitive apprenticeship helped them to design a better course to improve students' learning.

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# Part V
# E-learning and Innovative Instruction

**Hsin-Kai Wu**

Recent advances in technologies have transformed ways of learning and teaching in chemistry. The four chapters in this section on the theme of E-learning and Innovative Instruction demonstrate new possibilities and learning opportunities provided by innovative use of technologies.

In the first chapter of the section, Lu, Zou, and Zhang show how the application of mind maps improved high school students' problem-solving competences. The findings indicate that the use of mind maps encouraged students' divergent thinking, guided students to approach a problem from different directions, helped students generate sub-questions, and enhanced the organization of the problem-solving process. These instructional functions cannot be easily fulfilled by traditional instruction, and the findings of this study suggest the effectiveness of e-learning.

Rather than using a single technological tool, Su presents an experimental chemistry course that integrated an effective computer-based platform to support college students' chemistry learning. The platform included animations, static charts, verbal descriptions, and multimedia presentations. By using a quasi-experimental approach, the study shows that students in the e-learning group performed significantly better in learning achievement and learning attitudes than the traditional teaching group. Similarly, the third chapter compares the differences between a computer-aided group and a traditional teaching group in high school students' chemistry performance and attitudes. The statistical results also indicate that the computer-aided instruction was significantly more beneficial to students' chemistry learning.

The fourth chapter demonstrates the potential of technologies in assessment. Chen and her colleagues integrated an instant response system (IRS) as an in-class

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assessment tool in their undergraduate chemistry course and examined students' perceptions about the learning effects of the system. The findings show students' positive perceptions toward the system and a positive correlation between students' perceptions on IRS use and their performance in learning chemistry.

Together, the four chapters present a spectrum of research on using technologies in chemistry education and provide more evidence on the effectiveness of e-learning.

# Application of Mind Maps and Mind Manager to Improve Students' Competence in Solving Chemistry Problems

**Zhen Lu, Zheng Zou, and Yitian Zhang**

## 1 Introduction

Chemistry instruction of high school students has become the focus of recent reform efforts with the goal of cultivating students' science literacy, optimizing the quality of students' thinking, and improving students' competence with problem-analyzing and problem-solving (Ministry of Education of People's Republic of China, 2005). How should a new mode of thinking be introduced to enable students to experience the process of problem-solving so as to improve their own problem-solving competence? By applying mind maps and the software Mind Manager to the study of solving chemical problems, this research tried to explore a new approach for enhancing students' problem-solving competence.

This chapter presents research results of the project "Action Research on Applying Mind Map to Optimize Teaching Effectiveness Under the New Curriculum," which is sponsored by the Nanjing Middle-Young Tip-Top Talents Program (2008), "Study and Reflection of Teaching Result on Applying Mind Map to Optimize Teaching Effectiveness Under the New Curriculum"; the eleventh Five-Year Provincial Educational Programming Research Topic: "Action Research on (Chemistry) Instructional Strategies, Pattern, and Excellent Case Under the New Curriculum" (No. D/2006/01/093).

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## 2 A New Mode of Thinking: Mind Maps

A mind map is a new mode of thinking that appeared in the late twentieth century. It emphasizes divergent thinking and focuses on the core concept or the crucial problem instead of on the process of knowledge acquisition (memorizing) and problem solving. It leverages associative thinking to understand concepts and solve problems (Buzan, 2004).

In China, the origins of mind maps can be traced back to the Warring States period, over 2,000 years ago. *Shan Hai Tu* is an example of a book that included pictures or hieroglyphs. Words illustrated by pictures are part of the Chinese reading tradition. Another classic work compiled by combining pictures with words is *Shui Jing Zhu*, the earliest comprehensive geography book to record a river course and water system, written by Li Daoyuan, who lived during the Beiwei Dynasty, 6 BC.

## 3 Chemical Problem-Solving Competence (CPSC)

According to the 20 years of profound research conducted on CPSC, during the process learners should first identify the problem and describe it, which determines the student's depth of comprehension of the chemical problem (Johnstone, 1991). Chemistry problem comprehension can be conceptualized as belonging to one of three categories: macro-level, micro-level, and symbol-level. This description from the specific level to the abstract level reflects the problem-solver's level of comprehension, which decides whether they can solve a particular problem. By describing and understanding the problem, an initial model is set up. The thinking mode and strategy directly determine the process of CPSC. In this way, mind maps can serve as a scaffold of thinking construction and guide the direction of thinking during the problem-solving process (Wu Xinde, 2006). This process promotes the formation of learners' CPSC. Such thinking enables the learner to think in a comprehensive way and solve the problem through a multi-dimensional means of representation (Zhen, 2006).

## 4 Theoretical Study on Problem-Solving Instruction

### *4.1 Theories of Problem-Solving*

From a psychological point of view, problem-solving is an extremely complicated psychological activity. Problem solving is a goal-directed sequence of cognitive operations. Anderson summarized the characteristics of problem solving as: (1) goal-directed (proceed from initial question to overcome obstacles until the goal is achieved), (2) arithmetic focus (a series of operations should be carried out until the final goal is reached), and (3) cognitive nature (the result is directly decided by the quality of the cognitive impressions).

Mayer (1992) emphasized that problem solving is cognitive, directional, and personal. Moreover, it is a series of processes. However, to Howard Gardner, problem solving is intelligence applied to the process to understand, deal with, and utilize information and then follow through with different methods and strategies. Mayer (1996) regards problem solving as an ability to apply knowledge to various situations. Some scholars hold different views on this area. For example, Ausubel (1978) thinks it is a kind of meaningful form of discovery learning, although it is not totally spontaneous. Ashmore, Fraze, and Case (1979) think problem solving is the result of applying knowledge and procedures to a problem. Problem solving is an intersection of creation where one employs knowledge and methodology to solve unconventional problems in a comprehensive and innovative manner.

We believe solving problems is based on thinking, which is influenced by the thinker's background knowledge, personal experience, brain development, and so on.

## 5 A Study on Chemical Problem Solving

### *5.1 Psychological Model of Chemical Problem Solving*

Ashmore et al. (1979) divided the problem solving process into four stages: discern the question, choose the appropriate information, combine independent information, and comments. Reif (year) proposed that students should be clearly taught about the professional procedure of solving a problem. Students should understand the three steps: Analyzing, reaching a solution, and checking the result. The problem-solving process is much more important than the consequence. Some scholars refined this process by calling for dividing standard questions into sub-questions. Generally speaking, problem solving centers on analyzing, solving the problem, and checking the result. It is not difficult to find that different problem-solving approaches depend on different psychological models. If teachers introduce the psychological theories, students' problem-solving ability could be greatly improved.

### *5.2 Influence of the Chemical Problem Solving*

Chemical problem solving is influenced by multiple factors, which mainly come from the question and the subjective and objective respects of the personal factors. The question factors relate to the type of question and its description. Personal factors include individual cognitive structure, metacognition level, cognitive style, motivation level, and so on.

### 5.3 Teaching Skills on Solving Chemistry Problems

To solve chemistry problems, we should concentrate on finding the best solution, supporting students to participate actively in the whole process. It is especially important to create an efficient environment in which students can obtain knowledge and the scientific methods to find the answer. This method not only requires students to focus on the specific knowledge of the subject, but also requires their sympathetic response to the issue. That is to say, efficiently creating the problem situation has a strong influence on students' emotions, attitudes, and their own value assessment of the problem.

During the process of analyzing and solving chemistry problems, most researchers will study and instruct those through organizing class discussions and resolving the problem layer by layer. However, some teachers and scholars noticed that the process of solving chemistry problems is abstract and hard to control, so they started to think of an alternative way of guiding students to inquiry with the help of some new tools, such as mind maps. Gradually, we applied the mind map tools to solve chemistry problems, which can effectively facilitate the problem solving process because of its intuition and controllability. This can also make it an empowering tool for discovering, simplifying, and resolving problems.

### 5.4 Applying Mind Maps to Promote Teaching Transformation

*Problem-solving mode changed linear mode to plane radiation mode.* For a long time, Chinese students were instructed by the model "remember what the teacher teaches," which makes learning a passive process. However, teachers can lead students to brainstorm and explore the whole course if they use mind maps. Mind maps first simulate the chemistry problem solving process in a general way, trying to solve the problem and learn from mistakes. Mind maps can clearly present the whole process and make the thinking process visible. Thus, it will help students to develop more than one way to solve the problem. The branch questions radiated by a mind map can be used as the theme of group discussion and research. Moreover, it will make the group work more practical. The extension of mind map branches will be determined by the students themselves, so that the group study will be better organized with clear goals and is easily monitored and instructed.

*Class organization changed from a single structural pattern to a comprehensive pattern.* Mind maps will change a simple linear structure into a three-dimensional comprehensive structure. The radiation characteristic of mind maps helps teachers transfer the linear structure of a class into a comprehensive one. Each different branch can be treated as the different angles of the problem that need to be solved, which can help students recognize those problems through different scientific dimensions and then synthesize the subject, so that those analysis results will be more realistic. In daily life, we can hardly limit those aspects related to chemistry.

On the other hand, we do have to admit that those problems under real conditions are complicated, and it is impossible to just use the knowledge or method of one single subject to solve such problems smoothly.

*Concept-learning procedure changed from isolated learning to network learning.* Every keyword subject in the picture is not an isolated concept. Mind maps require the teacher to examine the problem and figure out the connections among each chemical concept in the course while representing the concepts involved as linking together in a comprehensive chemical knowledge system.

*Study process changed from left brain learning to whole brain learning*. Color and pattern are needed in using mind maps. Color is used to indicate and strengthen the memory, vocabulary, data, logic, and most important details while solving chemistry problems. Applying vivid figures and symbols instead of single characters or chemical symbols helps the left and right intersections of the brain work cooperatively and efficiently and thus strengthens the students' problem-solving ability. Through these steps, what students study is not mechanical formula, chemical equation, or stiff chemical concepts, but a kind of reflection from students' experiences, arousing the whole brain to understand chemistry knowledge more clearly, adequately, and intuitively.

## 6 Research on Applying Mind Maps to Cultivate Students' CPSC

We set up an elective course in the 10th grade to learn mind maps and the software Mind Manager in Nanjing No. 3 High School in Fall 2008. The aim of this action research was to explore the effective way to enhance students' CPSC. By administering a questionnaire, collecting students' assignments, and running statistical analyses of the final exam scores, we observed the influence of this new thinking approach on students' CPSC.

### *6.1 Design of the Action Research*

There were 19 students taking part in this course, totaling 20 lessons. The course included four parts: introduction and learning of mind maps, drawing and mastering mind maps, presenting the chemical exploration process and history of chemistry, and self-exploration of CPSC.

### *6.2 Introducing and Learning of Mind Maps*

In this step, the students experienced the whole process of problem solving: self-questioning, ascertaining problems, finding solutions, and thereby developing thinking skills. At the same time, they understood the philosophy of mind maps and learned to use the software to assist them.

## 6.3 Drawing and Mastering Mind Maps

*Phase I – brainstorming.* All the students discussed and thought of a topic together. The teacher drew a mind map to represent what the students thought. Then the students learned the procedures and methods of drawing mind map.

*Phase II.* The students drew mind maps with the teacher's instruction toward CPSC. The students were divided into five groups (with 3–4 members per group), solved a chemical problem by teamwork, and presented their thinking on a mind map.

## 6.4 Presenting Chemistry Exploration Process with Chemistry History

The students learn creative (critical) thinking in CPSC by watching the mind map presentation on the working process of scientists. The students learn to use the software, Mind Manager X5, to draw a mind map and compare it with a hand-drawn mind map.

## 6.5 Self-exploring CPSC

The students were provided with a list of chemistry problems. Each group chose one topic from the list and worked out the solution using a mind map. At the end, each group had a student present their group and give a report by using Mind Manager X5.

## 6.6 Cases of Action Research

*Exercise for problem representation-dissolution of NaCl (sodium chloride).* Students placed sodium chloride dissolution as the core subject of the mind map. They understood NaCl dissolved at different levels by drawing a mind map (see Fig. 1). With literal representation, iconic representation, and the ionization equation comprising the three branches, students came to more deeply understand the process of ionic crystals.

*Exercise for strategy and competence of CPS.* Separation and purification of mixtures is one of the most important components of practical instruction at the 10th grade chemistry level. It takes time and effort to cultivate the students' practical theory and skills to solve practical problems. First, we should focus students' attention on understanding the characteristics and properties of the mixture as well as finding the best means of separation and purification. The mind map (see Fig. 2) indicates how separation and purification are the keys to solving the problem. According to the composition of the mixture, the topic is divided into different related branches (solid – solid, solid – liquid, liquid – liquid, etc.). Students find methods, apply principles to design experiments, and verify in the lab.

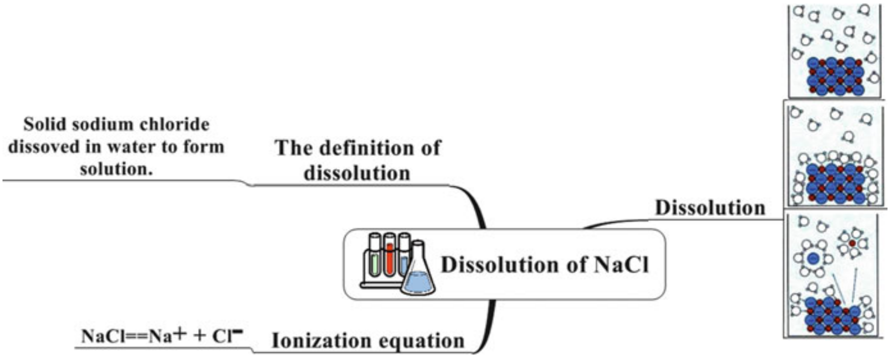


**Fig. 1** Mind map for NaCl dissolution

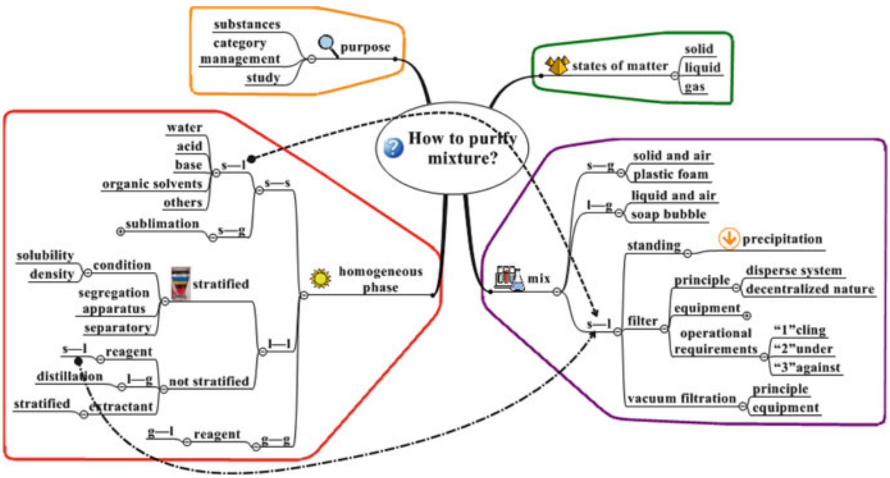


**Fig. 2** Mind map for how to separate and purify a mixture

# 7 Influence of Action Research on the Improvement of Students' CPSC

## *7.1 Effects on the Scores of Students Who Have Taken the Elective Course*

After the research, we analyzed the students' exam scores and observed their problem-solving processes. The number of 10th grade students who took part in the midterm exam and final exam was 595 (N = 595). The experimental group was composed

**Table 1** Average score of each group and standard deviation*

| | | Mid-term exam | | Final exam | | D-value |
|---|---|---|---|---|---|---|
| | Number | Average score | Standard deviation | Average score | Standard deviation | Average score |
| Total | 595 | 57.945 | 16.865 | 59.567 | 16.159 | 1.622 |
| Experimental group | 19 | 62.895 | 11.493 | 66.947 | 11.336 | 4.052 |
| Control group | 576 | 57.846 | 16.955 | 59.324 | 16.257 | 1.478 |

*Table 1 is date analysis of chemical mid-term exam in Grade 10, in Nov. 2008. The significant value is 0.05.

**Table 2** Variance analysis results and *t*-test results of two groups' scores on mid-term exam and final exam**

| | Homogeneity test of variance | | *t*-test | |
|---|---|---|---|---|
| Type of score | F | P | t, | P |
| Mid-term exam scores | 2.127 | 0.030 | 1.782 | 0.090 |
| Final exam scores | 2.056 | 0.036 | 2.826 | 0.010** |

**Table 2 is date analysis of chemical final exam in Grade 10, in Jan. 2009. The significant value is 0.05.

of 19 students who had taken part in the elective course ($N_1 = 19$). The control group was composed of 576 students who had not taken part in the elective course ($N_2 = 576$). We analyzed the scores on the mid-term exam and final exam (see Table 1) through SPSS and found the experimental group showed a greater increase in test scores.

Meanwhile, the scores on the mid-term exam and final exam were converted to Z scores, where they appeared as a normal distribution. A *t*-test was also carried out between the experimental group and the control group.

From Table 2, we can see the standard F of variance test of mid-term and final exam scores was 2.127, one-tail critical value $F_{0.05(19,576)} = 1.928$, $F = 2.127 > 1.928$, so the homogeneity of variance assumption was rejected. Given the F value of the experimental group and control group, there was no homogeneity of variance. Therefore, *t*-test was carried out on the two independent samples. $P = 0.090 > 0.05$ means there was no significant difference in the mid-term exam scores.

However, the F value of homogeneity test of variance for the final exam between the two groups was 2.056, $F = 2.056 > 1.928$, Thus, there was no homogeneity of variance, either. *T*-test was carried out and $P = 0.010 < 0.05$. There was significant difference in scores on the final exam between the experimental group and the control group.

The result was that the increasing range of chemistry scores of students who had taken the course (4.052) was higher than the range of scores of those who had not taken the course (1.478).

## 8 Analysis of the Results of Action Research to Improve CPSC

In order to further observe the change of students' CPSC, a case study on Student A is introduced here to demonstrate how to use mind maps to solve chemical problems.

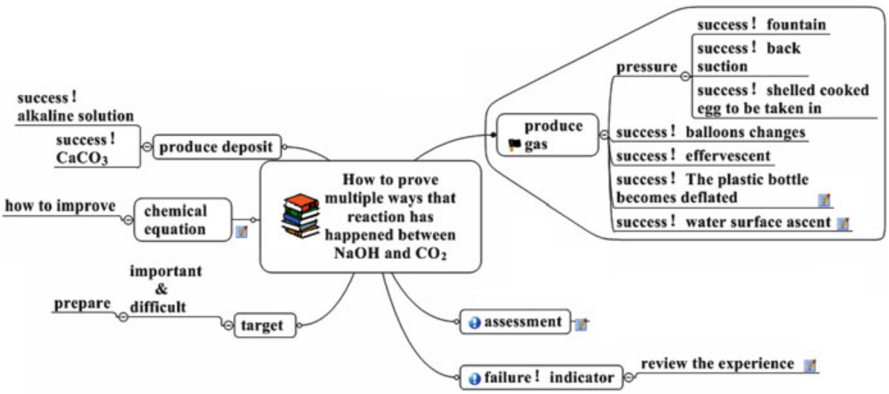


**Fig. 3*** Mind map for how to prove multiple ways that reaction has happened between NaOH and $CO_2$

* Figure 3 indicates the mindmap which is applicated for solution through MINDMANAGER by Student A.

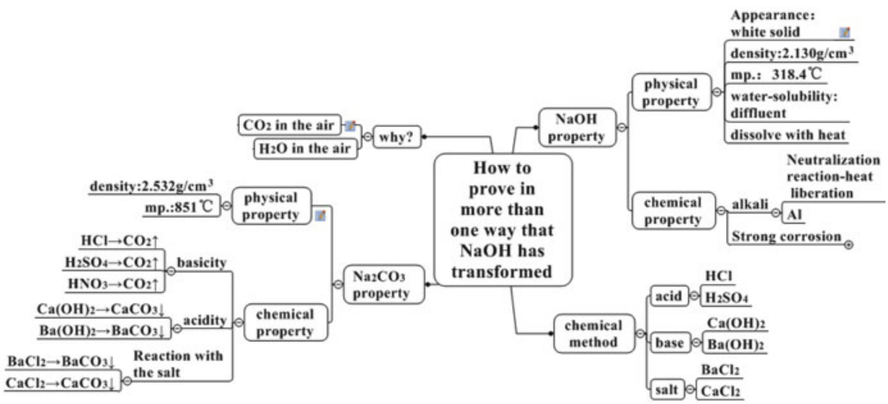


**Fig. 4**** Mind map for how to prove multiple ways that NaOH has transformed

**Figure 4 indicates the mind map which is made for the same question after one-semester training by Student A.

In the first period of "drawing and mastering mind maps," the student had almost mastered the characteristics and drawing methods of mind maps. We presented the students with a central question: "how to prove in more than one way that a reaction has happened between NaOH (sodium hydroxide) and $CO_2$ (carbon dioxide)?" Figure 3 is a mind map drawn by Student A.

This mind map lacks logic between levels, so it fails to present the process of problem analyzing, recounting, hypothesis-setting, model-constructing, and plan-proposing, which means that this student did not make it clear how to solve the problem.

After a semester's instruction on CPSC with mind maps, we observed the mind map drawn by student A again about same subject.

By observing this mind map, we found that student A had made an initial model for analyzing problems. In order to solve this problem, he first analyzed the characters of NaOH and judged which character was most likely to cause the transformation of NaOH, and then analyzed the characters of the reaction products and compared them with NaOH. He changed the problem to "check whether there is a little amount of $Na_2CO_3$ (sodium carbonate) blended in NaOH." Two equations were set to present different reactions of two substances. Finally, by doing so, he successfully solved the problem.

It can be found that the number of branches in the former map is 3 and in the latter is 7. We can conclude that both the depth of this student's thinking and the extent of knowledge construction improved. The level of presenting problems also improved from sentence to equation of chemical reaction. This student constructed his own model of problem solving, and he analyzed key words of the problem, singled out and tackled the essence of the problem, and accordingly changed the problem in a familiar way that suited him best and finally solved the problem.

Meanwhile, by analyzing the scores of exam papers and drafting papers, we found most students who had taken the elective course could apply mind map to their daily chemical problem-solving practice. They could present their thinking in a more direct and multi-dimensional way, such as with words, numbers, images, charts, and symbols. These are basic elements that are used to construct a mind map and provide students an effective approach to dive into problems a little deeper. In general, after the training in making mind maps, students became more flexible in critical thinking and problem solving.

## 9 Significance of Applying Mind Maps to Improve Students' CPSC

Mind maps are not only a learning tool, but they can also be the basis for teachers to make formative assessments. Since students present their thinking and relative concepts in one mind map, it becomes easier for teachers to identify problems in concept relation as well as to present the students' different ways of thinking, such as whether the problem is clearly presented and whether the concepts are correctly defined.

Teachers can better judge problems that occur in the students' thinking from their mind maps (Gabal 1998). Presentation of a mind map can also reflect students' individual differences and highlight students' personal learning styles, which helps teachers to better deal with individual differences between students so as to teach them in accordance with their aptitude.

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# An Integrated-ICT Assessment for College Students' Performances of Chemical Learning

**King-Dow Su**

## 1 Introduction

ICT chemistry experiments offering both declarative and procedural knowledge could be beneficial to facilitate scientific learning. At the present time, most students simply learn to memorize algorithms and lower-level content in order to pass examinations without developing a meaningful understanding of the higher-level chemical concepts and unifying principles. Furthermore, much misunderstanding of chemical ideas and alternative conceptions hinders further effective learning (Calik & Ayas, 2005; Coll & Treagust, 2001). Enhancing students' understanding of chemistry concepts and process skills, rather than only teaching lower-level chemical knowledge, has become a major goal for chemistry educators (Ardac & Sezen, 2002; Nakhleh, 1993). Many have explored the implementation of some promising practices that are not commonly used in chemistry teaching, such as integrating multimedia into the learning environment (Ardac & Akaygun, 2004; Su, 2008a, 2008b, 2011; Yang & Andre, 2003) to achieve this goal (Lin, 1998; Lin, Hung, & Hung, 2002; Rodriguez & Niaz, 2002).

Our tactic of incorporating new content into chemistry courses and creating a new environment, such as by the use of ICT programming texts (Ardac & Akaygun, 2004), integrating some science history into the courses (Lin et al., 2002), and applying network technology (Keengwe, Onchwari, & Wachira, 2008), not only increased students' learning motivation and interest but also improved their performance and study attitudes at the same time, as well as leading to more intimate communicative interactions between teachers and students. This redesign of an ICT-based chemistry experiment course contributes to students' learning performance. It will become more important in our study of chemical teaching in the future.

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Hofstein and Lunetta (2004) have suggested carrying out scientific experiments helps learning of concepts and characteristics; therefore the importance of such experimental activity should not be underestimated.

Our ICT experimental chemistry course is an example of an effective platform that can arouse students' interest, allowing them to absorb new scientific knowledge and foster the development of professional skills. Students' learning motivation and efficiency is largely dependent on well-prepared course designs. Therefore, a well-designed program of ICT chemistry experiments becomes a necessity for teachers.

The aims of this study are to construct ICT chemistry experiment courses, to build a foundation that will be both efficient and facilitate tactical teaching for the learner, as well as increase the mutual interaction between teachers and students.

This study takes a quasi-experimental approach. Questionnaires were used to test different criteria related to learning performance, and statistical analysis of the learning efficiency and attitudes of tenth grade students were carried out. At the end of our study, we evaluated the progress the students had made in terms of technological creativity and manipulative competence to solve their chemistry-related problems.

With the rapid development of ICT technology, human beings' living and learning styles change enormously day by day. ICT interactions could develop into varied and extensive learning programs, which will eventually replace traditional classrooms. This new type of learning pattern has more flexibility, can save the learners time, and does not need a special space or location. The most effective learning can be transmitted from two dimensions into three dimensions in ICT.

## 2 Theoretical Background

### *2.1 Constructivism Theory*

The importance of incorporating constructivism into scientific teaching has already been recognized by most science educators, with many studies carried out over the past 20 years. Trumper (1997) and Yore and Treagust (2006) maintain that constructive knowledge is the result of students' thinking ability. Ideas are constructed from preknowledge and from students' social and cultural backgrounds. Ausbel (1968) found that the best principles of constructivism help students to demonstrate and assess their learning. Several methods based on constructivism have been developed from these basic teaching principles. These principles of constructivism have given rise to several interpretations ranging from information processing, interactive constructivism, and social constructivism to radical constructivism approaches (Yore, 2001). Moreno and Valdez (2005) regard the function of a multimedia environment in the situated constructivist design, either as abundant reality or as simulation, to encourage learners to decipher knowledge on their own, to grasp and control the learning process by themselves, and to facilitate the exploration and reorganization of acquired knowledge. Another recent study (Frailich, Kesner, & Hofstein, 2007) shows how the building of an ICT-based experimental chemistry environment has the potential to enhance the comprehension of basic chemistry concepts, stimulating students' attitudes and interests to increase their awareness regarding the relevance of chemistry in their daily life.

### *2.2 Development of Teaching Tactics*

ICT tactics are combined with animations, static charts and descriptions of characteristics. The unit is divided to include several relevant and meaningful experimental models. These minor experimental models include the teaching of cognitive contents of chemistry text designs, teaching methods, teaching situations, course skills technology and scientific attitudes, and so on. All these aspects are flexibly combined together to create new learning styles and reliable applications.

PowerPoint presentations are prepared using animated examples. Parts of our Flash animations are converted using the Adobe Photoshop 7.01 software (see Fig. 1); each animation lasts for almost 20 s. Students in the experimental group have 5 min after the classroom demonstrations to practice with the animation.

## 3 Methodologies

### *3.1 Participants*

For convenience of discussion, all 49 selected participants are from the same class, which was divided into the experimental group (a total of 25 participants) that was taught using the ICT model methods; the remaining students formed the control group (a total of 24 participants), who were taught with traditional teaching methods.

#### 3.1.1 Constructing Classroom Facilities

The science teacher needed to be able to use a range of ICT resources in this chemistry classroom (see Table 1).

#### 3.1.2 Applied Method

There are four stages in our research design; namely pretesting, target group teaching, posttest, and questionnaire evaluation. It is expected that all methods, including pretests and posttests, experimental teaching, learning questionnaire, and statistical analysis of students' learning achievements and attitudes, should significantly help students improve problem-solving ability and promote positive efficiency.

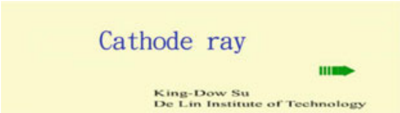
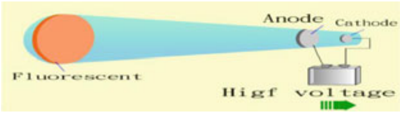
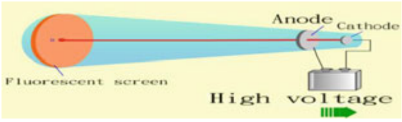
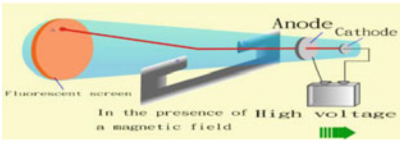
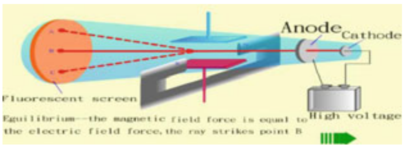
| Animated representation | Statements |
|---|---|
| a   | Cathode-ray tubes conducted by J. J. Thomson, an English physicist at Cambridge University. |
| b   | Cathode-ray tubes conducted electricity when subjected to HV. |
| c   | Particles were accelerated from cathode toward anode, which has a hole in its center. |
| d   | Electron path bent (+) in the process of the electrical field. |
| e   | Electron path bent (N) in the process of a magnetic field. |
| f   | Electron path does not bend in the processes of a magnetic field and electrical field.<br>The evidence shows this kind of particle has a negative charges and is called an electron. |

**Fig. 1** Replace by Adobe Photoshop 7.01 **cathode ray tube** that software deal with experiment cartoon arrange by (a) to (f), show the order picture

**Table 1** ICT resources in this chemistry classroom

| | |
|---|---|
| Software | Flash animations, PowerPoint and Microsoft Word 2007 |
| Hardware | Data projector and screen, online networks, laptop, digital camera |

Five aspects of student achievement (including knowledge, understanding, application, analysis, and synthesis) were tested by way of pretests and posttests. The draft test design was evaluated by staff members at the Joint College Entrance Examination Center in Taiwan and by five senior chemistry professors. The reliability of the achievement tests was analyzed by Cronbach's α. Reliability was expressed in terms of the Cronbach's α coefficients to determine the internal

**Table 2** Mean (M), standard deviation (SD), and Cronbach's α

| Aspect | M | SD | Cronbach's α |
|---|---|---|---|
| SQ1 | 3.8 | 0.6 | 0.8 |
| SQ2 | 3.7 | 0.8 | 0.8 |
| SQ3 | 3.4 | 0.8 | 0.8 |
| SQ4 | 3.7 | 0.8 | 0.7 |
| TA (the whole scale) | 3.6 | 0.8 | 0.9 |

consistency of the total questionnaire and subscales. The α coefficients obtained for TCR pretest and posttest were 0.7 and 0.7, respectively. The same test was employed for both the pretest and posttest so as to record changes and detect differences in performance.

The questionnaire for assessing the students' learning attitudes contains 23 items. A five-point Likert-type scale is used (1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, and 5 = strongly agree). All tests underwent several revisions from the author's (Su, 2008a) draft design.

There are a total of 23 items divided into four aspects in our questionnaire:

SQ1, learning attitude toward chemistry experiments
SQ2, learning attitude toward experimental teaching
SQ3, learning attitude toward experimental activities
SQ4, learning attitude toward the instructor

All mean values, standard deviations, and Cronbach's α values are indicated in Table 2. Katerina and Tzougraki (2004) posit that a Cronbach's α value of 0.90 and up is considered excellent, 0.80 very good, and 0.70 acceptable. The internal consistency of the four questionnaire components and total scale reaches a satisfactory degree. This questionnaire had higher reliability than most others previously reported.

## *3.2 Data Analysis*

All information acquired before and after the classes are on file and some statistical analysis was carried out using the SPSS 15.0 Windows software. Our study carried out covariance analysis adjusting for the significant difference between the experimental group and the control group. Due to the limitations of our text models, it was necessary to divide groups alternatively with covariance analysis to reduce effect of the factor interference upon our study. Our emphasis is primarily on covariance analysis of both the experimental group and the control group. Thus, group assumptions of coefficient homogeneity will be examined to test whether there existed any significant interactions between co-variants (pretests) and self-variants (posttests). Data from pretests of the experimental and control groups were used to find the covariance of the slope homogeneity ($p > 0.05$), after ensuring validity of the teaching method to precede covariance analysis. An independent *t*-test was employed to examine whether there was any significant difference in students' learning attitudes between the experimental group and the control group before and after administration of the questionnaire.

# 4 Results and Discussion

## *4.1 Analysis of Students' Learning Achievement*

Statistical ANCOVA analysis was carried out using data for students' posttest learning achievement, using students' pretest data as covariate variables, posttest data as by-variants, and divided groups as self-variants. Results obtained by homogeneity examination of the regression slope indicate that there was no significant difference between the groups for the learning unit between self-variants and by-variants, responding to group assumptions of covariate variable analysis in the homogeneity examination of the regression slope; thus we were able to proceed with further covariance analysis. Results of covariance listed in Table 3 show that there was a significant difference in students' posttest achievement between the experimental teaching group and traditional teaching group.

It is noted that the Cohen's experimental effect size *f* value of 0.49 indicates a higher effect size. The pairwise comparisons listed in Table 4 also show that posttest scores of the experimental group are superior to those of the control groups, this confirms our assumption that the experimental teaching strategy is better than the traditional teaching strategy.

**Table 3** Summary of F-ratio, p-value, and effect size (*f*) for learning achievement posttest of the ANOVA

| | Analysis of variance | | |
|---|---|---|---|
| Experimental course | F-ratio | p-value | *f* |
| TCRTE[a] | 9.7 | 0.003** | 0.49 |

[a]TCRTE is the cathode ray tube experiments
**$p<0.01$

**Table 4** Adjusted posttest mean scores of experimental and control group and pairwise comparison of the students' learning for the chemistry course

| | Experiment group | Control group | |
|---|---|---|---|
| Experimental course | Mean | Mean | Pairwise comparisons |
| TCRTE[a] | 60.9 | 49.2 | * |

[a]TCRTE is the cathode ray tube experiments
*$p<0.05$

**Table 5** Summary of F-ratio, p-value, and effect size (*f*) for learning attitude posttest of the ANCOVA

| | Analysis of variance | | |
|---|---|---|---|
| Experimental course | F-ratio | p-value | *f* |
| TCRTE[a] | 8.09 | 0.007* | 0.45 |

[a]TCRTE is the cathode ray tube experiments
*$p<0.05$

**Table 6** Difference between experimental group for each learning attitude in pretest and posttest, *t*-test, and p-value

| | Pretest | | Posttest | | | |
|---|---|---|---|---|---|---|
| Experimental course | M | SD | M | SD | t | P |
| TCRTE[a] | 76.88 | 11.29 | 86.91 | 7.51 | −3.776 | 0.0001*** |

[a]TCRTE is the cathode ray tube experiments
***$p<0.001$

## 4.2 *Statistical Analysis of Learning Attitudes*

(1) Comparison of teaching strategies for the experimental group and the control group

The pretest scores of learning attitude are defined as covariant, the posttest scores as the dependent variables. All results of covariate variable analysis are listed in Table 5. There is a significant difference in students' learning attitude between the experimental group and the control group for the cathode ray tube experiments (TCRTE). Students' learning attitude was influenced by our ICT teaching strategy. The experimental result shows that effect size for the cathode ray tube is 0.45, exceeding a large effect size.

(2) Comparative analysis of students' learning attitudes

The Cronbach's α value for the cathode ray tube unit was .808 as individually measured in students' posttests of learning attitude. All results for the average, standard deviations and *t*-test from students' pretests and posttests are listed in Table 6.

It was expected that there would be a difference in students' learning attitudes between groups, as evidenced by differences from pretest to posttest. Analysis of the experimental design and independent *t*-tests showed significant differences in students' learning attitudes, giving greater influence for the experimental group than the control group. On average, the posttest scores were higher than the pretest scores, showing the modules contributed to students' learning.

Comparative analysis of students' attitudes for the control group assumed that there should be no significant difference between pretests and posttests. All *t*-test results shown in Table 7 indicated that the p value of the control group (traditional teaching) was more than .05. There was no significant difference expected in the control groups' learning attitudes.

**Table 7** Difference in attitude toward study of the control group before and after every teaching unit

| | Pretest | | Posttest | | | |
|---|---|---|---|---|---|---|
| Experimental course | M | SD | M | SD | t | P |
| TCRTE[a] | 84.06 | 5.51 | 84.41 | 7.15 | −0.161 | 0.873 |

[a]TCRTE is the cathode ray tube experiments

## 5 Discussion and Conclusions

Based on the above results, we summarize the following conclusions:

We carried out covariance analysis on the test results for all students in our ICT experimental group who were taught with our teaching strategy. These results, together with their learning achievement for the teaching unit, showed a significant difference ($p < .05$) and major effect size of the experimental result ($f$ value is 0.494). Pairwise comparison of students' achievement shows obvious superiority to those in the control group. The results show that our experimental teaching tactics were superior to those of traditional teaching.

The $t$-test was used to examine the difference in students' learning attitudes before and after the teaching unit. The results showed no significant difference for students in the control group (traditional teaching) ($p = 0.873$). The implementation of computer teaching regarding the experiment had a major influence on students' learning attitudes. The average for the experimental group was higher after than before the tests, which is indicative of improvement after implementation. Our results are consistent with those of other researchers in relation to experimental chemistry teaching strategies and ICT research. These positive results indicate that our teaching strategy is worth popularizing.

To sum up, this project takes advantage of incorporating ICT chemistry textual material into teaching strategies to help students understand how to reduce chemical waste pollution and also to understand chemical experiments. This will help students to learn creative environmental skills, to upgrade their chemistry learning environment vision, and to strengthen learning performance. Our future study aims at the development of multimedia experimental texts, and continuous horizontal expansion, so as to establish simultaneous and non-simultaneous learning environments, free from the obstacles of time and space. We demonstrate an experimental platform for ICT teaching that will help both students and teachers to become involved in meaningful learning. It is our goal to let students continue this type of learning and to popularize this project.

ICT can play a vital role in helping students to understand many difficult and abstract concepts; and it appears to have potential benefits for integrating meaningful individual learning and group study into classroom teaching. The results of this study support the utilization of the constructivist approach, which posits that connections between verbal stimuli and visual representations enhance students' science learning and attitudes. Despite the statistical significance of the results, readers are reminded that the samples in our case study were based on convenience and that these results cannot be generalized beyond the context of this study. Continuing efforts are also needed to confirm extended approaches to fulfill the benefits of future teaching designs. Other individual student characteristics, such as age, information-processing capacity, and information literacy, need to be explored in future studies.

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# Academic Performance and Attitude Toward Computer-Aided Instruction in Chemistry

**Ronaldo C. Reyes**

## 1 Introduction

Science teaching plays an important role in the attainment of a country's developmental goal toward global competition and excellence. Technological innovations in the field of science contribute greatly to the economic growth and security of a country, and quality science education makes students globally competitive.

If the Philippines aim to be globally competitive, the country has to strengthen its science education system. The goal of science education in the Philippines is to develop the population's science and technology literacy. If citizens attain a high level of scientific literacy, they can initiate innovations that can help address the country's needs and the growing demands of society.

The implementation of the 2002 Basic Education Curriculum (BEC) aimed to raise the quality of Filipino graduates and empower them for lifelong learning. This means that after completing their basic education, students should be able to apply scientific concepts, principles, processes, skills, and values to daily life and work. Such a goal, however, still seems to be far from the present reality and condition of science education, especially at the secondary level. Students have not yet developed scientific literacy as shown by their poor performance in science exams. Laviña (2000) interpreted the dismal results of the Third International Mathematics and Science Study (TIMSS) as a much-needed wake up call for the Philippines. According to the TIMSS results, the Philippines' first year high school students ranked 36th out of 38 countries in both Science and Mathematics. This poor performance has been attributed to the absence of a science culture in the Philippines. Condes-Tandog (1998) concluded that Filipino students have difficulty for the following reasons: (1) they have not mastered the concepts; (2) they do not understand

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the problem; and (3) the content of some TIMSS items is not formally taken up in the science curriculum in the Philippines. This implies that students are not being taught enough science and that science needs to be taught more effectively so students understand and retain the information.

Lawson (1991) stated that most central of all educational objectives is helping students to think. This is achieved with the use of instructional strategies and materials to integrate the learning of subject matter with learning how to learn.

One of the strategies and approaches that can be used in chemistry teaching is the use of computer-aided instructions (CAI). The use of CAI in the classroom is intended to give all students a learning environment that allows discovery and creativity through the use of computer visualizations, such as modeling and simulations. It also allows students to work at their own pace and review the instructional content as often as needed.

However, in the Philippines, CAI is not that popular among teachers and students compared with other country. That is why only few researches have been conducted about its effect on student's performance and little has been reported on the specific impact of CAI on classroom activities. In addition, here in our school, this is the first time that this kind of research will be conducted.

Tabaco National High School (TNHS) envisions serving as a creative catalyst of change and a dynamic center of excellence that provides an equitable means of obtaining a meaningful, relevant, and quality education. However, in the 2007 National Achievement Test (NAT) in science, TNHS scored at a very low performance just roughly equal to 30%. It is for this reason that the researcher aimed to investigate other instructional tools that can raise student performance in science.

## 2 Statement of the Problem

The main purpose of the study is to determine the effects of computer-aided instruction on the performance and attitude of chemistry students from the Engineering Science Education Program (ESEP) at Tabaco National High School, Philippines. It also sought to find out the correlation between performance and attitude towards CAI lessons in Chemistry. Specifically, it sought answers to the following sub-problems:

1. What is the pre-test and post-test performance of the students in Chemistry among
   1.1. control group
   1.2. experimental group
2. Is there a significant pre-post mean gain in student performance in Chemistry in both groups?
3. Is there a significant mean gain difference on performance between the two groups?
4. What is the level of students' attitude toward computer-aided instruction?
5. Is there a significant correlation between level of attitude and students' performance in chemistry?

## 3 Significance of the Study

The Philippine government, through the Department of Education, has implemented different reforms on science education through various programs and projects. The teachers are sent to seminars, workshops, training, and research to improve the teaching competencies of teachers as well as the academic performance of students. Education reform, particularly in science, has recently received preferential attention by government officials and education professionals. To contribute to these efforts, this study will determine whether the use of Computer-Aided Instruction can raise students' performance in Chemistry, and prepare them for the global marketplace.

## 4 Literature Review

The advent of computers has had a great impact on many fields of human endeavor, including education (Douglas, 2006). It has led to the development of computer-aided instruction (CAI) which is used nowadays by some schools globally.

Klemp and Trautman (2002) cited that the integration of technology in education is a growing phenomenon. A tremendous amount of time and money has been devoted to making technology accessible to students with the promise of increased student achievement. Computers are used as teaching machines, research tools, and a means for creating work products. A closer look at the connection between students' use of technology and the resultant learning is needed.

Computers can be used to promote learning using simulations of physical phenomena. Steinberg pointed out that computer simulation can help students extend their experience with hands-on experiments, collect additional phenomenological data, make models explicit, help students collect model-based evidence, and provide multiple representations of the same related concepts. In addition, computer technology provides an influential and multifaceted tool that can change the way we teach and the way students learn. In turn, there is an improved ability to search for abstract or complex material with increased student comprehension and interest Achterberg and Matheson (1999).

Promising results about use of computer technology fosters academic achievements of the students. Research shows significant links between multimedia instruction and achievement in traditional subject matter. Schools that integrate technology into the traditional curriculum have higher student attendance and lower drop out rates, which leads to greater academic results (Fisher, 1999).

Tinzmann asserted that use of technology in the classroom tends to foster collaboration among students, which positively affects student achievement. To further strengthen the study about multimedia, Perry (1998) concluded that their participants preferred to attend classes that utilized multimedia presentations and that they found class more interesting and more enjoyable with multimedia. The students also reported that multimedia was able to hold their attention better than other presentation methods.

Iwanski (2000) conducted a study on students' attitude and acceptance of computer enhanced instruction in a college nutrition course. Results of the study confirmed that CEI was significantly preferred when compared to traditional instruction; it had increased student enthusiasm and satisfaction. Moreover, Szabo and Worthington (2000) conducted also a study on "Interactivity in Computer-Based Aural Skills Instruction". Results of the study revealed that the experimental group showed greater skill development than the control group in identifying harmonic voicing.

The use of CAI also upgrades skills of the students. In the study conducted by Wade, she integrated CAI on teaching information literacy skills. The results of the study indicated that computer-assisted instruction is an effective method of delivering information literacy skills instruction. Moreover, Christensen (1997) conducted a study on the effect of technology integration education on teachers' and students' attitudes toward information technology. It was anticipated that properly instructing teachers to use information technology in the classroom would positively affect, not only their attitudes toward information technology, but also the attitudes of their students.

## 5 Theoretical Framework

This study is anchored on the two theories of learning that are very important in enhancing students' academic performance: cognitive theory and theory of behaviorism.

Behaviorism was used as the basis for designing early audio-visual materials and was the impetus behind many related teaching strategies, such as the use of teaching machines and programmed texts. Skinner's (1958) theory about behaviorism is being applied to the tutorial type of CAI. Good tutorial programs put students in control of learning while the computer facilitates learning by presenting materials, questioning, providing help messages, and providing reinforcement for the correct answers. The use of behaviorism in education is based on the principle that instruction should be designed to produce observable and quantifiable actions by the learner.

The cognitive theory proposed by Jerome Bruner (1960) focuses attention on the learning process itself and attributes a greater degree of autonomy and initiative to the learner than do behaviorists. Cognitive theory concentrates on the conceptualization of students' learning processes. It focuses on the exploration of the way information is received, organized, retained, and used by the brain. When instruction is designed, the cognitive structure of the learner, and groups of learners, should be taken into account. Moreover, according to cognitive theory, information must be organized in a way that helps learners connect the new information with current knowledge in a meaningful way.

From the two theories mentioned above, CAI will enhance students' performance in Chemistry. The attitude of the students toward CAI will contribute in elevating their performance and will lead them to have positive attitude towards science.

## 6 Research Methodology

### 6.1 Participants

The researcher teaches chemistry at the high school where this study took place. Two of the researcher's chemistry classes were selected randomly to participate. There were 48 students in the experimental group and 48 students also in the control group of same ages.

### 6.2 Research Instruments

*Test questionnaires.* The researcher-made test questionnaire was administered to both the experimental and control group during the pretest and posttest. The test questionnaire contains 50 multiple choice questions which measure the skills of the students in the chemistry learning competencies.

*CAI attitude questionnaire*. This consists of 14 statements which reflect how and what the experimental group feels about CAI. It is a Likert-scale with four response options. This questionnaire was made to determine the attitude of the respondents towards CAI and its relation to academic performance.

*Computer-aided instruction.* This is a type of instruction received by the experimental group using the computer. One hour is devoted to CAI and each student has his/ her own computer. It consists of drill and practice techniques, tutorial or dialogue. Some CAI lessons in Chemistry were downloaded/adopted from the internet and the others were from Department of Science and Technology (DOST) compact disk (CD).

### 6.3 Research Procedure

Before administering the test to the subjects, the test questionnaire as well as the CAI attitude questionnaire was validated and submitted to jurors for corrections and suggestions. A dry-run was conducted at Tabaco National High School to measure its content validity and an item analysis was made. Suggested items which were not clear and understood were deleted, modified, or reworded.

After giving the pre-test, the researcher conducted the study in which the experimental group received instructions utilizing CAI. The execution of CAI was done in all parts of the lesson; from various activities, drills up to evaluation. The CAI consisted of games, simulations, laboratory activities, and the questions for exams were already here, the students will just press in the right key for their answers. In addition, the assignments, tutorials/enrichment were also done by using CAI. The control group received instruction from the teacher through conventional method, using the board, visual aids, and conventional laboratory lecture/demonstration.

The CAI implementation was conducted during the 3rd week of November through the 3rd week of March 2010. Administration of the post-test was then conducted 2nd week of March to the experimental and control group. CAI attitude questionnaires were also administered to the experimental group and 100% of the respondents returned the questionnaires.

After the retrieval of the CAI questionnaires and checking the papers, the researcher tabulated and processed the data quantitatively using mean, t-test, Pearson r to arrive at scientific analysis and interpretation of results.

## 7 Results and Discussions

Table 1 reveals that during the pretest, the control group obtained a mean of 18.33 or 36.66% performance level which is higher compared to the experimental group which had only a mean of 17.40 or 34.80% performance level. Both the pretest performance level of the two groups signifies that they had little knowledge about the topics covered in the test and no mastery at all. The posttest results however show that the experimental group obtained the higher mean of 35.05 for a performance level of 70.04%. Moreover, the control group got only a mean of 31.81 for a 63.62% performance level. Nevertheless, both groups were still at the average level in Chemistry.

Table 2 indicates the pre/post mean gain of students' performance in Chemistry. The resultant t-test of the two groups was 4.22 for the experimental and 1.43 for the control group. It can be claimed that there was a significant improvement from the pretest to the posttest in the group where CAI was implemented.

The result of the pretest showed no significant difference on the performance of the experimental and control group. However the computed t-test during the posttest is 3.90 which is significant at .05 level. A significant difference existed between the two groups favoring the experimental group (Table 3).

**Table 1** Pre-test and post-test performance of the control and experimental group

| | Pre-test | | | Post-test | | Post-test |
|---|---|---|---|---|---|---|
| Group | Mean | Performance Level | Description | Mean | Performance Level | Description |
| Control | 18.33 | 36.66% | Below ave. | 31.81 | 63.32% | Average |
| Experimental | 17.40 | 34.80% | Below ave. | 35.05 | 70.04% | Average |

Range:
0.00–49.99, below average
50.00–74.99, average
75.00–100.00, above average

**Table 2** Pre-post mean gain of the students' performance in chemistry

| | Groups | Mean gain | T-test | Interpretation | Decision |
|---|---|---|---|---|---|
| Pre-post | Experimental | 17.65 | 4.22* | Significant | Reject |
| Pre-post | Control | 13.48 | 1.43 | Not significant | Don't reject |

*Significant at .05 ___ 1.97

**Table 3** Difference between the experimental and control group in their chemistry performance

| Test | Groups | Mean | SD | Mean diff. | T-ratio | Interpretation |
|---|---|---|---|---|---|---|
| Pre-test | Experimental control | 17.40 | 3.47 | 3.93 | 1.43 | Not significant |
| | | 18.33 | 2.46 | | | |
| Post-test | Experimental control | 35.05 | 3.24 | 3.24 | 3.90* | Significant |
| | | 31.81 | 3.84 | | | |

*Significant at .05___1.97

**Table 4** Students' attitude toward CAI

| | Scale | | | | Weighted | |
|---|---|---|---|---|---|---|
| Attitude toward CAI | 4 | 3 | 2 | 1 | mean | Description |
| 1. I find the presentation of the CAI lesson appealing. | 6 | 22 | 14 | 1 | 2.77 | D |
| 2. I get bored with the CAI lesson if it lasts for more than 1 h. | 3 | 4 | 30 | 6 | 2.93 | D |
| 3. I enjoy the motivational activities in the CAI lesson. | 3 | 22 | 18 | 0 | 2.65 | D |
| 4. I easily understand the concepts and questions posted in CAI. | 4 | 18 | 21 | 0 | 2.60 | D |
| 5. I can grasp the lesson that seemed to be abstract using CAI. | 2 | 17 | 23 | 1 | 2.47 | FD |
| 6. I occasionally skip my attention during the CAI lesson once in a while. | 2 | 1 | 32 | 8 | 3.07 | D |
| 7. I give my full concentration when the CAI lesson starts. | 4 | 23 | 14 | 2 | 2.76 | D |
| 8. I sometimes drift my thoughts during the progress of CAI. | 1 | 5 | 29 | 8 | 3.02 | D |
| 9. I appreciate the importance of the CAI more than I appreciate my book. | 1 | 15 | 18 | 9 | 2.19 | FD |
| 10. I prefer to listen and watch CAI rather than read my book. | 1 | 19 | 17 | 6 | 2.35 | FD |
| 11. I find it disappointing whenever I miss an episode of CAI. | 2 | 8 | 23 | 10 | 2.05 | FD |
| 12. I easily recall the concepts in CAI. | 1 | 25 | 17 | 0 | 2.63 | D |
| 13. I prefer to have my teacher discuss all the concepts using chalkboard than to have the CAI. | 4 | 14 | 22 | 3 | 2.56<br>2.37 | D<br>FD |
| 14. I can repeat/synthesize the explanation of the concept with CAI. | 0 | 18 | 23 | 2 | | |
| AVERAGE | | | | | 2.60 | D |

Scale:
3.26–4.00, Always (Very desirable)
2.51–3.25, Often (Desirable)
1.71–2.50, Sometimes (Fairly desirable)
1.00–1.73, Never (Not desirable)

The data in Table 4 reveal that students find the presentation of the CAI lesson appealing and they enjoy its motivational activities. They can easily understand the concepts and questions posted on CAI. Students also give their full attention/concentration when the presentation of the CAI lesson starts.

**Table 5** Correlation between attitude toward CAI and students' performance in chemistry

| Variables | x | Computed r | Computed t-test | Tabled t-test |
|---|---|---|---|---|
| Performance vs Attitude | 35.05<br>33.21 | 0.79 | 2.39* | 2.02 |

*P>0.5

The computed t-test value was 2.39 which means that there is a significant relationship between the attitude level toward computer-aided instruction and students' performance in Chemistry, hence, the null hypothesis is rejected (Table 5).

This also means that attitude has an influence on the performance of the students. The better the attitude of the students the higher is their performance.

### *7.1 Findings*

1. *On the pretest and posttest performance of the control and experimental group.* During the pretest, both the experimental and control group had little knowledge about the topics covered on the test, thus they performed below average. The posttest results however showed that the control group and experimental group were on the average level in Chemistry.
2. *On the pre/post mean gain of the students' performance in Chemistry*. The null hypothesis is rejected. There is a significant pre/post mean gain in the performance of the experimental group in Chemistry.
3. *On the students' attitude toward CAI*. The students had strongly positive attitudes toward CAI lessons in Chemistry.
4. *On the correlation between attitude toward CAI and students' performance in Chemistry*. There is a significant correlation in performance and attitude toward CAI lessons in Chemistry.

## 8 Conclusions

Since the experimental group obtained a higher performance level compared to the control group during the posttest, CAI enhanced the performance of the former group. Likewise, the attitude of students towards CAI has a great effect on their performance. Positive attitude towards CAI leads to a better performance in Chemistry.

## 9 Recommendations

1. Computer-aided instruction can be used in the classroom to support student learning in the sciences.
2. Supervisors and administrators should encourage teachers to use CAI as an alternative approach in teaching Chemistry and other related subjects.

3. Curriculum developers and textbook writers may consider reviewing the instructional materials to incorporate CAI in science teaching.
4. Opportunity should be given for teachers to attend seminars/training on the use of computers in their instruction.
5. For the students to have a positive attitude toward CAI, the teacher should continuously motivate them to enhance their performance.
6. Research on the use of CAI is encouraged to find out the applicability to other learning areas/subjects as well as to other populations of students.

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# Integrating Instant Response System (IRS) as an In-Class Assessment Tool into Undergraduate Chemistry Learning Experience: Student Perceptions and Performance

**Tzy-Ling Chen, Yan-Fu Lin, Yi-Lin Liu, Hsiu-Ping Yueh, Horn-Jiunn Sheen, and Wei-Jane Lin**

## 1 Background of the Research

The development and utilization of interactive technology in classroom teaching, such as SMART boards and clickers, is one of the fastest-growing segments in both the information technology industry and educational institutions at all levels. Although in existence for several years, the Instant Response System (IRS) or Audience Response System (ARS), often called "clicker," is only now enjoying

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widespread success as a teaching tool within higher education (Abrahamson, 2006; Burnstein & Lederman, 2006). IRS offers tremendous potential for improving the learning process in a variety of fields in education and provides a management function for engaging students in large classroom settings. As evidence for the pedagogical value of this sort of technology continues to accumulate and competition between manufacturers drives technical improvements, leading to an increase in user-friendliness and decrease in price, the use of IRS is growing rapidly in large science courses at the university level (Caldwell, 2007; Crossgrove & Curran, 2008). However, while faculty are convinced and encouraged to use IRS in their large lecture classes, there has not been sufficiently clear evidence revealing how students perceive this tool when it is in use differently in terms of pedagogical strategies for assisting their learning and increasing their interest in a particular subject. Thus, the aim of the present study was to assess student's experiences and perceptions toward the use of IRS in a large introductory chemistry course at National Chung Hsing University of Taiwan.

As an in-class assessment or test tool, IRS enables students to obtain performance feedback immediately after submitting their responses. Considering this unique attribute of IRS, the main purpose of the present study was to examine the degree to which students perceive or believe that using IRS in class has an effect on their understanding of course content, engagement in classroom learning, and preparation to take class tests. Moreover, the data derived from different students' performance assessments, including pre-class chemistry proficiency test scores, midterm and final examination scores, and semester grades were used to explore correlations between student perceptions of IRS and their academic performance in the course. In the end, the current study may shed light on the impact of IRS on student chemistry learning in large introductory university classes.

## 2 Literature Review

Interactive technology like IRS (also referred to as Audience Response Technology, Student Response System, Electronic Voting System, and "clicker") has become an increasingly popular tool in higher education and is viewed positively by students and instructors in numerous studies, particularly in the disciplines of STEM (Science, Technology, Engineering, or Mathematics) (MacGeorge et al., 2008). Instructors across varied disciplines are realizing the pedagogical value of such systems, such as increased student engagement with lecture content and interactive participation in presentations as well as increased student awareness and motivation of learning course material, class attendance, interest in the course, and performance on examinations (Preszler, Dawe, Shuster, & Shuster, 2007). IRS is widely used for promoting interactivity, gathering feedback, pre-assessing knowledge, and assessing students' understanding of lectured concepts. Specifically, IRS is considered effective for supporting instructional activities in large classes such as taking attendance, polling to create initial interest among students, promoting critical thinking and active learning, incorporating problem-based learning, community building, and discussion initiation. Research on teacher responses to the class application of IRS further shows their attitudes are mostly positive, and that instructors are willing to continue to use it in class (Barnett, 2006; Blackman, Dooley, Kuchinski, & Chapman, 2002; Stuart, Brown, & Draper, 2004).

A review of literature on the effects of using IRS in higher education also shows generally positive feedback and impact on student learning (Caldwell, 2007; Crossgrove & Curran, 2008; Eilks & Byers, 2010; Fies & Marshall, 2006; Hoffman & Goodwin, 2006; Judson & Sawada, 2002; Preszler et al., 2007). Some student reactions to the use of IRS in higher education classes focused on the ease of use, benefits to their classroom engagement, positive influences on their attention, interest, and involvement during learning the class content (Copas & Del Valle, 2004; Fitch, 2004; Hall, Collier, Thomas, & Hilgers, 2005; Latessa & Mouw, 2005; Reay, Li, & Bao, 2008; Rice & Bunz, 2006; Sharma, Khachan, Chan, & O'Byrne, 2005). Both students and faculty consistently indicate that they have a positive view of IRS, especially related to perceived improvement in attendance, engagement, and motivation (Hansen, 2007). Most IRS literature on student perception suggests that learners appear to have positive attitudes regarding the use of IRS in class. Reinforcement of content, provision of feedback, anonymity in participation, increased interest in the course, and ability to compare one's level of knowledge with the rest of the class have all been reported as positive characteristics of IRS use within lectures. Taking into account a lack of objective measures of IRS influence on students' learning outcomes in previous research, the current study includes multiple student performance evaluation results for better understanding of the interactions between student perceptions toward IRS and their actual learning outcomes. In this case, the use of IRS in a large introductory course on chemistry is specifically designed as an in-class assessment or test tool to examine students' learning progress of course contents from time to time throughout the semester.

## 3 Methodology

The study aimed to evaluate the use of IRS supplementary to traditional face-to-face classroom instruction on basic chemistry in large introductory university classes. Survey data were collected from students enrolled in two different courses taught by the same professor from the department of chemistry at National Chung Hsing University, Taiwan to examine student perceptions of IRS use as an in-class assessment or test tool alternative to conventional paper-based tests in class. This study was conducted in 2008, when IRS was first introduced to the university, so students surveyed had no prior experience with IRS in college courses. The student survey instrument included six quantitative items (Table 1). In total, 151 students participated in the questionnaire survey on perceptions of IRS usage. Overall, 61.1% of participants were male, and almost all of them were freshmen. Of the survey participants, 56.3% were from the college of agriculture and natural resources and 31.1% were

**Table 1** Student perception survey on the use of IRS (N = 151)

| Question | Agreed (%) | Disagreed (%) | Mean (SD) |
|---|---|---|---|
| 1 I found the use of IRS as a test tool in this course to be easy | 74.2 | 25.8 | 2.16 (0.83) |
| 2 The use of IRS as a test tool in this course interfered with my thinking while taking the exam | 49.0 | 51.0 | 1.96 (0.83) |
| 3 The use of IRS as a test tool in this course helped me engage more in classroom learning | 57.0 | 43.0 | 2.38 (0.85) |
| 4 I found the use of IRS as a test tool in this course to be fun | 68.9 | 31.1 | 2.25 (0.82) |
| 5 The use of IRS as a test tool in this course is beneficial to my learning of chemistry | 66.9 | 33.1 | 2.29 (0.79) |
| 6 The use of IRS as a test tool in this course helped to enhance my learning effectiveness | 60.3 | 39.7 | 2.35 (0.79) |

The response of each question was measured using a Likert scale: 1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree. Mean is the average response value, and SD is standard deviation. The number of students that participated in the survey is 151. Agreed % is calculated from the number of students who responded agree or strongly agree. Disagreed % is calculated from the number of students who responded disagree or strongly disagree

students in engineering disciplines. In addition to the perception survey, student performance data included the grade scores of pre-class chemistry proficiency tests, weekly online homework, midterm and final examinations, in-class IRS tests, and semester course grades. The research attempted to understand student perceptions on the use of IRS and to further explore the relationship between students' perceptions and learning performance in a particular classroom learning environment in higher education.

The two courses in the study were mostly taught by lecturing. Students' learning outcomes were determined by the semester course grade consisting of scores on paper-based midterm and final examinations, weekly online homework, and in-class tests taking advantage of IRS. Periodically, there were IRS quizzes in class to help both the instructor and students understand the learning progress of the courses, and the use of IRS was also expected to prevent students' attention from drifting too far afield from the topic at hand when no IRS quiz was taking place. Every lecture session included IRS application. The in-class IRS test involved a straightforward pedagogy of multiple-choice questions periodically during lectures as the check points of students' learning throughout the course. The contents quizzed were review of course materials taught in the past class sessions, which may have been clarified afterward depending on student performance on the quiz. In this case, students received immediate feedbacks on not only their performance on learning the course subjects, but also on which question, deficiency, or misunderstanding of learning contents required further clarification.

## 4 Findings and Discussion

Based on the results of analysis as shown in Table 1, overall student perceptions on the use of IRS as an in-class assessment or test tool were positive. This finding corroborates the research results of Caldwell (2007), Crossgrove and Curran (2008), Eilks and Byers (2010), Fies and Marshall (2006), Hoffman and Goodwin (2006), Judson and Sawada (2002), and Preszler et al. (2007). The ratios of positive to negative responses in every constituent item of the perception instrument, except question 2, ranged from 1.3:1 to 2.9:1. However, students actually experienced an interference from the use of IRS as an assessment or test tool when taking the quiz. Nearly half (49%) of them expressed that they were interrupted in terms of thinking when taking the IRS test. One of the primary causes of such a problem may be lack of flexibility and autonomy of taking the exam questions and the constraints of time or peer pressure resulting from the reply process of each question. As for this pedagogical disadvantage, more attention on finding out the exact causes and improving the use of IRS toward a more learner-centered instructional design is necessary.

Student performance data were collected for analysis. The grade scores of multiple learning outcome assessments conducted in the courses of this study are reported in Table 2.

As detailed in Table 3, performance on the pre-class chemistry proficiency test was significantly correlated with the scores from the weekly online homework ($\gamma$=.37), midterm exam ($\gamma$=.34), and semester course grade ($\gamma$=.44), with $p<.01$ of Pearson correlation analysis. The in-class IRS score is significantly correlated with scores of midterm exam ($\gamma$=.51), final exam ($\gamma$=.71), weekly online homework ($\gamma$=.56), and semester course grade ($\gamma$=.58), with $p<.01$ of Pearson correlation analysis. In summary, most student performance scores were found to be significantly correlated with each other.

As revealed in the results of Tables 1 and 3, student perceptions on the use of IRS as an in-class test or assessment tool were mostly positive, except they also viewed it as interfering with their thinking while taking the exam. The perception of ease of use is significantly correlated with the other four perception measures, with $p<.01$ of Pearson correlation analysis, excluding the perception of interference with exam taking.

**Table 2** Means and standard deviations of student performance assessment scores (N = 151)

| Student performance variable | Mean | SD |
|---|---|---|
| Pre-class chemistry proficiency test | 47.75 | 9.07 |
| Online homework | 47.07 | 36.99 |
| Midterm exam | 74.91 | 14.98 |
| Final exam | 48.28 | 13.06 |
| In-class IRS test | 49.42 | 17.86 |
| Semester course grade | 62.66 | 15.29 |

**Table 3** Correlation between student performance and perception on the use of IRS in class

| | Student perception on IRS | | | | | | Student performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Ease of use (1) | 1 | **.60**$^{**}$ | .15 | **.56**$^{**}$ | **.58**$^{**}$ | **.56**$^{**}$ | .03 | −.02 | −.10 | −.00 | **−.16**$^{*}$ | −.09 |
| Fun (2) | | 1 | .09 | **.59**$^{**}$ | **.73**$^{**}$ | **.65**$^{**}$ | .01 | .05 | −.08 | .07 | −.07 | −.05 |
| Interference with exam taking (3) | | | 1 | **.21**$^{**}$ | **.17**$^{*}$ | .15 | −.02 | .12 | .10 | **.17**$^{*}$ | .08 | .06 |
| Learning engagement (4) | | | | 1 | **.68**$^{**}$ | **.75**$^{**}$ | .06 | .08 | −.01 | .09 | −.04 | .01 |
| Beneficial to learning (5) | | | | | 1 | **.82**$^{**}$ | .01 | −.02 | −.11 | −.00 | **−.20**$^{*}$ | −.09 |
| Learning effectiveness (6) | | | | | | 1 | .04 | .03 | −.05 | .06 | −.15 | −.14 |
| Pre-class chemistry proficiency (7) | | | | | | | 1 | **.44**$^{**}$ | **.37**$^{**}$ | **.34**$^{**}$ | −.02 | .13 |
| Semester course grade (8) | | | | | | | | 1 | **.66**$^{**}$ | **.76**$^{**}$ | **.54**$^{**}$ | **.58**$^{**}$ |
| Grade of online homework (9) | | | | | | | | | 1 | **.63**$^{**}$ | **.59**$^{**}$ | **.56**$^{**}$ |
| Grade of midterm exam (10) | | | | | | | | | | 1 | **.48**$^{**}$ | **.51**$^{**}$ |
| Grade of final exam (11) | | | | | | | | | | | 1 | **.71**$^{**}$ |
| Grade of in-class IRS test (12) | | | | | | | | | | | | 1 |

With respect to the analysis of interactions between student perceptions on IRS and performance, t-tests were used was to compare the mean variance in student performance by the agree and disagree groups in terms of perception on IRS. Clearly, student perceptions of ease of use and benefits to chemistry learning were significantly correlated with the score of the final exam, with $\gamma = -.16$ and $\gamma = -.20$ ($p < .05$) respectively. The perception of interference with exam taking was significantly correlated with the score of midterm exam ($\gamma = .17$, $p < .05$). Additionally, what is confirmed in t-tests shows that students who agreed that use of IRS increases their engagement in classroom learning had significantly higher weekly online homework scores than the disagree group ($t = 2.22$, $p < .05$). Those who agreed that use of IRS is beneficial to their chemistry learning had significantly higher final exam scores than the disagree group ($t = 3.70$, $p < .001$). Students who agreed that use of IRS helps enhance their learning effectiveness had significantly higher scores on weekly online homework ($t = 3.66$, $p < .001$) and in-class IRS test ($t = 2.02$, $p < .05$) than the disagree group. As for the relationship between student perception on IRS and semester course grade of this general chemistry course, it was found that students who agreed that use of IRS was beneficial to their learning ($t = 3.09$, $p < .01$) and helped them enhance learning effectiveness ($t = 2.56$, $p < .05$) had significantly higher semester grades for this course than the disagree group. As a result, certain interactions between students' perceptions on the use of IRS as an in-class assessment tool and their learning performance are identified in the study. In particular, significant relationships emerge when use of IRS is perceived by students having positive effects on their learning, such as the benefits to their learning or an increase in their learning effectiveness.

## 5 Conclusions and Implications

Recently, numerous university instructors around the world have begun to utilize interactive technologies, such as IRS or "clicker," to enhance teaching and learning in their classrooms, particularly in large-enrollment introductory STEM classes. In this study, we adopted IRS as an in-class assessment or test tool to understand its effects on student learning of basic chemistry in higher education. Therefore, the findings from the current research help to extend knowledge about IRS benefits and possible shortcomings to traditional undergraduate learning in large lecture classes in STEM disciplines.

Consistent with previous studies, this study confirmed that students find IRS easy and fun to use, and perceive it as beneficial to their learning and encouraging of class engagement as well as contributing to learning effectiveness of the class in general (MacArthur & Jones, 2008). What remains unclear, however, is whether the use of IRS can be a reliable vehicle for improvement in learning in terms of student performance, although some findings of this study reveal such interaction to a certain degree. The scope of the present study is limited by the fact that some variables regarding the population size, changes in instructional design, or data on students' attributes, such as learning style or self-efficiency, are not included. Further studies need to probe the positive effects of IRS while addressing these limitations. More research is also recommended to examine what specifically about IRS contributes to certain learning outcomes of a large class in higher education.

One of our research findings points to the importance of instructional design regarding the use of IRS. Most accounts of studies we came across that evaluate the use of IRS or clicker do not specify pedagogical position or values of its application when examining effects on learners. Apparently, when utilized particularly as a test tool in this study, some pitfalls for IRS use were unveiled by students even with reservations. There is no doubt that interactive technology like IRS can make it possible to design courses in diverse ways. This is where interest lies when studying the effects that may be associated with pedagogical interventions of choice the instructor makes regarding technology. With this perspective in mind, future research could inquire into the effect that variance in instructional design perhaps has in combination with the use of IRS.

For those faculty members who have not yet tried teaching with IRS and may have heard some unsettling stories about technical problems with earlier models, the results from the present study may offer them some useful information to make their decision. Moreover, like any other instructional technology, IRS is simply a tool and will not automatically improve teaching or enhance student learning. The tool can only achieve desired results when it is utilized appropriately and effectively (Eilks & Byers, 2010). When introducing it into the class, it is also advised to enable both students and teachers to become accustomed to its use incrementally (Orzechowski, 1995). In addition to student perception, what teachers perceive or believe its usefulness and benefits to instruction to be is similarly critical (Chen & Chen, 2006). Current research on the efficacy of IRS to promote student learning still lacks control designs that are necessary to help determine whether the technology or accompanying pedagogical changes are responsible for an apparent increase in learning. To sum up, it appears the use of IRS in college chemistry learning holds great potential to contribute to more effective teaching strategies and increased student learning.

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# Part VI
# Microscale Lab Chemistry

**Chin-Cheng Chou**

With environmental issues a worldwide concern, micro-chemistry has evolved to address these issues as they relate to chemistry teaching and learning. Microscale chemistry in particular reduces equipment, supplies, and waste without sacrificing student learning. These innovative techniques are reforming the field of chemistry. In this section, six chapters address the advantages and trade-offs of microscale chemistry experiments.

Inoue et al. use aqueous reaction media in microscale experiments. Their results demonstrate how to diminish damage to the experimenter's health as well as the environment. Yasuoka reports on a device that facilitates observing the gaseous mixture. Bergantin Jr. et al. apply a simple gas analysis method to analyze chemical phenomena. Abdullah et al. outline a low-cost conductance meter and provide evidence for microscale chemistry's reduced reagent storage space, chemical waste, and increased experimental safety. Chan discusses how microscale experimentation is designed to reduce the cost of experiments in the educational laboratory and simplify complex experimental procedures. To improve time and space limitations in the laboratory, microscale experiments afford students the opportunity to conduct experiments individually so all students receive hands-on experience. Nakagawa demonstrates how small-scale experiments are cost effective and environmentally sound compared with more traditional methods.

In conclusion, microscale experiments provide advantages in terms of cost, ease of implementation, speed of implementation, and safety.

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# Aqueous Cationic and Anionic Surfactants for Microscale Experiments in Organic Chemistry Teaching Laboratories

**Masayuki Inoue, Yuko Kato, Emi Joguchi, and Wataru Banba**

## 1 Introduction

One of the most important benefits of microscale experiments is the reduction of risk and waste. When large amounts of volatile organic solvents are used in experiments, vapors can pollute the air in the laboratory, which could adversely affect the experimenter's health. Organic solvents also pose a serious fire hazard. Moreover, the processing of organic solvent waste is costly. For these reasons, avoiding the use of organic solvents for reactions and extractions is highly desirable. Against this background, we investigated the use of aqueous reaction media in microscale experiments for organic chemistry teaching laboratories. In general, the rate of reactions utilizing hydrophobic organic compounds becomes slower in aqueous media, so it is necessary to accelerate the rate of reaction to complete the experiment within the allocated class time.

It is important to learn that the rate of chemical reaction becomes faster by adding catalysts. And the phenomenon that chemical reactions are accelerated by adding only small amounts of substrates often surprises students. In a microscale experiment, the amount of product will decrease along with the reduction of reagents. Therefore, it is necessary to add the catalyst in order to raise the yield of products.

New experiments using an aqueous media are available for teaching chemical organic chemistry. In these experiments, we used cationic or anionic surfactants as the catalysts. With these teaching materials, students will learn about organic reactions with surfactants and catalysts and avoid the health risks.

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## 2 Synthesis of Fragrant Aldehydes by Using Active $MnO_2$ Integrated with Anionic Surfactants

Benzaldehyde and cinnamaldehyde can be prepared through the oxidation of benzyl alcohol and cinnamyl alcohol. Benzaldehyde, which has an almond-like odor, is commonly used as a flavor additive, and cinnamaldehyde is the compound that gives cinnamon its scent and flavor. Active manganese (IV) oxide ($MnO_2$) is well known as a reagent for oxidizing primary and allylic alcohols. However, as conventionally carried out, oxidation reactions using $MnO_2$ require large amounts of oxidant and organic solvent (Fatiadi, 1986).

We investigated active $MnO_2$ integrated with anionic surfactants as a new reagent for the oxidation of primary aryl and allylic alcohols in aqueous media into the corresponding aldehydes (Inoue & Joguchi, 2010). Active $MnO_2$ is prepared by the reaction between manganese (II) sulfate and potassium permanganate, with a catalytic amount of anionic surfactant in the aqueous solution (Eq. (1)). On the surface of the $MnO_2$ particles, a lipophilic environment forms as shown in Fig. 1.

$$2MnO_4^{-} + 3Mn^{2+} + 2H_2O \rightarrow 5MnO_2 + 4H^{+}. \tag{1}$$

The alcohols will be incorporated into this lipophilic environment. When sodium dodecyl sulfonate was used as an additive in the oxidation of benzyl alcohol with active $MnO_2$, the yield of benzaldehyde improved remarkably (Fig. 2). When sodium dodecylbenzene sulfonate (DBSNa) was used, the yield of benz-aldehyde also improved, but a small amount of benzoic acid was generated (Table 1, Entry 3). When sodium *p*-toluene sulfonate (TSNa) was used, the yield of benzoic acid increased further (Table 1, Entry 4), because the lipophilicity of the environment formed by TSNa around $MnO_2$ was low in comparison with that formed by DSNa or DBSNa. When the amount of oxidant was decreased to less than 2.0 equivalent with respect to benzyl alcohol, the yield of benzaldehyde decreased substantially.

In the oxidation of cinnamyl alcohol, the yield of cinnamaldehyde also increased with the addition of DSNa. Under these conditions, the yield of cinnamaldehyde was less than that of benzaldehyde (Table 2, Entry 1). However, as the amount of DSNa was increased, the yield of cinnamaldehyde increased (Table 2, Entry 2, 3). When higher amounts of DSNa were used, little benzaldehyde was produced as a by-product.

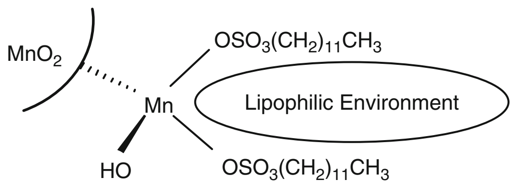


**Fig. 1** Lipophilic environment around $MnO_2$

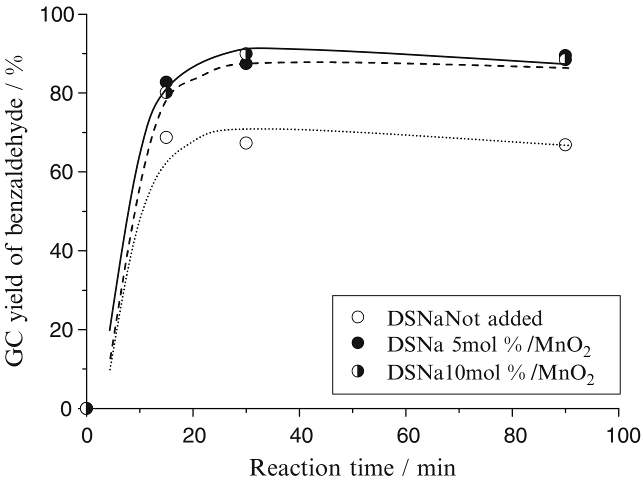


**Fig. 2** Effect of DSNa

**Table 1** Effect of sulfonates on oxidation of benzyl alcohol[a]

| Entry | Sulfonate | Benzaldehyde/% | Benzoic acid/% |
|---|---|---|---|
| 1 | None | 67 | 0 |
| 2 | DSNa | 87 | 0 |
| 3 | DBSNa | 82 | 7 |
| 4 | TSNa | 54 | 23 |

[a] 80 °C, 30 min., DSNa/$MnO_2$ = 0.050 (molar ratio), $MnO_2$/benzyl alcohol = 2.0 (molar ratio)

**Table 2** Oxidation of cinnamyl alcohol[a]

| Entry | DSNa/$MnO_2$ | Cinnamaldehyde/% |
|---|---|---|
| 1 | 0 | 34 |
| 2 | 0.050 | 41 |
| 3 | 0.10 | 68 |

[a] 80 °C, 30 min,$MnO_2$/alcohol = 2.0 (molar ratio)

Experimental Procedure

(a) Preparation of active $MnO_2$

In test tube A (φ18 mm), aqueous $MnSO_4$ (1.0 M, 2.0 mL) was mixed with aqueous DSNa (0.10 M, 1.5 mL). Then, aqueous $KMnO_4$ or $NaMnO_4$ (0.50 M, 1.0 mL) was added into the test tube, and the solution was shaken to mix well. Without being isolated, the prepared active $MnO_2$ in test tube A was used for the following oxidations.

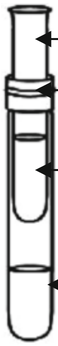


**Fig. 3** Device for the reaction

(b) Oxidation of benzyl alcohol

A piece of tissue paper was wrapped around a small test tube B (ϕ15 mm) and bound with a rubber band (Fig. 3). Crushed ice and water were added into test tube B, making a cold finger. Three drops of benzyl alcohol were added into tube A with a Pasteur pipette. Test tube B was then inserted into test tube A as shown in Fig. 3. This apparatus was placed in boiling water and heated for 10 min with occasional shaking. When all the ice in the cold finger melted, the water in test tube B was removed and more ice was added.

A drop of water containing benzaldehyde adhered to the bottom of test tube B. Test tube B was gently pulled out, and this drop was transferred to clean test tube C, and test tube B was returned to its previous position. This transfer operation was repeated three times. During this operation, the odor of the benzaldehyde adhered to test tube B could be smelled. (In the oxidation of cinnamyl alcohol, more DSNa (about 10 mg) was added into test tube A before adding the alcohol dropwise, and the heating time was extended up to 20 min.)

Tollen's reagent (2 mL) was poured into test tube C, which was then placed in hot water (about 60 °C). The silver mirror reaction was observed within a few minutes.

By combining the silver mirror reaction and a test for odor to detect these aldehydes, it is possible to pique the interest of students by engaging the senses of both sight and smell.

## 3 Bromination of Benzene Accelerated by Cationic Surfactants

The direct bromination of aromatic compounds by elemental bromine ($Br_2$) is cumbersome because of safety hazards and the hydrobromic acid produced as a by-product. To avoid the use of $Br_2$, methods involving *in situ* generation of positive bromine species via the oxidation of bromide anion ($Br^-$) have been developed. Bromination of activated benzenes by electron donating substituent, utilizing

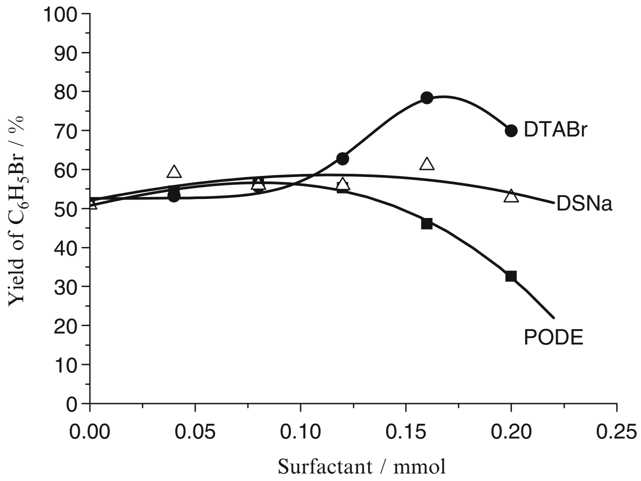


**Fig. 4** Effect on bromobenzene yield of various surfactants

bromides, oxidants, and cationic surfactants, were reported (Bahhate, Gajare, Wakharkar, & Bedekar, 1998; Bora et al., 2000; Conte, Furia, & Moro, 1994; Moriuchi, Yamaguchi, Kikushima, & Hirao, 2007; Vyas, Bhatt, Ramachandraiah, & Bedekar, 2003). In the present study, a new method for the bromination of benzene was developed (Inoue, 2009). When potassium bromide (KBr) and potassium bromate ($KBrO_3$) are placed under acidic conditions in an aqueous medium, the addition of a catalytic amount of cationic surfactant promotes the bromination of benzene, as shown in Eq. (2).

$$3C_6H_6 + BrO_3^- + 2Br^- + 3H^+ \rightarrow 3C_6H_5Br + 3H_2O. \tag{2}$$

Figure 4 shows the effects on the yield of bromobenzene of the following surfactants: dodecyl-trimethylammonium bromide (DTABr, a cationic surfactant), sodium dodecylsulfate (DSNa, an anionic surfactant), and polyoxyethylene dodecyl ether (PODE, a nonionic surfactant; average molecular weight: $1.2 \times 10^3$). When 0.15 mmol of DTABr, 1.0 mmol of $KBrO_3$, 2.0 mmol of KBr, 1.0 mL of 3 M aqueous sulfuric acid ($H_2SO_4$), and 1.0 mL of benzene were combined and stirred at 70 °C for 60 min, the yield of bromobenzene ($C_6H_5Br$) as measured by GC increased by 78% (calculated from the amount of $KBrO_3$ in Eq. (2); that is, 100% yield would correspond to 3.0 mmol of $C_6H_5Br$).

The effects of adding alkyltrimethylammonium bromides were then examined. Figure 5 shows the effects of four such additives. Tetradecyltrimethylammonium-bromide (TTABr) was found to be the most effective (yield increased by 84% when only 0.12 mmol of TTABr was used). The addition of tetramethylammonium bromide and octyltrimethylammonium bromide resulted in yields less than 1% yield of *o*- and *p*-dibromobenzene. In addition, using the data shown in Figs. 5 and 6, we

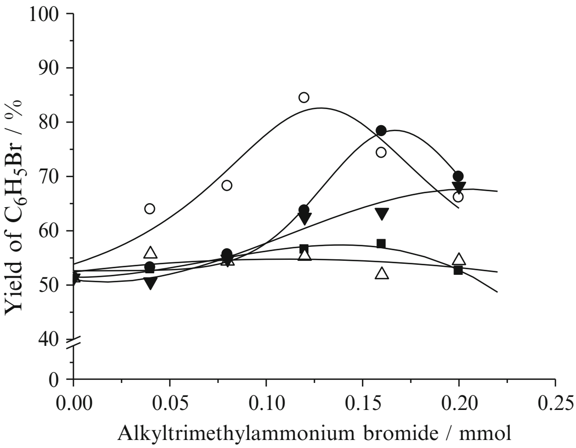


**Fig. 5** Effect on bromobenzene yield of alkyltrimethylammonium bromides
**(Δ: $(CH_3)_4NBr$, ■: $CH_3(CH_2)_7N(CH_3)_3Br$, ●: $CH_3(CH_2)_{11}N(CH_3)_3Br$, ○: $CH_3(CH_2)_{13}N(CH_3)_3Br$, ▼: $CH_3(CH_2)_{17}N(CH_3)_3Br$)**

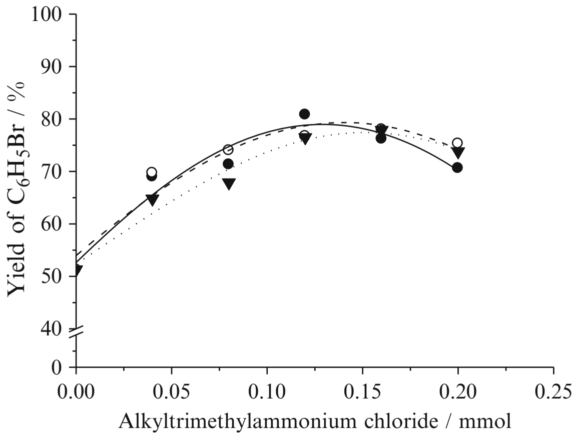


**Fig. 6** Effect on bromobenzene yield of alkyltrimethylammonium chlorides
**(●: $CH_3(CH_2)_{11}N(CH_3)_3Cl$, ○: $CH_3(CH_2)_{13}N(CH_3)_3Cl$, ▼: $CH_3(CH_2)_{17}N(CH_3)_3Cl$)**

compared the effects of bromides and chlorides. The chlorides were more effective than bromides, especially at low concentrations. However, the use of DTACl and tetradecyltrimethylammonium chloride (TTAC) yielded very small amounts of *p*-dibromobenzene.

Two factors may account for the effect of alkyltrimethylammonium salts in this bromination. The first factor is the surface activity of the ammonium salts. When hydrophilic tetramethyl ammonium bromide or octyltrimethylammonium bromide was used as the catalyst, the bromination was not facilitated because of insufficient surface activity and the hydrophilic nature of these ammonium salts. The second factor is the localization of positive charge on the nitrogen atom. This charge promotes the polarization of $Br_2$, which facilitates the bromination of benzene. When TBABr formed ion pairs with sulfonate, perchlorate, or tetraphenylborate anions by adding sodium salts, the positive charge on the nitrogen atom was partially negated and the yields of bromobenzene decreased under 60%. $Cl^-$ is a hard anion in comparison with $Br^-$, and quaternary ammonium cations are soft. When using DTABr, for example, the positive charge on the nitrogen atom was partially negated by the affinity of $Br^-$ for the quaternary ammonium cation. Thus, the yield of bromobenzene when using DTABr was less than that when using DTACl. Because DTACl is more hydrophilic than DTABr, owing to the localization of the positive charge on the nitrogen atom, bromination of polar bromobenzene occurred to a lesser extent when chlorides were used. This bromination of bromobenzene can be carried out in the aqueous phase. When using the bulkier ammonium salt $(C_{12}H_{25})_2N(CH_3)_2Br$, $Br_2$ might not be able to approach the nitrogen atom.

Experimental Procedure

(a) Preparations of reagent
Mixture containing $KBrO_3$ and KBr $KBrO_3$ (0.84 g, 5.0 mmol) and KBr (1.20 g, 10.0 mmol) were mixed well in a glass sample tube. If the container is properly sealed, the reagent mixture can be stored for more than 1 year.

(b) Bromination of benzene
The microscale experiment was conducted using the above-mentioned apparatus shown in Fig. 3. About 40 mg of the reagent mixture was added into test tube A, followed by 0.4 mL of aqueous DTMACl (0.040 M). Then, five drops (about 0.1 mL) of benzene were added with a Pasteur pipette. After shaking, 0.1 mL of aqueous $H_2SO_4$ (3 M) was added.

The cold finger (φ15 mm test tube) was filled with crushed ice and wrapped with tissue paper and a rubber band. An aqueous solution of 5% $Na_2SO_3$ was added to test tube A to absorb $Br_2$ vapor. Then, the apparatus was placed in hot water (70 °C) and heated for 20 min with occasional shaking. Then, test tube A was cooled in an ice bath, and 0.1 g of $Na_2SO_3$ was added to the reaction mixture to reduce the remaining oxidant.

Microporous polypropylene film (2 × 1.5 cm; a commercial product for removing oil from the face) was inserted into tube A to absorb the product. The film was removed with tweezers and washed with water to collect the product. The use of a volatile organic solvent for extraction can be avoided by using this technique.

The Beilstein test was performed to confirm the presence of the brominated product. A copper wire with its end rolled into a loop was heated with a burner flame; then the wire was brought into contact once with the film, removing the product. When this copper wire was again inserted into the burner flame, a green flame was observed.

From this experiment, students will experience the bromination of benzene without exposure to harmful steams of bromine and organic solvents.

## 4 Saponification of Benzyl Benzoate Accelerated by Cationic Surfactants

We investigated a microscale experiment for saponification of benzyl benzoate (Fig. 7). We used benzyl benzoate as the substrate for the following reasons.

The starting material benzyl benzoate is a liquid, and the product benzoic acid is solid. Accordingly, the progress of the saponification can be easily observed from the formation of the solid. Benzoic acid is detected through reaction with aqueous $NaHCO_3$.

Because benzyl alcohol is hydrophobic, the separation from sodium benzoate in the aqueous phase can be carried out.

After being separated, benzyl alcohol can be oxidized with active $MnO_2$ by using the procedure presented in Sect. 2; the resultant aldehyde can then be detected from its odor.

In general, the saponification of aromatic carboxylic acid esters such as benzyl benzoate is slower than that of aliphatic carboxylic acid esters. Consequently, extreme reaction conditions, such as high concentrations of aqueous NaOH, are necessary to complete the experiment within the allotted class time. Aiming to find reaction conditions under which the saponification proceeds rapidly to completion, we examined catalysts. It has been reported that some quaternary ammonium salts, such as those shown in Fig. 8, accelerate the saponification of PET fiber

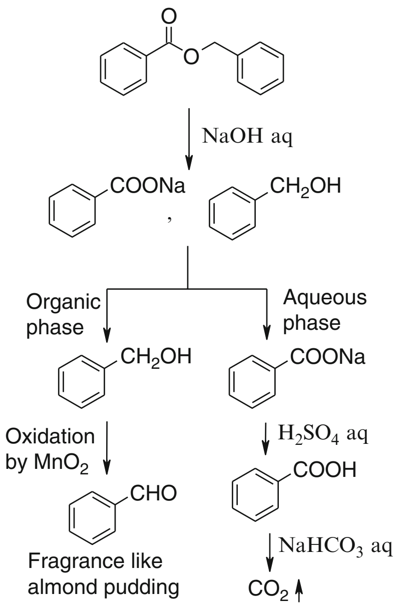


**Fig. 7** Saponification of benzyl benzoate

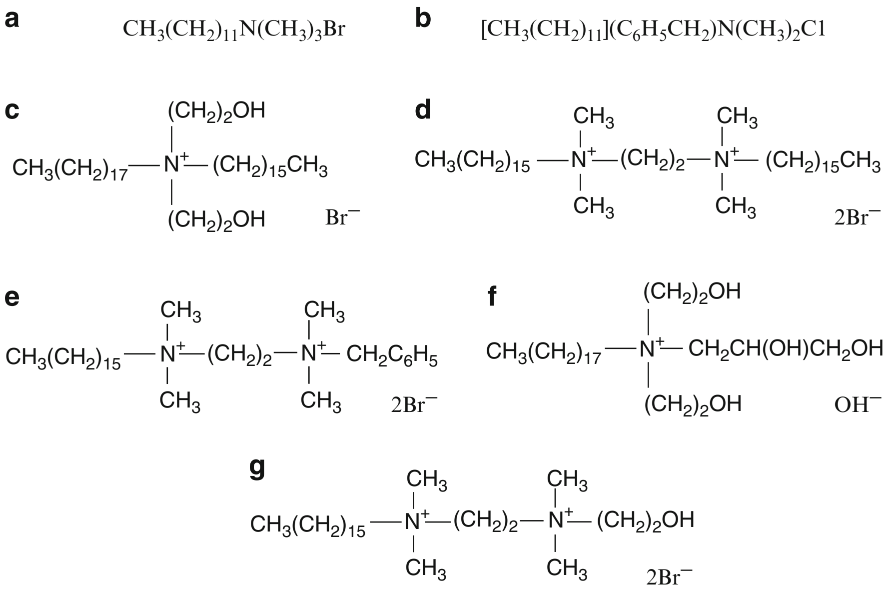

**Fig. 8** Quaternary ammonium salts that accelerate saponification of PET and plant oil

**Table 3** Examined cationic surfactants

| Entry | Formula | Abbreviation |
|---|---|---|
| 1 | $CH_3(CH_2)_{11}N(CH_3)_3Br$ | DTMABr |
| 2 | $CH_3(CH_2)_{17}N(CH_3)_3Br$ | OTMABr |
| 3 | $[CH_3(CH_2)_{11}]_2N(CH_3)_2Br$ | DDDMABr |
| 4 | $[CH_3(CH_2)_{13}]_2N(CH_3)_2Cl$ | DTDMACl |
| 5 | $[CH_3(CH_2)_{17}]_2N(CH_3)_2Br$ | DODMABr |
| 6 | $[CH_3(CH_2)_{13}](C_6H_5CH_2)N(CH_3)_2Cl$ | TBDMACl |

(Gawish, Mosleh, & Ramadan, 2002) and plant oil (Entezari & Keshavarzi, 2001). Hoping to apply these findings to the reaction at hand, we investigated commercially available cationic surfactants to find which was optimal for the saponification of benzyl benzoate.

First, we examined the cationic surfactants listed in Table 3 (reaction conditions: surfactant, 0.050 mmol, 0.15 mmol or 0.30 mmol; benzyl benzoate, 0.50 mmol; NaOH, 20 mmol; water, 10 mL; 50 °C; 30 min). The yields of benzyl alcohol as determined by GC are shown in Fig. 9. Among the examined cationic surfactants, TBDMACl and DDDMABr exhibited excellent performance. Next, we attempted to reduce the required amount of NaOH (reaction conditions: TBDMACl or DDDMABr, 0.30 mmol; benzyl benzoate, 0.50 mmol; 70 °C; 20 min). The yield of

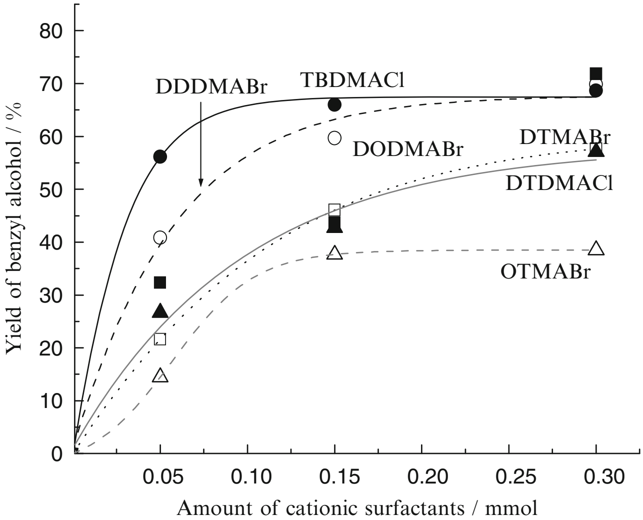


**Fig. 9** Effect of cationic surfactants on yield of benzyl alcohol

benzyl alcohol was excellent (greater than 80%), even when the amount of NaOH was reduced to 2.0 mmol. Next, we attempted to shorten the reaction time (reaction conditions: TBDMACl or DDDMABr, 0.30 mmol; benzyl benzoate, 0.50 mmol; NaOH, 2.0 mmol; 70 °C). The yield of benzyl alcohol was over 70% for a reaction time of 5 min. In these reactions, the amount of cationic surfactants was 0.6 equivalent with respect to benzyl benzoate. When we attempted to reduce the amount of cationic surfactant used in the reaction at 70 °C, the yield of benzyl alcohol decreased in proportion to the decrease in the amount of cationic surfactant. However, when the reaction temperature was increased, the yield of benzyl alcohol increased considerably (greater than 95%).

Experimental Procedure

(a) Saponification of benzyl benzoate

In test tube A (φ15 mm), TBDMACl (about 10 mg), aqueous NaOH solution (0.5 M, 2 mL) were mixed. Into this test tube, two drops of benzyl benzoate were added with a Pasteur pipette. Test tube A was heated for 3 min with the flame of a Bunsen burner, while taking care that the solution did not boil. A piece of microporous film (2 × 1.5 cm) was inserted into test tube A to absorb benzyl alcohol, one of the products. This operation was repeated twice. When 0.5 mL of aqueous $H_2SO_4$ (3 M) was added to the solution in test tube A, white crystals of benzoic acid were observed (if few crystals were observed, the test tube could be cooled in an ice bath to promote precipitation). The crystals were filtered and washed with a small amount of ice water. When saturated aqueous $NaHCO_3$ was added dropwise to the crystals, $CO_2$ was generated and the crystals disappeared.

(b) Oxidation of benzyl alcohol

In test tube B (φ18 mm), aqueous $MnSO_4$ (1.0 M, 0.5 mL) was mixed with aqueous DSNa (0.10 M, 0.5 mL). Into tube B, aqueous $NaMnO_4$ (0.50 M, 0.5 mL) was added, and the solution in test tube B was mixed well by shaking. Prepared active $MnO_2$ in test tube B was used for the following oxidation without being isolated. A piece of microporous film was pushed into test tube B with a glass stirring rod to absorb benzyl alcohol (as described above). Test tube B was heated gently over a Bunsen burner flame for 1 min, the fragrance of benzaldehyde was felt to emanate from the mixture in test tube B.

## 5 Detection of Esters with the Hydroxamic Acid Method

The hydroxamic acid method is a classic technique for the detection of esters prepared from carboxylic acids and alcohols. In the conventional method, an organic solvent such as methanol is used as the medium for the reaction between hydrophobic esters and hydroxylamine under basic condition (Davidson, 1940; Hauser & Renfrow, 1943). The reaction of esters prepared from low molecular weight aliphatic carboxylic acids such as ethyl acetate proceeds smoothly in aqueous media. However, the reaction of esters prepared from aromatic carboxylic acids such as benzyl benzoate is extremely slow in aqueous media. Therefore, we attempted to find a suitable catalyst to accelerate the reaction between an aromatic carboxylic acid ester, namely, benzyl benzoate, and hydroxylamine in basic aqueous solution. As a result, we found that certain cationic surfactants such as dodecyltrimethyl-ammonium chloride (DTMACl) were able to promote this reaction well (Figs. 10 and 11). The progress of the reaction can be monitored from the purple color ($\lambda_{max}$ = 520 nm) of the produced hydroxamic acid-iron complex. We compared the effects of various cationic surfactants (quaternary ammonium salts; see Table 4) and found that an appropriate balance between hydrophobicity and hydrophilicity was an essential trait of the catalyst. As judged from the absorbance at 520 nm, the reaction proceeded to a greater extent when alkyltrimethylanmonium chlorides were used as the catalysts, in comparison with the bromides. This method can be used to indentify various esters other than benzyl benzoate.

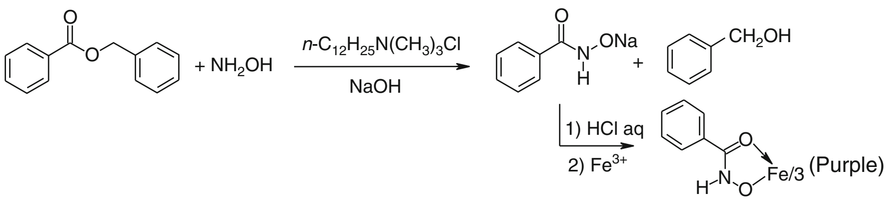


**Fig. 10** Hydroxamic acid method for detecting benzyl benzoate

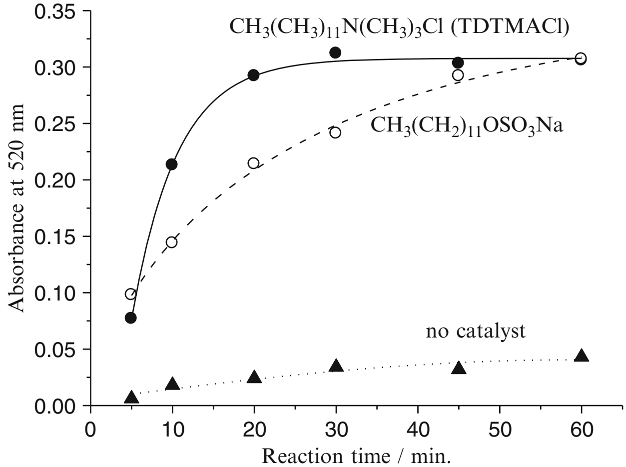


**Fig. 11** Effect of surfactants on absorbance

**Table 4** Effect of $CH_3(CH_2)nN(CH_3)_3X$ on absorbance at 520 nm

| *n* | X | abs.* |
|---|---|---|
| 12 | Cl | 0.21 |
| 12 | Br | 0.22 |
| 14 | Cl | 0.21 |
| 14 | Br | 0.26 |
| 16 | Cl | 0.15 |
| 16 | Br | 0.19 |
| 18 | Cl | 0.14 |
| 18 | Br | 0.16 |

Experimental Procedure

Into a test tube (φ18 mm), one drop of benzyl benzoate (0.1 mmol) was added with a Pasteur pipette, followed by 0.6 mL of aqueous NaOH (1 M), 0.2 mL of aqueous DTMACl (0.1 M) and 20 mg of hydroxylamine chloride. The test tube was then shaken to mix well. The mixture was heated at 70 °C for 10 min. After adding 2 mL of aqueous solution of HCl (3 M), 0.3 mL of aqueous solution of $Fe(NH_4)_2(SO_4)_2$ (0.1 M) was added, and the solution was mixed well by shaking. Then, the purple color of the complex between hydroxamic acid and $Fe^{3+}$ ion appeared immediately, and the solution was diluted with a mixture of water and ethanol (1:1 v/v) for observation.

From this experiment, students will be able to detect various products including esters (such as aromatic oils; fruits flavor; solvents of adhesives, fibers, and resins) in their surroundings.

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# Development of an Analytical Method of Gaseous Mixtures Using a Syringe

**Takashi Yasuoka**

## 1 Introduction

Observation of actual chemical reactions and phenomena occurring in a flask or other media is essential for understanding and satisfaction of scientific aspects of chemistry. However, in the field of analytical chemistry, we can only see the actual reactions and phenomena when using highly developed instrumental analysis. As for gas analysis, gas chromatography (GC) is commonly used for the determination of the complex gas composition at a wide range of concentration levels (from percent to ppb) with excellent repeatability and sensitivity, while the separation and detection processes are not able to seen. It seems like a "black box" to operators. So, using GC for gas analysis makes it very difficult to understand the principle of the chemical phenomena occurring in the device by visual observation and fails to promote interest in science, especially for middle school, high school, and undergraduate university students who are not specializing in chemistry.

This study aimed to develop a novel, simple, and self-assembly gas analysis method that has "visible" processes for students, realizing the actual chemical phenomena with easy handling and preparation. The device was then prepared based on the principle of the Orsat gas analyzer by replacing some special equipment with common materials, and its analytical performance was tested in this study.

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## 2 Literature Review

The fundamental gas analysis method is based on the principle of gas absorption, which involves the incorporation of a gaseous mixture into an absorption solution. The original method of gas analysis was first developed by Walther Hempel around 1870 (Ihde, 1963). However, the device was not portable and required complicated procedures. Then, the Orsat gas analyzer was developed based on the Hempel's method with some modifications in safety, portability, and handling (British Standard, 1952; Meites, 1963). This apparatus consists of a calibrated gas burette connected by capillary tubing to absorption pipettes containing trapping solutions that absorb the target gases such as potassium hydroxide for carbon dioxide ($CO_2$), alkaline pyrogallol for oxygen ($O_2$) and ammoniacal cuprous chloride for carbon monoxide (CO). This is a typical manual analysis method. Gas analysis then evolved from manual analysis to automatic analysis such as GC (Tohjima, 2000), infrared absorption analysis, and electrochemical analyses (Verdin, 1973), under the demand for highly sensitive, rapid, and simultaneous determination of gas samples. Even though the Orsat analyzer is still recommended for use in an authorized industrial protocol (Japanese Industrial Standard K 0301, 1998: Methods for determination of Oxygen in flue gas), it is merely used for field measurements.

However, manual analysis is still widely used for educational purposes. Typical methods applied to the science classes of primary and secondary schools are the Gastec Detector Tube (also known as a dositube) for various kinds of gases (Japanese Industrial Standard K 0804, 1998) and the disposable body warmer (made of iron oxides) for $O_2$. The Orsat analysis is also used for chemical education, because the apparatus is suitable for chemistry undergraduate students to understand the basic concept of gas adsorption. However, the equipment and its operations are too complex for secondary school students and university students other than chemistry majors. The author modified the Orsat analyzer so that every student can prepare it and operate it in any chemistry course.

## 3 Development of the Device

Photo 1 shows an overview of the device developed in this study. The device simply consists of a calibrated syringe, pressure gauge, and three-way stopcock. A sample gas is drawn into the cylinder by pulling the rod and the gas volume is read at constant pressure (atmospheric pressure) monitored by the gauge. An absorbent solution is subsequently introduced into the syringe and mixed by vigorous shaking for full adsorption. The inner pressure is then kept at constant pressure and the reduced volume of gas in the syringe indicates the percentage of absorbed analyte. While the absorption solution should be switched at every gas analysis in the basic Orsat method, various kinds of solutions corresponding to analytes are serially added into the syringe in this method. This method affords simple operation so all students may benefit from its use.

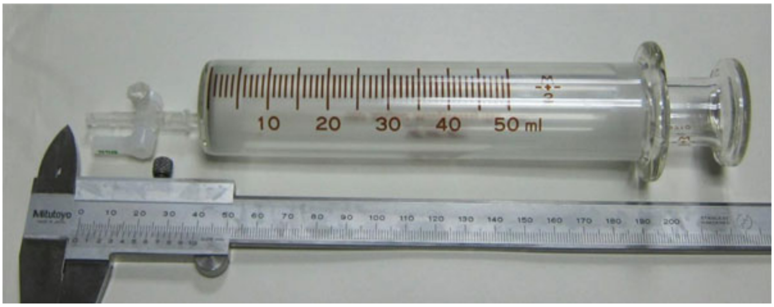


**Photo 1** Overview of the developed gas analyzer

## 3.1 Development of the Pressure Gauge

### 3.1.1 Requirement of the Pressure Gauge

Assuming an ideal gas, volume of the gas changes according to Boyle-Charles's law. Therefore, in this kind of gas analysis, temperature and pressure must be kept constant to measure the volume of gas. In the Orsat apparatus, a calibrated water-jacketed gas burette is employed to keep temperature constant, and the pressure is controlled to equal the atmospheric pressure by raising and/or lowering the leveling bottle. In our case, the temperature was regarded as constant because of the short use time, while the pressure gauge was required to adopt the syringe as a possible alternative to the leveling bottle.

### 3.1.2 Principle of the Pressure Gauge

Then, a novel pressure gauge was developed using a thin flexible film made of polyethylene as an indicator of pressure. The principle is very simple using a syringe connected by tubing to a thin film. When the pressure inside the syringe is higher than atmospheric pressure, the film becomes convex as shown in Photo 2a. On the other hand, the film becomes concave, when the internal pressure is lower than the external pressure (Photo 2b). When the internal pressure is equal to the atmosphere, the film stands flat (Photo 2c). Watching the shape of the film tells us the internal pressure of the syringe.

The novel pressure gauge was designed to reduce measurement error in this syringe-based gas analyzer system. For example, when measuring 40 mL of gas using a glass syringe, a plunger smoothly moves from 38 to 42 mL graduations and this may cause ±2 mL errors. The pressure gauge is also essential for a plastic syringe whose plunger is too tight to follow changes in internal and atmospheric pressure.

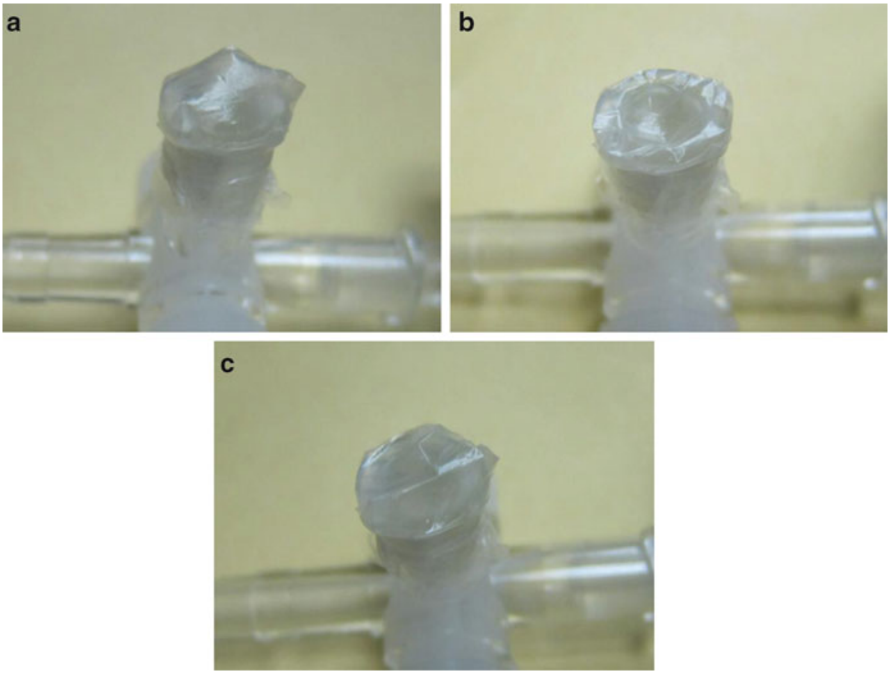


**Photo 2** Changes in shape of the thin film that indicate a balance between internal pressure and atmospheric pressure: (**a**) internal > atmospheric, (**b**) internal < atmospheric and (**c**) internal equal to external pressure

### 3.1.3 Preparation of the Pressure Gauge

A three-way stopcock (Nipro, Japan, ED type stopcock) with two female luer connectors and a male luer was employed in this study. One of the female connectors was tapered to connect the syringe. The tapered male luer was connected to a rubber tube. The other female luer, perpendicular to the main stream, served as the pressure indicator. The female luer was first jacketed by a piece of Parafilm "M" (American National Can, 3 mm width, 50 mm length), and the open-center was then covered by a polyethylene film. The film was fixed by overlapping its edge by a piece of the Parafilm "M".

When a three-way valve is not available, a tee tube with a rubber tube and pinch cock also works for this purpose.

### 3.1.4 Measurement of Gas Volume by the Pressure Gauge

Two volunteers validated the developed device (Photo 1) by measuring the gas volume using the pressure gauge. After approximately 40 mL of air was drawn

**Table 1** Results of measurement of gas volume using the developed device by two volunteers

| Run # | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Volunteer | 1st | 2nd | 3rd | 4th | 5th | Mean | SD | RSD(%) |
| A | 40.2 | 40.4 | 40.5 | 40.2 | 40.3 | 40.3 | 0.13 | 0.32 |
| B | 40.0 | 40.5 | 40.5 | 40.5 | 40.2 | 40.3 | 0.23 | 0.57 |

*SD* standard deviation, *RSD* relative standard deviation

into the syringe, each volunteer balanced the inner pressure to atmospheric pressure by observing the thin film status and then reading the gas volume. The measurement was repeated five times by each volunteer. Excellent repeatability was found from the results of readings, as shown in Table 1. Variation of the measured values was within 0.5 mL with 0.32 and 0.57% of relative standard deviations (RSDs), and no significant difference was found between the two volunteers (t-test, $p < 0.01$). This shows the accuracy of the test device is adequate for use for educational purposes.

# 4 Absorption Media

## 4.1 Preparation of Absorbent Solutions

Absorbent for $CO_2$: 60 g of potassium hydroxide (caustic potash) was dissolved in 300 mL of deionized-distilled water (DIW).

Absorbent for $O_2$: 10 g of pyrogallol was dissolved in DIW. Then, 60 g of potassium hydroxide was dissolved in 200 mL of DIW. After cooled in an ice bath, both solutions were mildly mixed well.

Absorption for CO: After dissolving 50 g of ammonium chloride and 40 g of copper (I) chloride in 200 mL of DIW, 100 mL of concentrated ammonia solution was added to the solution.

## 4.2 Introduction of Absorbents into the Syringe

As shown in Photo 3, two separate transparent tubes made by polyvinyl chloride were connected by a piece of rubber tube. The rubber tube was stopped by a simple pinch cock. Connect the transparent tube to the syringe, release the pinch cock, suck up the absorbent solutions stored in a flask, and then fill up the solution to the entrance of the syringe. Photo 4 shows a case of alkaline pyrogallol, after disconnecting the syringe. The equipment in the figure is ready for the next injection, preventing air flow into the tube.

**Photo 3** A prepared tube for introduction of absorption solution into the syringe


**Photo 4** Absorbent solution ready for injection into the syringe

We have to note that the absorption capacity is reduced by long-term exposure to air. In this case, a closed system is required for preventing contact with the air. For example, a polyethylene bag can be used into which the introduction tube is inserted and tied up at its open face.

## *4.3 How to Explain Absorption Mechanism*

When demonstrating the device to students who are not familiar with chemistry, it is necessary to explain the absorption mechanism of analytes using a simple concept and phrases. In this case, the following explanation is proposed. “Chemistry is a science to study how substances react when combined and in contact with one another. In this practice, you can see a gas changes into the liquid phase by reacting with specific compounds in the aqueous solution, and learn three kinds of gases, even though they are mixed, separately react when using absorbents which react with specific analytes. These specific reactions are due to the nature of the substances. For example, an acid ($CO_2$, more precisely carbonate ion) is neutralized by a base (potassium hydroxide), an oxidant ($O_2$) is reduced by a reducing agent (alkaline pyrogallol) and a ligand (CO) binds to a central metal atom ($Cu^+$) to form a coordination complex."

## 5 Analytical Procedure

Gas analysis by the developed syringe method was conducted according to the following procedure:

1. After expelling the air from the syringe, the lever of the three-way stopcock was moved to connect the syringe to the pressure gauge, to ensure the volume is zero.
2. Turning the lever to close the pressure gauge and to open the path, 30–40 mL of sample gas was introduced into 50 mL of the syringe. The path was then closed and the pressure gauge became active.
3. Observing the pressure gauge, internal pressure was adjusted to equal the atmospheric pressure by moving the piston rod.
4. The male luer was connected to one end of the introduction tube, whose other end was immersed in the absorbent solution of $CO_2$. After releasing the pinch cock, 5 mL of potassium hydroxide solution was introduced into the syringe.
5. Stopping the rubber tube by the pinch cock, the introduction tube was disconnected.
6. After shaking the syringe for full absorption, the internal pressure was then adjusted to the atmospheric pressure, and the remaining gas volume was measured by simply reading the graduation.
7. Step 6 (above) was repeated until the gas volume became constant, and the remaining gas volume was measured by reading the graduation.
8. The absorbent solution was switched to alkaline pyrogallol, and 5 mL of the absorbent was added into the syringe. Then, steps 5–7 (above) were repeated.
9. After step 8 (above), the absorbent solution was expelled from the syringe while retaining the remaining gas, because contamination of ammoniacal cuprous chloride with other absorbents causes a precipitation of copper hydroxide that reduces the absorption capacity. Then, switching to the CO absorbent, steps 5–7 (above) were repeated.
10. When measurements were finished, all of the equipment was rinsed and, if necessary, used for additional experiments.

## 6 Analysis of Oxygen in Air

The device was then actually tested to measure $O_2$ concentration in ambient air. Two volunteers tried to perform measurements following the steps from 1 to 8 described above. Table 2 shows the results: values in upper rows of each volunteer are direct readings (mL) and those in bottom rows are $O_2$ concentration in air (% in volume)

**Table 2** Analytical results of $O_2$ concentration in air by two volunteers

| Volunteer | | Run # 1st | 2nd | 3rd | Mean | SD | RSD(%) |
|---|---|---|---|---|---|---|---|
| A | Reading (mL) | 31.0 | 31.8 | 31.3 | 31.4 | 0.40 | 1.3 |
| | O2 conc. (%) | 22.5 | 20.5 | 21.8 | 21.6 | 1.0 | 4.7 |
| B | Reading (mL) | 31.0 | 31.9 | 31.5 | 31.5 | 0.45 | 1.4 |
| | O2 conc. (%) | 22.5 | 20.3 | 21.3 | 21.4 | 1.1 | 5.2 |

**Table 3** Analytical results of $CO_2$, $O_2$, and CO concentrations in the prepared gas mixture using the developed device (unit: % in volume)

| Gas species | set | Run # $1^{st}$ | 2nd | 3rd | Mean | SD | RSD(%) |
|---|---|---|---|---|---|---|---|
| CO2 | 14.3 | 13.8 | 13.2 | 14.6 | 13.9 | 0.70 | 5.1 |
| O2 | 15.0 | 16.1 | 16.8 | 14.4 | 15.8 | 1.2 | 7.8 |
| CO | 14.3 | 13.1 | 11.2 | 13.7 | 12.7 | 1.3 | 10 |

calculated from beginning volume of air in the syringe, volume of $CO_2$, and reading at step 8. Even though visual readings often involve personal bias that leads to uncertainty, obtained $O_2$ concentrations by both volunteers indicated normal atmospheric $O_2$ concentration levels (21.0%) with excellent repeatability (5% of RSD).

## 7 Analysis of Prepared Gas Mixture

A gas mixture was then prepared by injecting 200 mL of $CO_2$ and 200 mL of CO into 1,000 mL of air in a sampling bag made of polyfluoroethylene (PTFE) that is air-tight and inert against the gas species. The gas composition then resulted in 14.3% $CO_2$, 15.0% $O_2$, and 14.3% CO. This gas mixture was subsequently measured by the developed syringe method following the procedure described in Sect. 5. Table 3 shows the analytical results. The gas concentrations were close to the set values, respectively. Note that uncertainty tended to increase from $CO_2$ (5.1% of RSD) to CO (10%) in order of the analytical step. This was because of error propagation in the operations. However, these results showed enough accuracy and repeatability to support applying this novel method for educational purposes.

Another gas mixture was also prepared by injecting random amounts of $CO_2$ and CO into 1,000 mL of air in the PTFE sampling bag. The gas mixture was then analyzed by both the conventional Orsat gas analyzer (Sibata Scientific Technology, Japan, No.2119) and this syringe method. Table 4 shows the analytical results measured by the developed syringe method, compared with those from the Orsat apparatus. Both results showed good agreement for each gas with 0.5–0.9 differences.

**Table 4** Comparison of analytical results of the gas mixture obtained by Orsat gas analyzer and the syringe method (unit: % in volume)

| Gas species | Orsat method | Syringe method | Difference |
|---|---|---|---|
| CO2 | 27.6 | 26.7 | 0.9 |
| O2 | 8.9 | 8.4 | 0.5 |
| CO | 10.1 | 9.5 | 0.6 |

This suggests the developed syringe method is a possible alternative to the previous Orsat gas analysis to learn about the contact gas absorption principle in any level chemistry class.

## 8 Conclusion

A novel, simple, and self-assembly gas analysis method was developed using common materials and tested in this study. The device showed reasonable analytical results for $CO_2$, $O_2$,and CO concentration levels with excellent repeatability. This suggests the developed syringe method is a useful way to learn the contact gas absorption principle for students who are not chemistry majors in undergraduate school.

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# Microscale Experiments Using a Low-Cost Conductance Meter

**Jose H. Bergantin Jr., Djohn Reb T. Cleofe, and Fortunato Sevilla III**

## 1 Introduction

The concept of ions is a basic lesson in the introductory chemistry course. It is commonly used to explain the observed properties of electrolytes. The presence of ions in solution can be demonstrated through the measurement of the solution conductivity.

The traditional setup for demonstrating conductance involves a mains-powered light bulb connected in series with a pair of wire electrodes that have uninsulated tips that are dipped in the sample solution. The conductance of the solution is indicated by the brightness of the bulb. The risk of electrocution is always present for users of this setup. A safer alternative is the battery-powered probe with an LED indicator. However, it can offer qualitative information only, much like the traditional conductivity apparatus.

Improved versions of conductance measurement instrumentation systems made use of oscillator circuits to avoid interference from the electrolysis of water at the electrodes. These conductance-measuring devices featured the use of flashing LEDs (Burns & Lewis, 1997), a buzzer (Gadek, 1987), or bar graph display (Ganong, 2000; Haworth, Bartelt, & Kenney, 1999; Zawacky, 1995) to indicate the conductance of sample solutions. At best, these devices could only offer semi-quantitative information regarding the conductance of solutions.

Quantitative devices that include a numerical display are more desirable because they provide much more information regarding the test solutions (da Rocha, Gutz,

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& do Lago, 1997; Ghatee, 1993; Guzman & Puga, 1993; Havrilla, 1991; Rettich, 1989; Sevilla, Andres, & Alfonso, 1993). Most of the designs of the probes used for these quantitative conductance meters are still in the macroscale, requiring at least 50 mL of test solutions. This work aimed to construct a low-cost quantitative conductance meter with a probe that can be adapted for use with microwell plates in microscale chemistry experiments.

Microscale chemistry or small-scale chemistry continues to gain following in laboratory courses because of the advantages offered such as reagent economization and reduction of reagent storage space, minimization of chemical wastes and safety hazards, and better laboratory time management. The benefits of microscale chemistry can be applied to experiments involving instrumentation in the measurement steps, and not just those that feature qualitative observations.

## 2 Methodology

*Circuit construction*. A conductance measurement circuit based on the TL084 integrated circuit was assembled on a breadboard (Fig. 1). It is powered by a ±5 V DC regulated power supply. It may also be powered with a pair of 9 V batteries regulated to an output of ±5 V DC using 7805 and 7905 voltage regulator ICs. A triangular wave is formed by the operational amplifier oscillator circuit. A DC voltage, proportional to conductance, is the final output signal after rectification. A digital multimeter was used to measure the output voltage.

*Probe development*. The probe was constructed using a plastic lid as support for a pair of pencil lead electrodes (Fig. 2). The plastic lid was of a diameter that snugly fit into the mouth of the wells of a 24-well microplate. Mechanical pencil leads (STAEDTLER) were used for the electrodes with a length of around 38 mm and 2.0 mm diameter. The leads were inserted into drilled holes on the lid, and fixed in position using a marine epoxy that is able to resist dilute acids and bases. The distance between the electrodes was fixed at 4 mm. The exposed portion of each electrode was around 5 mm in length, and was completely submerged in 1.5 mL of a solution contained in the well. Connection of the probe electrodes to the circuit was accomplished with a pair of alligator clips with wires. Alternatively, wires can also be soldered or glued to the electrodes using conducting epoxy.

*Conductance measurements*. The total volume of the test solutions was limited to a minimum of 1.5 mL and a maximum of 2.0 mL. The volumes were measured and delivered using 1- and 3-mL syringes. Standard solutions were prepared and diluted to the required total volume in 2-mL microtubes. These syringes and microtubes are low-cost, standard volume measuring labware for microscale experiments. For the titration experiments, mixing was done through the use of a plastic cable tie. The test solutions were placed in the wells of a microplate and the probe assembly was covered over the well in order to fix the position of the electrodes immersed in the solution. The voltage output was recorded after the readings stabilized a few seconds after the immersion of the electrodes.

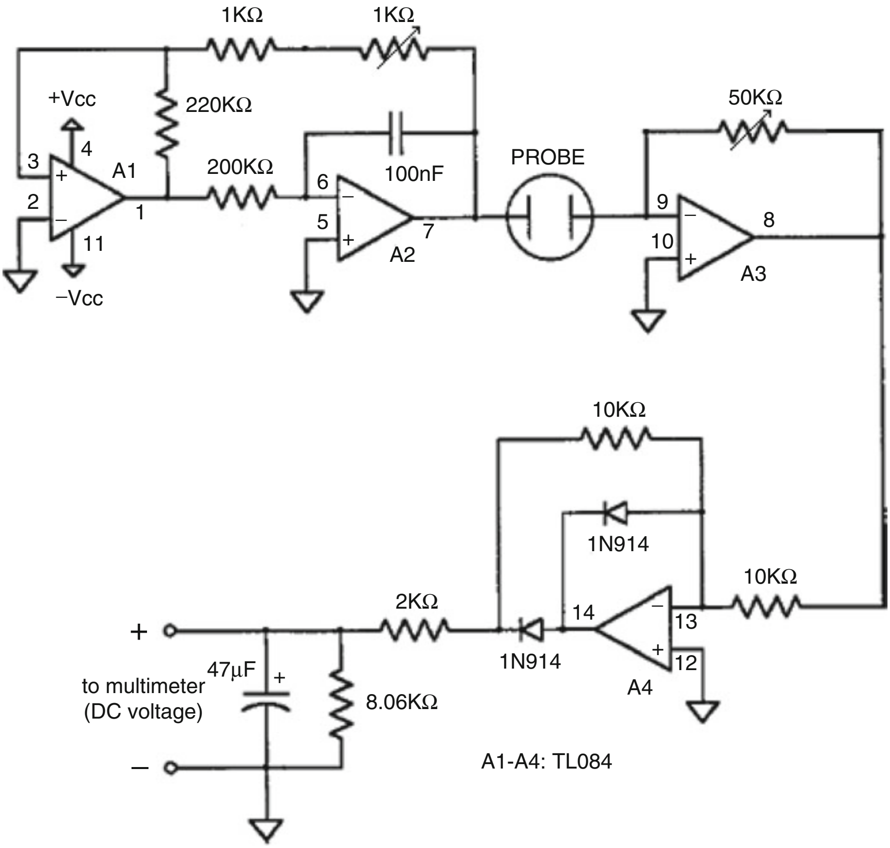


**Fig. 1** Circuit diagram used for the conductance meter; numbers *1–14* indicate pin numbers on the TL084 IC (da Rocha et al., 1997)

## 3 Results and Discussion

The circuit used for the conductance meter was adapted with modifications from the work of da Rocha et al. (1997). It is based on the quad operational amplifier integrated circuit – the TL084. The oscillator component of the circuit provides a triangular waveform output with a frequency of 1.67 kHz. High-frequency oscillation is required in conductance measurements in order to avoid the electrolysis of water that could lead to erroneous results.

The current passing through the probe and the test solution is converted to voltage, and the wave is rectified to obtain a DC voltage output that can be easily displayed on a digital multimeter. Some of the circuit parameters have been optimized in order to make the final voltage output directly proportional to the concentration of ions in the solution. The conductance meter was not configured further

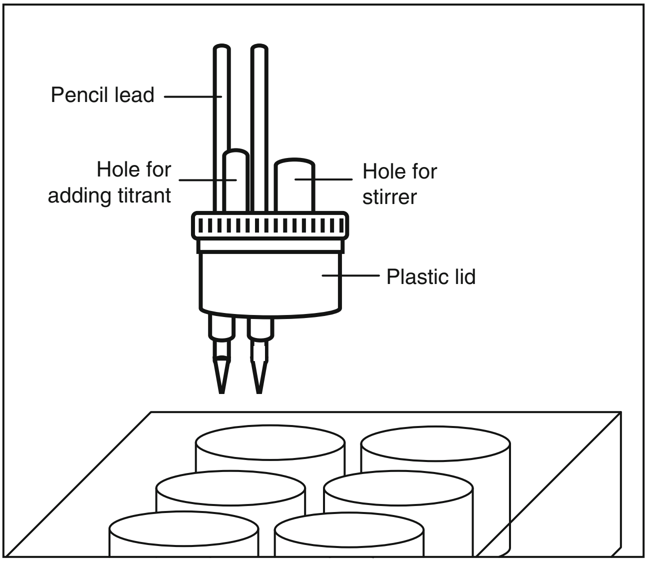


**Fig. 2** Conductance meter probe

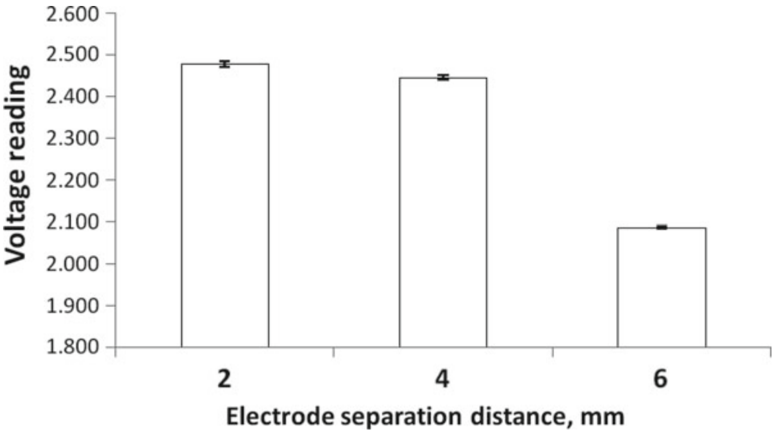


**Fig. 3** Effect of electrode separation distance on the voltage output of the conductance meter ($n = 3$, error bars: ±1SD)

to give a direct readout of conductance in units of Siemens because it was originally intended for use in general chemistry laboratory experiments only.

The distance between the electrodes was found to affect the voltage output (Fig. 3). A separation distance of 2 mm produced the highest readings, but the 4 mm distance was chosen in order to avoid accidental shorting of the electrodes by the

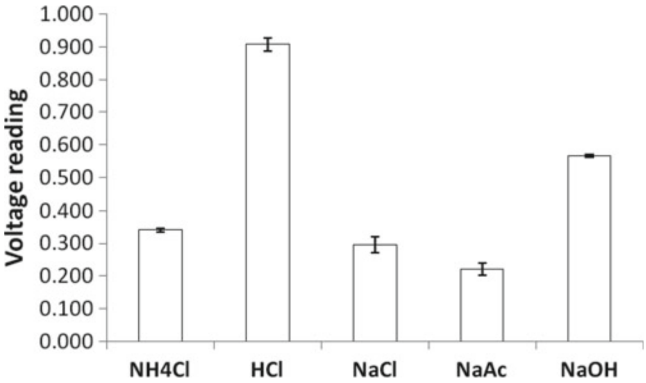


**Fig. 4** Voltage output for 0.01 M solutions of some electrolytes (NaAc is $NaCH_3COO$, $n=3$, error bars: ±1SD)

alligator clip connectors. There is only a small difference between the voltage output obtained using electrode separation distances of 2 and 4 mm.

The effect of the volume of the test solution on the voltage output was minimized by setting the exposed length of the electrodes to 5 mm and maintaining a minimum sample volume of 1.5 mL. This volume of test solution is one-half of the capacity of the microwell and it is enough to submerge completely the exposed portion of the electrodes.

*Experiment 1. Electrolytic conductance and ionic mobility*. In this experiment, the relative mobility of some monovalent ions was determined through the measurement of the conductance of 0.01 M solutions of the following electrolytes: $NH_4Cl$, HCl, NaCl, $NaCH_3COO$, and NaOH. For the solutions containing chloride ions, the correct order of the relative mobility of the positive ions was obtained: $H^+ > NH_4^+ > Na^+$. For the solutions containing sodium ions, the correct order of relative mobility of the negative ions was obtained: $OH^- > Cl^- > Ac^-$ (Fig. 4). These are the correct trends based on textbook values of ionic mobilities for these ions.

*Experiment 2. Variation of conductance with concentration*. This experiment investigated the effect of concentration on conductance. A series of dilute solutions of HCl was prepared from a 0.01 M stock solution. These volumes were measured using a 0.3 mL insulin syringe and diluted to 1.5 mL in a microtube. A linear calibration curve was obtained by plotting the voltage output of the conductance meter versus the concentration of HCl solutions in the range from $2.0 \times 10^{-4}$ M to $3.0 \times 10^{-3}$ M (Fig. 5). High sensitivity was also exhibited in the calibration curve.

*Experiment 3. Determination of the dissociation constant (Ka) of a weak electrolyte*. The calibration curve that was constructed for HCl in Experiment 2 was used to determine the hydrogen ion concentrations present in 0.01 and 0.1 M solutions

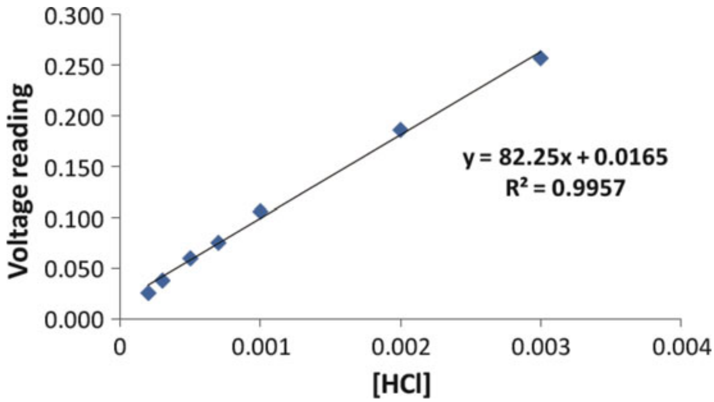


**Fig. 5** Calibration curve for HCl ($n = 3$)

of the weak acid acetic acid. The hydrogen ion concentrations or the values for [$H^+$] in these two solutions were interpolated from the graph in Fig. 5 using the voltage output measured with these acetic acid solutions (three trials).

The [$H^+$] values obtained together with the respective initial concentrations of the acetic acid were then used to compute the Ka values for acetic acid. The best result exhibited an 8% error relative to the theoretical value for the Ka of acetic acid, which is $1.75 \times 10^{-5}$. The discrepancy can be attributed to the effects of laboratory temperature variations, as well as to the errors in the volume measurements using the syringes during the preparation of the test solutions.

*Experiment 4. Conductimetric acid–base titrations*. The experiment on conductimetric titration involved 1.5 mL of the HCl or $CH_3COOH$ starting solution to which 0.03 mL increments of 0.1 M NaOH were added. A small plastic cable tie was used for stirring the solution. Incremental amounts of the titrant were added through the tube on the lid using a syringe.

The typical conductimetric titration curve was obtained for the HCl vs NaOH titration, characterized by an initial decrease in conductance due to the removal of $H^+$ by reaction with $OH^-$ ions to form water. Beyond the equivalence point, the conductance increased sharply because of the excess $Na^+$ and $OH^-$ ions. The endpoint obtained (0.15 mL) practically coincided with the theoretical value at the addition of 0.15 mL of the 0.1 M NaOH (Fig. 6).

For the acetic acid vs. NaOH titration, the typical conductimetric titration curve was also obtained, characterized by an initial increase in conductance due to the formation of acetate ions from the reaction of acetic acid and NaOH. Beyond the equivalence point, the conductance increases sharply because of the excess $Na^+$ and $OH^-$ ions from the added titrant (Fig. 7). The endpoint (0.12 mL) is near the theoretical value of 0.14 mL for a volume of 0.01 M NaOH. The discrepancy could be attributed to the approximate concentrations of reagents used, and the errors associated with volume measurement using syringes.

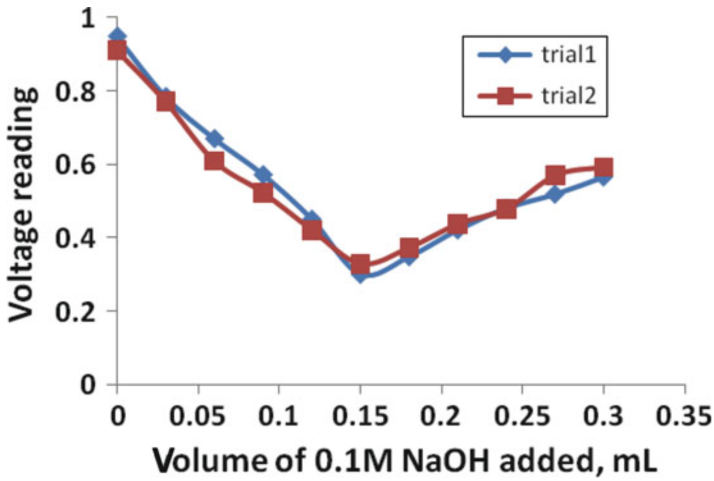


**Fig. 6** Titration curves for 1.5 mL of 0.01 M HCl that was reacted with 0.03 mL increments of 0.1 M NaOH

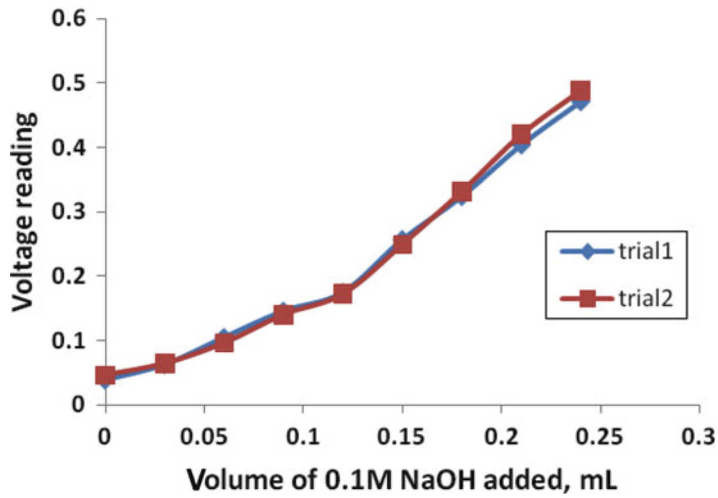


**Fig. 7** Titration curves for 1.5 mL of 0.0922 M $CH_3COOH$ that was reacted with 0.03 mL increments of 0.1 M NaOH

## 4 Conclusions

In this work, a simple portable conductance meter that is convenient to use was developed. The cost of materials used was around $10 (U.S.). The parts are visible to the students, hence the qualifier "clear-box" or "no-box." The clear-box approach demystifies instrumentation principles, but this hypothesis has not been formally assessed yet for this particular instrument. The scope of this work is at the developmental stage only. The instrument has not been used yet in a general chemistry laboratory class, and the effect of its use on the learning of students has not been evaluated. The degree of relative error obtained in the various experiments performed is acceptable for general chemistry courses. It is therefore possible to carry out experiments involving instrumentation in the measurement steps using small amounts of reagents.

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# Introducing Microscale Experimentation in Volumetric Analysis for Pre-service Teachers

**Mashita Abdullah, Norita Mohamed, and Zurida Haji Ismail**

## 1 Research Background

Chemistry is an experimental science and its development and application demand a high standard of experimental work. Experiments are considered a subset of practical or laboratory work that is a didactic method of learning and practicing all the activities involved in chemistry. Hegarty-Hazel (1990) defined laboratory work as a form of practical work taking place in a purposely assigned environment where students engage in planned learning experiences and interact with materials to observe and understand phenomena.

Central to the teaching-learning approach in the chemistry curriculum is the mastery of scientific skills that are comprised of process skills, manipulative skills and thinking skills. Manipulative skills are psychomotor skills used in scientific investigations such as proper handling of scientific equipment, substances, living, and non-living things. Laboratory work also has great potential in promoting positive attitudes and providing students with opportunities to develop skills regarding cooperation and communication (Hofstein, 2004).

The science 1 and science 2 for pre-service teachers (PPISMP) syllabus is designed to enable students to acquire and further their knowledge and understanding of biology, chemistry, and physics equivalent to the Malaysian Higher School Certificate (STPM) level. Both are organized under five main components consisting of biology,

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chemistry, physics, practical science, and mathematics. The course content of science 1 and science 2 are similar to pre-university levels. Completion of science 1 and science 2 offers students a broad and balanced study of science and mathematics, which are needed for a degree program. This syllabus aims to enhance students' knowledge and understanding of biology, chemistry, and physics to enable them to further their studies at a degree level in science and to promote awareness on the role of science in the universe.

Volumetric analysis is one of the important concepts in chemistry that is applied in practical science 1 and 2 for the PPISMP program. It involves an acid–base titration, which is a useful method in chemistry to determine the molarity of a solution, to standardize the solutions, and to determine the molecular mass of an unknown. The manipulative skills involved in this experiment include proper handling of a burette for a titration and also reading the meniscus accurately. Students require the hands-on practical and personal laboratory experiences to acquire these skills. These skills can be gained by the students if each student is wholly responsible for conducting the experiment from start to finish.

However, chemistry practicum classes for PPISMP students are normally conducted in groups of four or five. But participation is limited to only one or two students. Restrictions on resources and time allocated to practical work cause a decline in the extent of practical work done and the standards achieved. This results in a low level of acquisition of scientific skills and knowledge among students. In addition, the traditional style practicum left little room for creativity since opportunities for students to be involved in the activities and the chances to create their own resources were limited.

Microscale chemistry experimentation could help overcome problems associated with the practical activities because this technique allows the students to conduct experiments individually. It is also an environmentally safe technique with a pollution-prevention approach accomplished by using miniature glassware and significantly reduced amounts of chemicals. This study was conducted to introduce microscale chemistry experimentation in the PPISMP practical science syllabus and evaluate the feasibility of conducting microscale chemistry with pre-service students. Findings from this research can be used to measure and evaluate the advantages of applying this approach in pre-service practical science in terms of economical sufficiency, environmental factors, and method precision as well as student feedback.

## 2 Literature Review

Microchemistry is an innovative approach and effective teaching tool. It is carried out by using drastically reduced amounts of chemicals, miniature labware, and safe and easy manipulative techniques. It is an alternative approach to overcome problems associated with practical work because it provides hands-on activities and personal experiences for students. Precision or accuracy of experiments is not compromised and teachers can also use it as a tool to design new lab activities (Bradley, 1999; Cooper, Conway, & Guseman, 1995; Singh, Szafran, & Pike, 1999; Tallmadge, Homan, Ruth, & Bilek, 2004). The UN General Assembly adopted a resolution to observe a UN Decade of Education for sustainable development beginning in 2005. Microscale experiments can contribute by providing quality chemical education with an environmentally safe approach.

Among the benefits of microscale chemistry are improved safety, cost and time savings, environmental friendliness, pollution prevention, more adaptable equipment, and also enhanced chemistry learning (Bradley, 1999; Cooper et al., 1995; Kelkar & Dhavale, 2000; McGuire, Ealy, & Pickering, 1991; National Microscale Chemistry Centre, 1993; Singh et al., 1999; Tallmadge et al., 2004; Vermaak & Bradley, 2003).

Some research in microscale chemistry has focused on titration experiments (Abdullah, Mohamed, & Ismail, 2006; Flint, Kortz, & Taylor, 2002; Patterson, 1998; Richardson, Stauffer, & Henry, 2003; Singh, McGowan, Szafran, & Pike, 1998; Singh, McGowan, Szafran, & Pike, 2000). Findings show that this experiment requires a student to be familiar in handling the microburette. The microburette can give precise measurements up to three decimal places (Patterson, 1998; Singh et al., 1998). The level of uncertainty of this technique is lower than doing titrations by the ordinary method. For an acid base titration, the relative error of the microscale technique is about 0.86%. In terms of precision, the value of relative standard deviation of the microscale technique is 2.0% compared with 1.3% by the traditional technique (Abdullah et al., 2006). The use of the microburette in general and analytical chemistry as illustrated by results from acid–base, oxidation-reduction, precipitation, complexometric, and pH titrations has also been proven to be as accurate as the traditional technique (Singh et al., 2000).

## 3 Research Objectives

The main purpose of this study is to introduce microscale chemistry experimentation in accordance with experiments found in the PPISMP practical science manual and evaluate the feasibility of conducting microscale chemistry with pre-service students. The objectives of the study include:

1. To introduce microscale chemistry volumetric analysis experiments for PPISMP students that correspond to traditional macroscale experiments.
2. To compare between microscale and macroscale volumetric analysis experiments in terms of precision of results obtained, cost of apparatus, time needed (duration), and amount of waste produced.
3. To investigate students' preferences in using the microscale and traditional technique.

# 4 Methodology

This study was conducted at the Institute of Teacher Education, Ipoh Campus with students enrolled in the PPISMP program, in particular, science 1, semester 2 classes. This study applied the survey method: students were exposed to microscale chemistry volumetric analysis experiments and an evaluation questionnaire was administered to the students. The sample consisted of 39 students from the J14 and J15 groups of students who did both the traditional version and microscale version of the volumetric analysis experiments. They conducted both macro and micro experiments in pairs (groups of two). The micro version used a 2-mL plastic micro-burette for volume measurement instead of a 50-mL glass burette. It used a plastic multiple-well plate as a titration container instead of a conical flask (glassware) (Fig. 1). The chemicals used in these analyses were scaled down by a factor of 100.

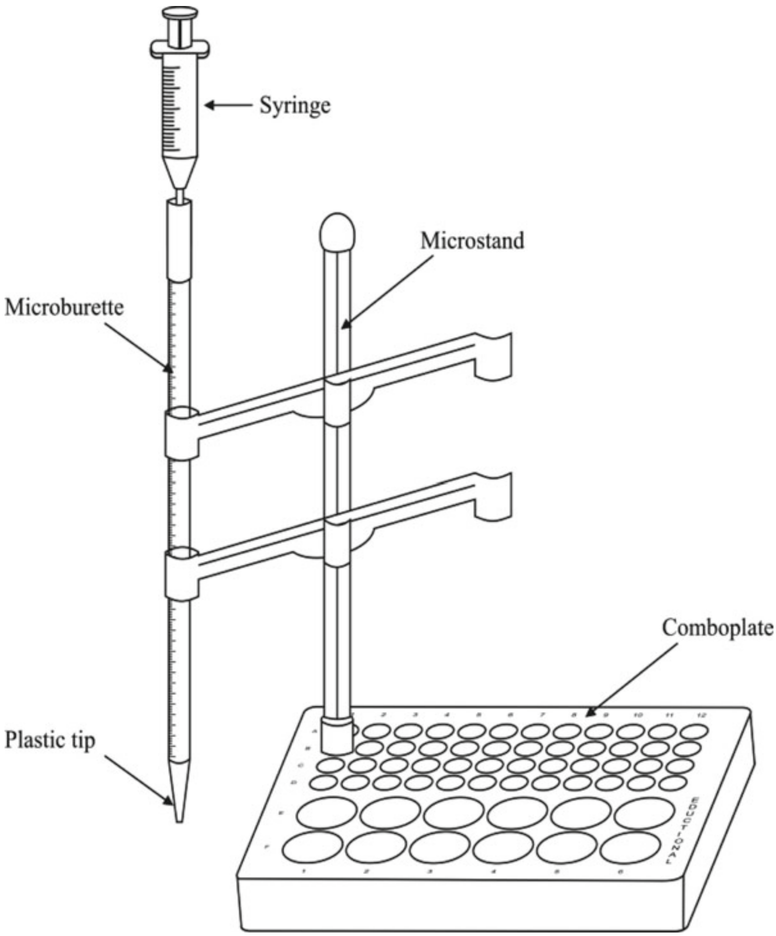


**Fig. 1** Microtitration set-up

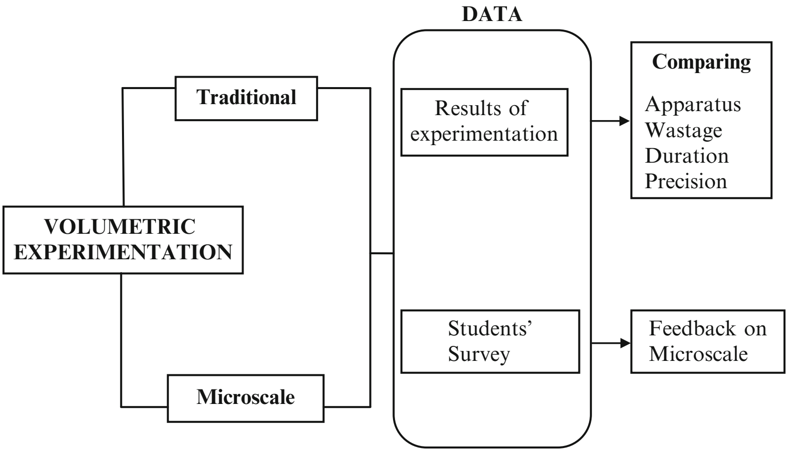


**Fig. 2** Working framework on volumetric experimentation using microscale and traditional methods

For this analysis, 0.5 mL rather than 50 mL of iodine solution was used. Comparisons were made between traditional methods of analyses and analyses using a microscale approach in terms of cost of apparatus used, waste produced, and time duration as well as the precision and accuracy of the results obtained.

During the lab session, time taken for the students to conduct both the macro and micro experiments was recorded. The waste produced also was recorded as all groups were asked to put all the titration waste in a large container. The precision of the results was calculated based on the volume of titer recorded for all groups.

To gauge whether the students preferred microscale or macroscale experiments, a questionnaire was administered. The questionnaire consisted of nine items related to perceptions towards microscale chemistry experiments (Vermaak, 1997). Questionnaire items were responded to according to a 5-point Likert scale including "strongly disagree," "disagree," "not sure," "agree," and "strongly agree." To score the scale the response options were coded 1, 2, 3, 4, or 5 according to the responses from strongly disagree to strongly agree. The data for perception towards microscale experiments were reported in terms of frequencies, mean values, and standard deviation for each individual item. The reliability value, Cronbach's α for the perception towards microscale experiments, is 0.81. Open-ended comments were analyzed and reported qualitatively. The student evaluations on microscale experiments also were reported qualitatively.

## *4.1 Working Framework*

Figure 2 illustrates the working framework on the volumetric experimentation.

## 5 Findings and Discussion

This study was conducted with 39 students who worked in pairs for the traditional setting and microscale setting of the volumetric experiment. Each pair of students performed a titration at least three times and an average of the value was calculated.

Table 1 shows a comparison between the traditional and microscale volumetric experiment in terms of cost of apparatus used, waste produced, and time duration. The traditional approach required about Malaysian Ringgit (MYR) 136.80 worth of apparatus, produced about 3,400–3,500 mL of waste and required about 75 min to complete the volumetric experiment. On the other hand, the microscale approach required only about Malaysian Ringgit (MYR) 25 worth of apparatus, produced about 25–30 mL of waste and required about 30 min to complete the experiment. It took less time to reach the end point using the microscale technique compared to the traditional technique (Abdullah, Ismail, & Mohamed, 2005; Singh et al., 2000). Table 1 shows that use of the microscale titration apparatus can reduce the cost of apparatus by 82%, reduce waste by 99%, and save up to 60% of time compared with the volumetric analysis experiment.

Relative standard deviation (RSD) is a measure of precision, sometimes called coefficient of variation (CV), and often is calculated as a percentage. To estimate the precision of microscale titrations, the titration data obtained by the students using the microburette is compared with data obtained using a 50 mL burette. The average titer from students' data of the titration were used. The value of RSD of the microscale technique is 16.7% compared with 10.1% for the traditional technique. This indicates that the data obtained with the 50 mL burette is comparable with those obtained using the microburette. The use of the microburette in general and analytical chemistry has been proven to be as accurate as the traditional technique (Singh et al., 2000).

Student perceptions toward the microscale chemistry experiments are presented in Table 2. The mean values for positive items, 1.2, 1.3, 1.6, 1.7, 1.8, and 1.11, ranged from 3.42 to 4.28. The values showed a trend closer to 4 and above. This indicates that students agreed that by doing the experiments individually, they understood the concepts better. They were also keen to do more experiments and perceived that microscale experiments were fun and could be done quickly. These findings are also supported by many researchers who found that conducting experiments with microscale techniques promoted time savings (Bradley, 1999; Kelkar & Dhavale,

**Table 1** Cost of apparatus, waste produced and time duration (per 20 students)

| | Methods | | |
|---|---|---|---|
| Parameters | Traditional | Microscale | Reduction (%) |
| Cost | RM 136.80 | RM 25 | 82 |
| Time | 75 min | 30 min | 60 |
| Waste | 3,400–3,500 mL | 25–30 mL | 99 |
| Precision (%RSD) | 10.1% | 16.7% | Acceptable |

**Table 2** Students' perceptions toward microscale chemistry experimentation

| Number of item | Perception toward microscale chemistry experiment | Percentage of responses (%) Disagree/Strongly disagree | Unsure | Agree/Strongly agree | Mean | S.D |
|---|---|---|---|---|---|---|
| 1.1 | It is difficult to handle the microscale equipment | 60.5 | 26.3 | 13.2 | 2.447 | 0.828 |
| 1.2 | Doing the experiment myself makes me understand the experiment and concepts better | 5.3 | 2.6 | 92.1 | 4.289 | 0.768 |
| 1.3 | I was interested in doing microscale experiments | 5.2 | 13.2 | 81.5 | 4.105 | 0.928 |
| 1.4 | The results of microscale experiments are not observed easily | 26.3 | 36.8 | 36.9 | 3.078 | 1.039 |
| 1.5 | I was afraid to try out these microscale experiments | 65.7 | 18.4 | 15.8 | 2.210 | 1.044 |
| 1.6 | The experiments could be done quickly | 29.0 | 15.8 | 55.3 | 3.421 | 1.246 |
| 1.7 | It was fun to do the microscale experiments | 5.2 | 10.5 | 84.2 | 4.184 | 0.926 |
| 1.8 | I am keen to do more microscale experiments | 7.9 | 15.8 | 76.3 | 4.026 | 0.999 |
| 1.9 | Microscale experiments are not real experiments | 68.5 | 28.9 | 2.6 | 2.210 | 0.704 |
| 1.10 | Microscale chemistry equipment is a cheap version: we should use the real equipment | 52.7 | 15.8 | 31.6 | 2.736 | 1.388 |
| 1.11 | I like to do microscale experiments | 7.9 | 21.1 | 71.1 | 3.868 | 0.875 |

2000; McGuire et al., 1991; Singh et al., 1999; Tallmadge et al., 2004; Vermaak & Bradley, 2003).

The mean values for items 1.1, 1.4, 1.5, 1.9, and 1.10 ranged from 2.21 to 3.07. The values showed a trend closer to 3 and lower. This indicated that students agreed that the microscale equipment was not difficult to handle, results of the experiments were observed easily, and that they were not afraid to try out the experiment. They also did not agree that the microscale experiments were not real. In this context, real means using ordinary traditional glassware apparatus.

The students also understood the experiments and concepts better by doing experiments individually. These findings are supported by Vermaak (1997), who reported high positive mean values for African pupils' perceptions of handling and managing microscale experiments. These students reported that microscale experiments were beneficial, fun to do, and made them enjoy practical work. In contrast, McGuire et al. (1991) found a persistent preference for macro experiments over microscale experiments. However, his findings are limited.

All students were asked their preferences in relation to the titration apparatus used in practical work (i.e., traditional or microscale apparatus). The responses indicated that most of the students preferred to conduct titration using the microscale titration apparatus. But, McGuire et al. (1991) reported that among the three microscale experiments, microtitration was particularly disliked by the students. The students involved in this study suggested that, in certain circumstances, this approach could teach them to be more careful in order to get more accurate results.

The comments from the students indicate that most of them had a positive view toward microscale chemistry experiments. Some of the positive responses from students included:

- *Saves time (7)*
- *Saves cost (7)*
- *Avoid waste of chemicals (6)*
- *Interesting because the equipment is small and easy to handle (4)*
- *Results were much more consistent (3)*
- *More careful in handling apparatus (3)*
- *Teach us how to be patient (2)*
- *Can repeat the experiment (2)*
- *Simple and easy to handle (2)*
- *Convenient (2)*
- *Safer to handle (1)*
- *All have opportunities to do the experiment (1)*
- *Help to learn better (1)*

The negative views included having difficulties in handling the microburette and readings requiring more time or skill. Conversely, these same points may encourage students to do experiments carefully and patiently. Kelkar and Dhavale (2000) reported that undergraduate students performed experiments with more care and their skills in handling the equipment were markedly improved after adoption of this new technique in their laboratory.

Examples of the negative comments from students involved in this study were:

- *Very difficult to handle because equipment so sensitive (6)*
- *Hard to measure quantitative data (2)*
- *Difficult to take the reading (2)*
- *Need a lot of time (2)*
- *Difficult but enjoyable (1)*
- *Need a lot of patience (1)*

## 6 Conclusions and Implications

Microscale titration can reduce the cost of apparatus by as much as 82%, reduce waste by 99%, and save up to 60% of the time spent on volumetric analysis experiments. The precision of this technique is acceptable. Overall, the students strongly supported this new approach. The students agreed that by doing the experiments individually, they could understand the experiments and concepts better. They also indicated their preference for microscale experiments and their interest in doing more experiments. They also perceived that microscale experiments were fun and could be done quickly. Despite having difficulties in handling the microtitration apparatus and taking the readings, and requiring more time, the students still perceived that this approach could make them more careful and patient in doing experiments. With the microscale approach, students should be able to perform volumetric analysis in pairs or individually. The microscale titration technique can be promoted to practical chemistry for the Malaysian Pre-service teachers (PPISMP) program based on the positive findings of this study and on the evaluation of this technique by students.

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# Innovative Techniques in Microscale Chemistry Experiments

**Kwok Man Chan**

## 1 Introduction

Innovation of techniques in practical chemistry at the school level has not been an issue, compared with the university or research levels. Recent worldwide promotion of adopting microscale approaches has prompted numerous publications on school-level microscale chemistry experiments. These instrument-based innovations depend heavily on school curricula and kits produced commercially and may not meet the requirements of individual public examination boards. Techniques, instead of instruments, seem to be a more universal area of effective innovation. In fact, these unique techniques stemming from newly designed microscale equipment are simple, designed based on elementary principles, and capable of enhancing student motivation in performing experiments. They also serve as tools for better understanding of chemistry principles.

## 2 Method

This chapter discusses three techniques developed by the author over years of promotion of microscale improvement of school-level chemistry experimentation. An illustrative experiment is included for each proposed technique. These missed techniques originated from traditional school chemistry, which most teachers are familiar with. Hence, reference to literature cited will not be included except for the "shake-down" technique. However, sources for obtaining relevant instruments will be provided.

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# 3 "1248" Technique

## 3.1 *Experiment: Microscale Iodine Clock Reaction Using the "1248" Technique*

This experiment is based on the traditional iodine clock reaction in studying the kinetic order of the reaction between iodide ions and hydrogen peroxide solutions in acidic medium. Essentially, time for the sudden appearance of blue color is determined in sequence by performing four experiments with reactant concentrations varying in a ratio of 1:2:4:8 at the same time altogether and not performed separately, as all traditional experiments do. The experiment requires the use of 8-well reaction strips and the "shake-down" technique (Ehrenkranz & Mauch, 1990).

## 3.2 *Theory*

The kinetics of the reaction:

$$2I^-(aq) + H_2O_2(aq) + 2H^+(aq) \rightarrow I_2(aq) + 2H_2O(l)$$

can be investigated by the addition of a small and fixed amount of $S_2O_3^{2-}$(aq) and starch indicator.

$$\begin{aligned} H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) &\rightarrow I_2(aq) + 2H_2O(l) \text{..........} \textit{main reaction} \\ 2S_2O_3^{2-}(aq) + I_2(aq) &\rightarrow S_4O_6^{2-}(aq) + 2I^-(aq) \text{......} \textit{monitor reaction} \\ \text{Starch solution} + I_2(aq) &\rightarrow \text{blue complex} \text{..................} \textit{indicator reaction} \end{aligned}$$

The added $S_2O_3^{2-}$(aq) consumes the $I_2$(aq) produced from the *main reaction*. As long as there are $S_2O_3^{2-}$(aq) ions in the reaction mixture, $I_2$(aq) formed from the main reaction will be instantaneously consumed by the $S_2O_3^{2-}$(aq) ions and the starch indicator will not be affected. However, when all $S_2O_3^{2-}$(aq) ions are consumed, $I_2$(aq) starts to form and will immediately turn the starch indicator deep blue. The time elapsed before the development of the blue color (dependent variable) depends on the amount of $S_2O_3^{2-}$(aq) used. The greater the amount of $S_2O_3^{2-}$(aq) used, the longer will be the time taken for the development of color.

Order w.r.t. $I^-$(aq) will be investigated by keeping concentrations of $H_2O_2$(aq) and $H^+$(aq) constant while varying the concentration of $I^-$(aq) in the ratio of 1:2:4:8 (independent variable). If the ratio of (1/t) doubles each time, the order of reaction w.r.t. to $I^-$(aq) will be determined as 1. If the ratio of (1/t) remains unchanged, the order can be regarded as zero. The experiment is then repeated for determining orders for $H_2O_2$(aq) and $H^+$(aq).

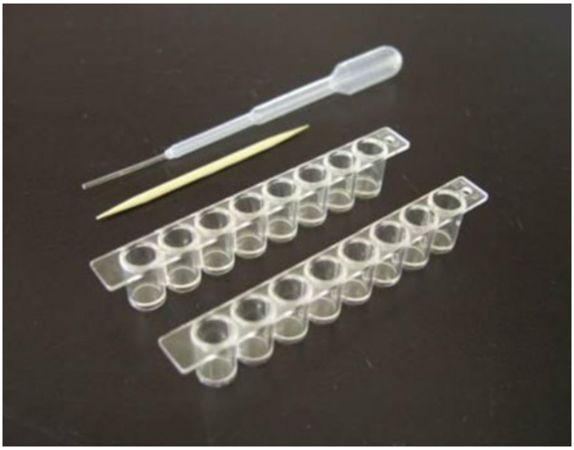


**Fig. 1** Size of 8-well reaction strip

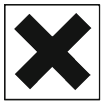
*Safety*

Wear safety glasses and avoid skin contact with the chemicals. Dispose of chemical waste and excess materials properly.

EYE PROTECTION MUST BE WORN

*Materials and Apparatus*

About 20 cm$^3$ of each of the following solutions in labeled plastic bottles:



HARMFUL/ IRRITANT

0.60 M $H_2SO_4$(aq), 0.60 M KI(aq), 1.50% $H_2O_2$(aq).
0.08 M $Na_2S_2O_3$(aq), starch solution, deionized water.
Two 8-well reaction strips, micro-tip plastic pipette, stop watch, micro-stirrer or toothpicks (unbleached).

*Experimental Procedure*

(A) Kinetic order w.r.t. iodide ion

1. Using a fresh and clean micro-tip pipette, transfer 1 drop each of 1.5% $H_2O_2$(aq), 0.6 M $H_2SO_4$(aq) and starch indicator solution to 4 separate wells of an 8-well reaction strip (call it strip A) so that each well has a total volume of 3 drops.
2. Take another 8-well reaction strip (call it strip B), again using a fresh and clean micro-tip pipette, transfer 1 drop of 0.08 M $Na_2S_2O_3$(aq) to each of the first 4 wells (Fig. 1).
3. Into the same 8-well reaction strip, place 1 drop of 0.6 M KI(aq) to the first well, 2 drops to the second, 4 drops to the third, and 8 drops to the fourth. Add 7 drops of deionized water to the first well, 6 drops to the second, and 4 drops to the third so that the total volume of reactant mixture in each of the 4 wells of strip B is 9 drops (see Table 1).

**Table 1** Filling scheme (order w.r.t. $I^-$(aq))

| | Number of drops | | | | | |
|---|---|---|---|---|---|---|
| | Strip A | | | Strip B | | |
| Well | $H_2O_2$(aq) | $H_2SO_4$(aq) | Starch solution | $I^-$(aq) | $H_2O$(l) | 0.08 M $S_2O_3^{2-}$(aq) |
| 1 | 1 or 2 | 1 | 1 | 1 | 7 | 1 |
| 2 | | | | 2 | 6 | |
| 3 | | | | 4 | 4 | |
| 4 | | | | 8 | 0 | |

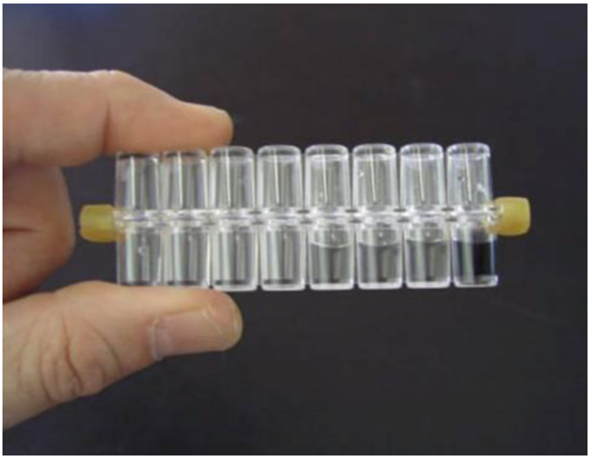


**Fig. 2** The "shake-down" technique

4. Stir the solution mixture in each of the wells of strip B with micro-stirrer or toothpick (unbleached).
5. Invert strip B and stack it atop strip A so that the first 4 wells of strip B are directly above the first 4 wells of strip A.
6. Hold the two strips firmly together by means of two small pieces of rubber tubing, one at each end, and lower the strip combination suddenly ("shake-down" technique) so that the two solution mixtures mix thoroughly (see Fig. 2). Start the stop watch at the same time.
7. Turn the strip combination upside down repeatedly and look for the sudden appearance of a deep blue color. Record the time taken. Carry on recording time until all 4 wells have developed color in the correct sequence.
8. Clean the reaction strips thoroughly with deionized water and empty the water in the wells.

(B) Kinetic order w.r.t. $H_2O_2$

9. Repeat steps (1) to (8) according to Table 2.

(C) Kinetic order w.r.t. $H^+$

10. Repeat steps (1) to (8) according to Table 3.

**Table 2** Filling scheme (order w.r.t. $H_2O_2$(aq))

| | Number of drops | | | | | |
|---|---|---|---|---|---|---|
| | Strip A | | | Strip B | | |
| Well | $I^-$(aq) | 0.08 M $S_2O_3^{2-}$(aq) | Starch solution | $H_2O_2$(aq) | $H_2O$(l) | $H_2SO_4$(aq) |
| 1 | 1 or 2 | 1 | 1 | 1 | 7 | 1 |
| 2 | | | | 2 | 6 | |
| 3 | | | | 4 | 4 | |
| 4 | | | | 8 | 0 | |

**Table 3** Filling scheme (order w.r.t. $H^+$(aq))

| | Number of drops | | | | | |
|---|---|---|---|---|---|---|
| | Strip A | | | Strip B | | |
| Well | $I^-$(aq) | 0.08 M $S_2O_3^{2-}$(aq) | Starch solution | $H_2SO_4$(aq) | $H_2O$(l) | $H_2O_2$(aq) |
| 1 | 1 or 2 | 1 | 1 | 1 | 7 | 1 |
| 2 | | | | 2 | 6 | |
| 3 | | | | 4 | 4 | |
| 4 | | | | 8 | 0 | |

*Results* (Solution temperature = 19 °C)

| Variable | Relative concentration | t (s) | Rel. initial rate, 1/t ($s^{-1}$) | Order |
|---|---|---|---|---|
| [$I^-$(aq)] | 1 | 104 | $9.6 \times 10^{-3}$ | 1 |
| | 2 | 55 | $1.8 \times 10^{-2}$ | |
| | 4 | 28 | $3.6 \times 10^{-2}$ | |
| | 8 | 14 | $7.1 \times 10^{-2}$ | |
| [$H_2O_2$(aq)] | 1 | 115 | $8.7 \times 10^{-3}$ | 1 |
| | 2 | 58 | $1.7 \times 10^{-2}$ | |
| | 4 | 29 | $3.4 \times 10^{-2}$ | |
| | 8 | 14 | $7.1 \times 10^{-2}$ | |
| [$H^+$(aq)] | 1 | 102 | $9.8 \times 10^{-3}$ | – |
| | 2 | 72 | $1.4 \times 10^{-2}$ | |
| | 4 | 51 | $2.0 \times 10^{-2}$ | |
| | 8 | 26 | $3.8 \times 10^{-2}$ | |

Because the "shake-down" mixing method is not as effective as conventional pouring and stirring, repeated "shake-down" is necessary to achieve a close to homogeneous solution mixture. Thus, each run has to be repeated two or three times to obtain concordant results.

For both variations of $I^-$(aq) and $H_2O_2$(aq), doubling the concentration also doubles the reaction rate. The reaction is therefore first order with respect to $I^-$(aq) and to $H_2O_2$(aq).

The figures for the $H^+$(aq) ion variation showed no strong indication for a first-order or a zero-order kinetics with respect to $H^+$(aq).

### 3.3 Discussion

(i) *Advantages in using the microscale technique.*
Besides the usual advantages enjoyed by performing an experiment in small scale, the following three advantages cannot possibly be achieved by conventional methods:

(a) The first has to do with expressing relative concentration in terms of number of drops of reagent rather than actual concentration in mol $dm^{-3}$. This greatly simplifies calculations.
(b) The second is that the experiment allows four kinetic runs to be performed at the same time instead of spending time on four different experiments. This shortens the time required for each order determination to as little as 1 min.
(c) The layout of the experiment enables students to understand the aim more coherently as order determinations are completed with minimal steps.

(ii) *The "1248" Method.*
The method offers a *non-graphical* approach to study reaction kinetics. Judging from the name of the method, it literally means varying the concentration of the reacting species according to a ratio of 1:2:4:8, or doubling the concentration of the species in succession. If the observed reaction rates also increase in the same order, (i.e., 1:2:4:8) then the kinetic order of the reaction with respect to the species must be one. On the other hand, if the observed reaction rates increase according to a ratio of $(1)^2$: $(2)^2$ : $(4)^2$: $(8)^2$, then the kinetic order of the reaction with respect to the species should be two. Lastly, if the reaction rate is insensitive to change in concentration, the reaction is obviously of zero order with respect to the species.

(iii) *Sources of materials.*
The crucial apparatus of the experiment is the 8-well reaction strip. Strips employed should be small enough so that contained liquids will not drop when they are turned upside down. The 8-well reaction strips offered by *MicroChem Lab* can be used in this experiment.

(Websites: www.mcl.hk)

Micro-tip plastic pipettes are available from the same supplier.

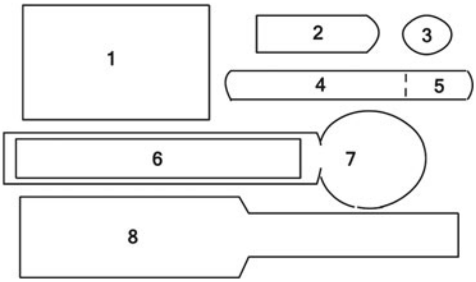
## 4 "CDS" (Collection of Distillate at the Source) Technique

Traditional distillation setup collects distillate at a certain distance from the boiling source, and this results in loss of product, which can be serious if the microscale method is used. By using special microscale instruments, it is possible to collect distillate immediately after vapor condensation at the boiling source. This is the rationale of designing the "CDS" technique. Setup used not only significantly improves product yield, but cooling water used for condensation can be recycled or not used at all for cooling. This offers a helpful means to enhance students' "Green awareness." Two modes of "CDS" using different innovative designs are introduced in the following two experiments.

The technique is illustrated by Experiment (A) and Experiment (B).

### 4.1 *Experiment (A): Preparation of Ethyl Ethanoate Using Microscale Waterless Reflux and Distillation*

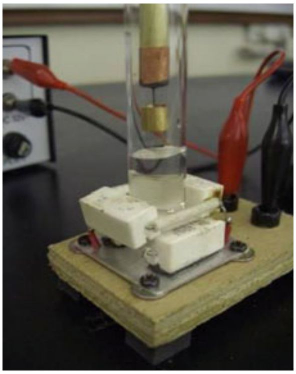
The Instrument – Microscale Distillation Set




| Label | Description |
|---|---|
| 1 | Micro-heater, a non-naked flame electrical heating device, made from arrays of resistors. |
| 2 | "Distillation Cap" An innovative device to collect distillate. When plugged into the cooling stick of the "Cold Stick," it can collect condensed distillate.  3 "Cold Ring" A simple circular sponge with a central hole to fit a small test tube. Acts as a simple cooling device when it is wetted with cold water.  |
| 4 | Small test tube 5 Silicone rubber teat 6 Pasteur pipette |
| 7 | Digital thermometer "Summit 310" |
| 8 | "Cold Stick" It is a kind of "cold finger." A special coolant, taken from commercial "Blue ice box" chillers commonly used for picnics, is housed in acrylate (transparent plastic) cylinders. The coolant encloses a brass rod for heat conduction – the "cold finger." Prior to the experiment, it is placed overnight in a freezer for prolonged cooling.  |

*Arrangements for (i) reflux, (ii) distillation and (iii) b.p. determination*


Reflux



Distillation

B.p. determination

*Experimental Procedure*

1. Determine the mass of an empty test tube.
2. Using a large plastic pipette, place 40 drops of ethanol into the test tube and determine the combined mass.
3. Add 60 drops of ethanoic acid to the same test tube followed by 3 drops of concentrated sulfuric acid. Add a small spatula measure of fine anti-bumping granules.
4. Clamp the setup and lower it into the micro heater. Switch on the low-voltage power supply. Clamp the "Cold Stick" and lower it into the test tube until the end of the brass stick is about 1 cm above the surface of the solution mixture. Reflux for 15 min.
5. Remove the test tube and its content, add 3 $cm^3$ 4 M NaOH(aq). Shake well and allow to settle. Withdraw the *top* organic layer by a large pipette and deliver it to another test tube.
6. Add enough spatula measures of solid calcium chloride and arrange for microscale distillation. Using the Pasteur pipette, collect *all* the ester, deliver it to a small test tube, and determine the mass collected.
7. Transfer some of the ester distillate to a small test tube and determine its b.p.

*Results*

$$\underset{46}{C_2H_5OH} + \underset{60}{CH_3COOH} \rightleftharpoons \underset{88}{CH_3COOC_2H_5} + H_2O$$

Mass of ethanol = 0.64 g
No. of mole of ethanol = 0.64/46 = 0.0139
Mass of ethyl ethanoate collected = 0.66 g
No. of mole of ethyl ethanoate = 0.66/88 = 0.0075
% yield of ethyl ethanoate = (0.0075/0.0139) × 100% = 54%
b.p. of ethyl ethanoate = 74.0 °C (Literature value: 78.3 °C)

As the ester produced has a lower b.p. than expected, it may contain some ether as impurities.

**Fig. 3** "Green Distelector" setup

### 4.2 *Experiment (B): "Green Distelector" and Ester Preparation*

The instrument –"Green Distelector"

"Green Distelector"("Distelector" means distillate collector) uses the same "CDS" technique as the Microscale Distillation Set. Instead of employing a brass"Cold Stick," an all-glass devise is used to reflux and collect distillate.

As shown in Fig. 3, water for cooling does not come from the water tap but from a pool of cold water contained in a plastic box. A small aquarium pump is used to inject water into the "Green Distelector." Used water is directed back to the plastic box and recycled.

The mechanism of vapor condensation is illustrated in Fig. 4. A small glass inverted L delivery tube, which accepts cold water, is joined to a T tube with a water outlet. Continuous flow of cold water in the combination offers an effective device for condensing vapor. A small glass cylindrical container with a hook attaching to the ring of the base of the T tube (Fig. 5) collects distillate. The setup is then placed inside an ordinary test tube (Fig. 6). Cold water from a plastic box is forced into the inverted L tube by a small aquarium pump. It then flows through the T tube and returns to the box through the outlet of the T tube. A hot sand bath is used to start the organic reaction (Fig. 7).

*Experimental Procedure*

Essentially, this is the same experimental procedure as that of Experiment (A), except for the refluxing and distillation procedures, which are illustrated in the earlier paragraph.

**Fig. 4** Inverted L tube and T tube combination

**Fig. 5** The base of the T tube has a glass ring that attaches to a small cylindrical container with a hook

**Fig. 6** Test tube, inverted L tube, and T tube with small cylindrical container combination

**Fig. 7** Sand bath and "Green Distelector" setup

# 5 "Known Sample Calibration" or "Dual Experiment Calibration" Technique

By referring to literature value of standard heat of combustion instead of specific heat capacity, and duplicating the experiment with a known sample, a value of standard heat of combustion of an experimental alkanol can be determined accurately, which corrects practically all heat loss to the surroundings.

## *5.1 Experiment: Heat of Combustion of Propan-1-ol*

*Purpose*

To determine the Standard Enthalpy of Combustion of propan-1-ol.

*Introduction*

Alkanol burns in excess of air to form carbon dioxide and water. Heat also evolves (e.g., complete combustion of propan-1-ol):

$$2C_3H_7OH(l) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(g) H = -2020 \text{ kJ mol}^{-1}$$

A simple homemade calorimeter can be used to determine the molar enthalpy change of combustion of propan-1-ol. A fixed small amount of the alcohol is burnt in air to heat up an aluminum block. The increase in temperature of the metallic block is measured and is used to calculate the molar enthalpy change of combustion of propan-1-ol, using the formula $\Delta H = (ms)\Delta t$.

Heat capacity of the calorimeter (i.e., ms) is not calculated from a literature value of the specific heat capacity (i.e., s) of aluminum and a knowledge of the mass of the aluminum block, but is derived from an experimental calibrated value using a known value of the molar enthalpy change of combustion of ethanol. The experiment involves a prior calibration of the heat capacity of the aluminum block by burning ethanol. The calibration step eliminates essential errors like major heat loss to the surroundings and incomplete combustion.

*Materials and Apparatus*

Ethanol, propan-1-ol

HARMFUL/
IRRITANT

Aluminum block calorimeter, small cylindrical glass vessel, digital thermometer, Pasteur pipette, top pan electronic balance (resolution ± 0.01 g) or equivalent conventional triple beam balance, lighter.

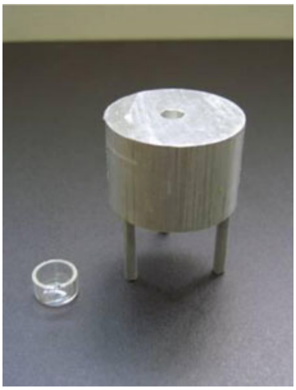
## Experimental Procedure

*Part I Calibration of the aluminum calorimeter*

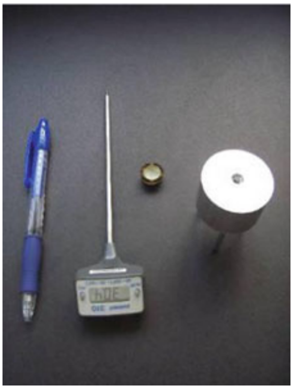
1. Using a Pasteur pipette, transfer 10 drops of ethanol to the small glass vessel and determine the mass of the ethanol.
2. Determine the initial temperature of the aluminum block.
3. Switch on the lighter and start to burn the ethanol. Wait until all the alcohol has burned completely. Determine the highest temperature reached.
4. Cool the aluminum block by immersing it under water at room temperature.

*Part II Combustion of propan-1-ol*

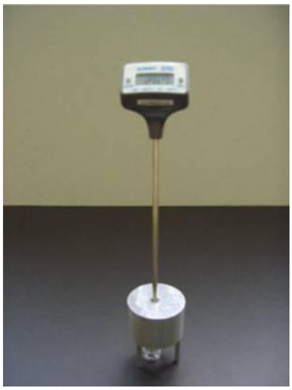
1. Using a Pasteur pipette, transfer 10 drops of propan-1-ol to the small glass vessel and determine the mass of the propan-1-ol.
2. Determine the initial temperature of the aluminum block.
3. Switch on the lighter and start to burn the propan-1-ol. Wait till all the alcohol has burned completely. Determine the highest temperature reached.



Aluminum block calorimeter and small glass vessel



Size of aluminum block calorimeter and digital thermometer



Experimental set-up

Results

*Part I*

Mass of ethanol = 0.0875 g
Initial temperature of Al block = 28.9 °C
Final temperature of Al block = 40.0 °C

*Part II*

Mass of propan-1-ol = 0.0925 g
Initial temperature of Al block = 28.8 °C
Final temperature of Al block = 43.7 °C

Calculation

*Part I*

Increase in temperature of aluminum block = (40.0 − 28.9) = 11.1 °C
Literature value of standard enthalpy of combustion of ethanol = −1,300 kJ $mol^{-1}$
Molar mass of ethanol, $C_2H_5OH$ = 46 g $mol^{-1}$
According to $\Delta H = (ms)\Delta t$

$$\text{Heat capacity of the Al block} = (ms) = \frac{\Delta H}{\Delta t}$$
$$= \frac{1300x1000}{11.1} x \frac{0.0875}{46}$$
$$= 222.8 J°C^{-1}$$

*Part II*

Increase in temperature of aluminum block = (43.7 − 28.8) = 14.9 °C
Molar mass of propan-1-ol, $C_3H_7OH$ = 60 g $mol^{-1}$
Standard enthalpy of combustion of propan-1-ol = $\Delta H = (ms)\Delta t$

$$= (222.8)(14.9)(\frac{60}{0.0925})\ J\ mol^{-1} = 2153 kJ\ mol^{-1}$$

Literature value of standard enthalpy of combustion of propan-1-ol = −2,020 kJ $mol^{-1}$

$$\text{Percentage error} = \left(\frac{2153 - 2020}{2020}\right) \times 100\% = 6.6$$

## Reference

Ehrenkranz, D, & Mauch, J (1990). *Chemistry microscale*, Kendall/Hunt. 2460 Kerper Boulevard, P.O. Box 539 Dubuque Iowa 52004–0539this figure will be printed in b/wthis figure will be printed in b/wthis figure will be printed in b/w

# Microscale Experiment on Decreases in Volume When Forming Binary Liquid Mixtures: Four Alkanol Aqueous Solutions

**Tetsuo Nakagawa**

## 1 Introduction

The basic physicochemical properties such as mass, number, amount of substance, volume, and their combinations (e.g., density = mass/volume, number density = number/volume, molar volume = volume/amount of substance, and molar mass = mass/amount of substance) are a necessary part of teaching the unit on solution chemistry containing dissolution, solvation, solubility, concentration, solute-solvent interaction in solution, phase diagram, colligative properties such as freezing point depression, boiling point elevation and osmotic pressure, partial molar volume, and so forth for high school (e.g., Carmichael, 2010; Deters, 2008; Inoguchi et al., 2010a; Nakagawa, 1998; Nomura et al., 2007; Umezawa et al., 2007) and university first grade (e.g., Brady & Holum, 1993; Inoguchi et al., 2010b; Nakagawa, 2000, 2010) chemistry classes. Therefore, it is of great importance that the characteristics of respective properties are well understood by students when they begin to learn the concept of solution.

The simple model of binary liquid mixture is shown in Fig. 1. Here, open and solid circles represent components 1 (solute) and 2 (solvent) respectively, and in real liquid mixtures both are different in size and shape. Intermolecular interactions between 1–1, 2–2, and 1–2 are also different, and consequently volumes in liquid mixtures are not equal to the estimated ones from their components on the

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DOI 10.1007/978-94-007-4860-6_29, 

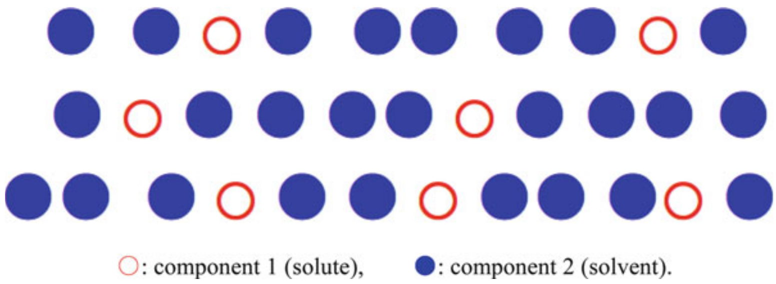



**Fig. 1** Simple model of binary liquid mixture (binary solution). ○: component 1 (solute), ●: component 2 (solvent)

supposition that the solutions are ideal. That is, the volumes of liquid mixtures are smaller or larger than the total volumes of their components, and binary liquid mixtures are a more convenient means for students to understand the nonadditivity of volume when forming liquid mixtures. For example, it is well known that the volumes of aqueous ethanol solutions are smaller than those of ethanol and water in the whole concentration range. When 50 mL of ethanol is mixed with 50 mL of water at room temperature and atmospheric pressure, the volume of their mixture shows 96–97 mL and never 100 mL (Nakagawa, 2003). Indeed this procedure appears in some references (Petruševski & Najdoski, 2001; Shakhashiri, 1989; Summerlin, Borgford, & Ealy, 1987) on chemical demonstrations, but much ethanol is needed and the cost is too high for this demonstration to be performed in a chemistry class.

Instead of the customary expensive methods, we propose an alternative to demonstrate the decrease in volumes when forming four alkanol (methanol, ethanol, 1-propanol, and 2-propanol) aqueous solutions. These microscale (or small-scale) experiments and their theoretical calculations from experimental data are described next.

There are many advantages to microscale experiments: they are easy, fast, safe, cost-effective, and environmentally friendly. Therefore, we try to develop teaching materials for the decrease in volume using microscale experiments. In place of 100-mL large graduated cylinders for chemical demonstrations or ordinary experiments, a 10-mL graduated cylinder with a glass stopper for water and a 5-mL one for alkanol are used.

Previously, microscale experiments involved mixing 5.00 mL of ethanol and 5.00 mL of water (Nakagawa, 2007). However, in the present work, we use less volume: mixing 3.00 (or 2.00) mL of each alkanol with 3.00 (or 2.00) mL of water. Consequently, the volumes of alkanols and water are reduced, and the observed volumes of alkanol aqueous solutions are obtained.

We calculate the volumes of binary liquid mixtures from their densities or their excess molar volumes theoretically. Although these calculations are simple, their derivative process has never appeared in textbooks and papers on chemical education. Hence, here we introduce this method and its appropriateness. Using this method, the calculated volumes of alkanol aqueous solutions are easily obtained. Our procedure is useful partially because the observed volumes using microscale experiments can be compared with the calculated ones, and partially because the volumes of liquid mixtures can be obtained without doing experiments if the data on densities or excess molar volumes are available.

The details on microscale experiments and theoretical calculations will be revealed in the following sections.

## 2 Observed Volumes Using Microscale Experiments

### *2.1 Materials*

Methanol, ethanol, 1-propanol, and 2-propanol (>99.5%) were purchased from Wako Pure Chemicals Industries, Ltd. and were used without further purification. Distilled water was prepared using the ADVANTIC automatic water distillation apparatus RFD240NA.

### *2.2 Procedure*

Before performing microscale experiments, a 5-mL graduated cylinder 1 and a 10-mL graduated cylinder 2 were rinsed with ethanol and distilled water respectively. First, 3.00 mL of distilled water (component 2, solvent) was placed in cylinder 2 with a glass stopper and 3.00 mL of ethanol (component 1, solute) was placed in cylinder 1. Second, the ethanol was thoroughly transferred from cylinder 1 to 2. The glass stopper was put into cylinder 2 quickly, and the ethanol-water mixture was violently shaken for 3 min. The mixture was kept motionless for about 5 min, and its volume was read.

The microscale equipment and results are shown in Fig. 2. This procedure was repeated five times, and the average and standard error of the observed volumes were calculated. Next, the mixing of 2.00 mL of ethanol with 2.00 mL of distilled water was also carried out.

For other alkanol-water mixtures, the microscale experiments were performed in the same way.

### *2.3 Safety Precautions*

The four alkanols are all toxic and flammable. Methanol is most toxic. Safety goggles must be worn, and no open flames should be in the laboratory.

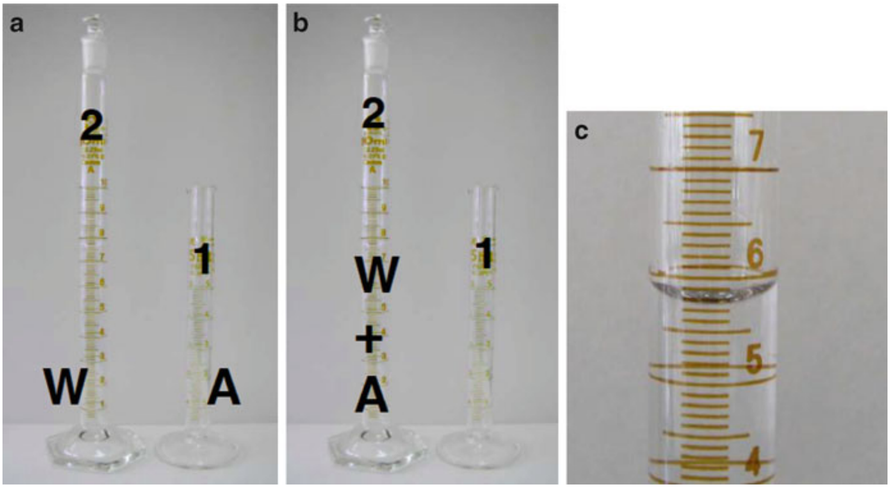
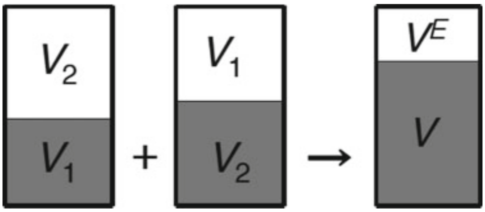



**Fig. 2** Equipment for microscale experiments of mixing alkanol (methanol, ethanol, 1-propanol, or 2-propanol) with water. (**a**) Before mixing, W: 3.00 mL of distilled water in a 10-mL graduated *cylinder 2* ($V_2$ = 3.00 mL), A: 3.00 mL of alkanol in a 5-mL graduated *cylinder 1* ($V_1$ = 3.00 mL). (**b**) In mixing, W + A: shaken 3.00 mL of distilled water plus 3.00 mL of alkanol in a 10-mL graduated *cylinder 2*. (**c**) After mixing, volume of ethanol-water mixture $V$ = 5.79 mL, excess volume $V^E$ = 5.79 mL − (3.00 mL + 3.00 mL) = −0.21 mL

**Fig. 3** Scheme for calculating the volume of binary liquid mixtures for volume decrease ($V^E < 0$). $V_i$ volume of component $i$ ($i$ = 1, 2) before mixing, $V$ volume of liquid mixture, $V^E$ excess volume




# 3 Calculated Volumes from Densities or Excess Molar Volumes

## *3.1 Theoretical Background*

The scheme for calculating volume of binary liquid mixtures is shown in Fig. 3.

In general, the following relations hold about mass $m$, amount of substance $n$, and volume $V$ of binary liquid mixture:

$$m = m_1 + m_2 \tag{1}$$

$$n = n_1 + n_2 \tag{2}$$

$$V \neq V_1 + V_2 \tag{3}$$

where suffix $i$ ($i$ =1, 2) denotes component $i$ and no suffixes binary liquid mixture. In Eqs. 1 and 2, $m$ is linked to $n$, namely,

$$m = nM \tag{4}$$

$$m_i = n_i M_i \tag{5}$$

where $M$ is the molar mass. Combining Eqs. 1 and 5, we obtain

$$m = n_1 M_1 + n_2 M_2 \tag{6}$$

In Eq. 3, if the symbol $\neq$ is replaced by =, the additional term is needed in the right-hand side:

$$V = V_1 + V_2 + V^{\mathrm{E}} \tag{7}$$

where $V^{\mathrm{E}}$ is the excess volume, which means the volume deviation from ideal solution. If $V^{\mathrm{E}}$ is negative, the volume decreases when forming binary liquid mixture. The term $V^{\mathrm{E}}$ is as follows:

$$V^{\mathrm{E}} = V - \left(V_1 + V_2\right) \tag{8}$$

In Eq. 8, $V$ is linked to $n$, namely,

$$V = nV_{\mathrm{m}} = \frac{m}{d} = \frac{nM}{d} \tag{9}$$

$$V_i = n_i V_{\mathrm{m},\,i} = \frac{m_i}{d_i} = \frac{n_i M_i}{d_i} \tag{10}$$

where $V_{\mathrm{m}}$ and $d$ are molar volume and density, respectively. At constant temperature and pressure, both $d_i$ and $V_{\mathrm{m},\,i}$ are regarded as constants.

Substituting Eqs. 9 and 10 for $V$ and $V_i$ in Eq. 8, respectively, and taking Eq. 6 into account, we obtain the following relation:

$$V^{\mathrm{E}} = \frac{n_1 M_1 + n_2 M_2}{d} - \left(\frac{n_1 M_1}{d_1} + \frac{n_2 M_2}{d_2}\right) \tag{11}$$

Dividing Eq. 11 by $n$ yields

$$V_{\mathrm{m}}^{\mathrm{E}} = \frac{x_1 M_1 + x_2 M_2}{d} - \left(\frac{x_1 M_1}{d_1} + \frac{x_2 M_2}{d_2}\right) \tag{12}$$

where $V_{\mathrm{m}}^{\mathrm{E}}$ and $x$ are excess molar volume and mole fraction, respectively, and these values are denoted as,

$$V_{\mathrm{m}}^{\mathrm{E}} = \frac{V^{\mathrm{E}}}{n} \tag{13}$$

$$x_i = \frac{n_i}{n} \tag{14}$$

In Eq. 14, obviously,

$$x_1 + x_2 = 1 \tag{15}$$

Therefore, Eq. 12 is reduced to

$$V_{\mathrm{m}}^{\mathrm{E}} = \frac{x_1 M_1 + (1-x_1) M_2}{d} - \left[ \frac{x_1 M_1}{d_1} + \frac{(1-x_1) M_2}{d_2} \right] \tag{16}$$

Equation 16 is a function of $x_1$, and it is fit to the Redlich-Kister (Redlich & Kister, 1948) equation, which is an empirical one, that is,

$$\begin{aligned} V_m^E &= x_1 x_2 \sum_{k=0}^{N} A_k \left(x_1 - x_2\right)^k = x_1 \left(1 - x_1\right) \sum_{k=0}^{N} A_k \left(2x_1 - 1\right)^k \\ &= A_0 x_1 \left(1 - x_1\right) + x_1 \left(1 - x_1\right) \sum_{k=1}^{N} A_k \left(2x_1 - 1\right)^k \end{aligned} \tag{17}$$

where $A_k$ ($k=0, 1, 2, \ldots, N$) is the fitting parameter, and in particular, $A_0$ denotes the contribution to quadratic function of $x_1$. In Eq. 17, $V_{\mathrm{m}}^E = 0$ at $x_1 = 0$ (neat component 2) and 1 (neat component 1), and this equation represents the character of excess molar properties well. Therefore, although the Redlich-Kister equation is empirical, this is useful for regression curves of excess molar properties such as excess molar volumes.

The amount of substance $n$ in a binary liquid mixture is obtained from Eqs. 2 and 10, that is,

$$n_i = \frac{V_i d_i}{M_i} \tag{18}$$

$$n = n_1 + n_2 = \frac{V_1 d_1}{M_1} + \frac{V_2 d_2}{M_2} = \frac{V_1 d_1 M_2 + V_2 d_2 M_1}{M_1 M_2} \tag{19}$$

From Eqs. 14, 18, and 19, $x_1$ is expressed as,

$$x_1 = \frac{n_1}{n} = \frac{V_1 d_1 M_2}{V_1 d_1 M_2 + V_2 d_2 M_1} \tag{20}$$

If densities or excess molar volumes of binary liquid mixtures are available as functions of $x_1$ ($0 \le x_1 \le 1$), their volumes are easily estimated in numerical order:

1. Determination of the initial $V_1$ and $V_2$
2. Calculation of $n_1$ and $n_2$ (using Eq. 18)
3. Calculation of $n$ (using Eq. 19)
4. Calculation of $x_1$ (using Eq. 20)

**Table 1** Densities $d_i$ and molar masses $M$ at 25 °C and 1 atm

| Compound | $d_i$/g·mL$^{-1}$ | $M_i$/g·mol$^{-1}$ |
|---|---|---|
| Water | 0.99705[a] | 18.015 |
| Methanol | 0.78635[a] | 32.042 |
| Ethanol | 0.78496[a] | 46.068 |
| 1-Propanol | 0.79935[a], 0.80021[b] | 60.095 |
| 2-Propanol | 0.78110[b] | 60.095 |

[a]Benson and Kiyohara (1980)
[b]Pang et al. (2007)

5. Calculation of $V_m^E$ (using Eq. 16). If the $V_m^E$ vales are available from references, this step can be omitted although the $d$ values are unknown.
6. Determination of $A_k$ (using Eq. 17, least square methods). If the $A_k$ values are available from references, this step can be omitted.
7. Estimation of $V_m^E$ at any composition (using Eq. 17)
8. Calculation of $V^E$ (using Eq. 13)
9. Calculation of $V$ (using Eq. 7)

## *3.2 Systems and Conditions for Calculations*

The systems for calculations were four alkanol–water mixtures, which were the same ones as for the microscale experiments. In this study, alkanol and water were regarded as components 1 and 2, respectively. The volume ratio of alkanol and water before mixing was 1:1 (the volumes of respective components are 5.00, 4.00, 3.00, and 2.00 mL), and the volumes of alkanol–water mixtures were calculated at 25°C and 1 atm from densities or excess molar volumes with the aid of our theory.

## *3.3 Data Sources*

The densities at 25 °C and 1 atm were cited from references (Benson & Kiyohara, 1980; Pang, Seng, Teng, & Ibrahim, 2007) and molar mass of respective components were calculated from atomic weights of atoms that compose the respective molecules. These values are listed in Table 1.

The excess molar volumes of methanol–, ethanol–, and 1-propanol–water mixtures at 25 °C and 1 atm were cited from Benson and Kiyohara's (1980) values, and the densities of 1-propanol and 2-propanol–water mixtures at 25 °C and 1 atm were taken from Pang et al.'s (2007) values, and converted to the excess molar volumes using Eq. 16.

The excess molar volumes were fit to Eq. 17 with five parameters using least square methods, and the obtained values were listed in Table 2.

**Table 2** Fitting parameters $Ak$ ($k$=0–5) in Eq. 17

| | $A_k$/mL·mol$^{-1}$ | | | | |
|---|---|---|---|---|---|
| | Methanol – water[a] | Ethanol – water[a] | 1-Propanol – water[a] | 1-Propanol – water[b] | 2-Propanol – water[b] |
| $k$=0 | −4.0172 | −4.2474 | −2.6093 | −2.5145 | −3.6559 |
| $k$=1 | 0.12692 | 0.78290 | 0.57008 | 0.41550 | 1.1178 |
| $k$=2 | 0.10085 | −2.2644 | −0.81009 | 0.44148 | −1.8580 |
| $k$=3 | 0.036458 | 2.6064 | 0.71260 | 3.6173 | 3.6062 |
| $k$=4 | 0.50590 | 2.0445 | −1.8603 | −4.1330 | −0.90204 |
| $k$=5 | −1.1516 | −3.7288 | 0.92642 | −3.1553 | −2.6776 |
| $s$* | 1.6e-03 | 7.7e-03 | 1.0e-02 | 1.4e-02 | 2.1e-02 |

*Standard deviation
[a]obtained from Benson and Kiyohara's (1980) excess molar volumes
[b]obtained from Pang et al.'s (2007) densities

For all systems, the fitting parameters $A_0$ are negative, and therefore the systems investigated have negative excess molar volumes. This implies that volume decrease occurs in forming aqueous alkanol solutions. Standard deviations are comparatively small, and our regression analysis is reasonable.

## 3.4 Example of Calculating Volume of Ethanol–Water Mixture

We introduce the example for calculating a volume of aqueous ethanol solution, which is composed of 3.00 mL of ethanol (component 1) and 3.00 mL of water (component 2) at 25 °C and 1 atm.

Using the physicochemical data in Table 1 and Eq. 18, the amounts of substance of ethanol $n_1$ and water $n_2$ are

$$n_1 = \frac{V_1 d_1}{M_1} = \frac{(3.00\ \text{mL})\cdot(0.78496\ \text{g}\cdot\text{mL}^{-1})}{46.068\,\text{g}\cdot\text{mol}^{-1}} = 0.0511174\cdots\text{mol}$$

$$n_2 = \frac{V_2 d_2}{M_2} = \frac{(3.00\ \text{mL})\cdot(0.99705\ \text{g}\cdot\text{mL}^{-1})}{18.015\,\text{g}\cdot\text{mol}^{-1}} = 0.166036\cdots\text{mol}$$

Hence, $n$ and $x_1$ are calculated using Eqs. 19 and 20:

$$n = n_1 + n_2 = 0.0511174\cdots\text{mol} + 0.166036\cdots\text{mol} = 0.217153\cdots\text{mol}$$

$$x_1 = \frac{n_1}{n} = \frac{0.0511174\cdots\text{mol}}{0.217153\cdots\text{mol}} = 0.235398\cdots$$

Using Eq. 17 and Table 2, $V_\text{m}^\text{E}$ at $x_1$=0.235398⋯ is as follows:

$$
\begin{aligned}
V_m^E &= (0.235398\cdots)\cdot(1-0.235398\cdots) \\
&\cdot[-4.2474+0.78290\cdot(2\cdot0.235398\cdots-1)-2.2644\cdot(2\cdot0.235398\cdots-1)^2 \\
&+2.6064\cdot(2\cdot0.235398\cdots-1)^3+2.0445\cdot(2\cdot0.235398\cdots-1)^4 \\
&-3.7288\cdot(2\cdot0.235398\cdots-1)^5]\,\mathrm{mL\cdot mol^{-1}} \\
&= -0.965990\cdots\,\mathrm{mL\cdot mol^{-1}}
\end{aligned}
$$

With the aid of Eq. 13, $V^E$ is

$$V^E = nV_m^E = (0.217153\cdots\,\mathrm{mol})\cdot(-0.965990\cdots\,\mathrm{mL\cdot mol^{-1}}) = -0.209767\cdots\,\mathrm{mL}$$

Thus, using Eq. 7, $V$ is determined as,

$$V = V_1 + V_2 + V^E = 3.00\ \mathrm{mL} + 3.00\ \mathrm{mL} + (-0.2097\cdots\,\mathrm{mL}) = 5.7903\cdots\,\mathrm{ml}$$

Taking the significant figure of $V$ into account, we obtain

$$V = 5.79\ \mathrm{mL}$$

For other aqueous alkanol solutions, their volumes are estimated in the same manner.

## 4 Results and Discussion

The volumes of alkanol-water mixtures are summarized in Table 3. In microscale experiments, the observed volumes of alkanol-water mixtures are smaller than the total ones of alkanol and water, even if the volumes of respective components are 2.00 mL.

**Table 3** Observed and calculated volumes of alkanol–water mixtures

| | $V$/mL | | | | |
|---|---|---|---|---|---|
| $(V_1+V_2)$/mL | Observed or calculated | Methanol – water | Ethanol – water | 1-Propanol – water[b] | 2-Propanol – water |
| 10.00 | Observed | – | 9.64 ± 0.01[a] | – | – |
| | Calculated | 9.66 | 9.65 | 9.80 | 9.69 |
| 8.00[c] | Calculated | 7.73 | 7.72 | 7.84 | 7.76 |
| 6.00 | Observed | 5.77 ± 0.01 | 5.77 ± 0.01 | 5.87 ± 0.01 | 5.79 ± 0.01 |
| | Calculated | 5.79 | 5.79 | 5.88 | 5.82 |
| 4.00 | Observed | 3.85 ± 0.01 | 3.84 ± 0.01 | 3.91 ± 0.01 | 3.85 ± 0.01 |
| | Calculated | 3.86 | 3.86 | 3.92 | 3.88 |

$V$ volume of alkanol-water mixture after mixing, $V_1$ volume of alkanol before mixing, $V_2$ volume of water before mixing. In this study, $V_1 = V_2$

[a]Previous result (Nakagawa, 2007)

[b]The calculated volumes of 1-propanol-water mixtures from both references (Benson & Kiyohara, 1980; Pang et al., 2007) were identical to three digits

[c]Mixing each alkanol with water was not observed at $V_1 = V_2 = 4.00$ mL

Although the volumes of methanol–, ethanol–, and 2-propanol–water mixtures are almost the same [~5.8 mL in (3.00+3.00) mL mixture], they are smaller than that of the 1-propanol–water mixture [~5.9 mL in (3.00+3.00) mL mixture]. This is why there is the difference in intermolecular interactions. In alkanol–water mixtures, methanol, ethanol, 1-propanol, and 2-propanol molecules are all self-aggregated because of the hydrophobic interactions between methyl, ethyl, 1-propyl, and 2-propyl groups, respectively, and water molecules are also self-aggregated because of the hydrogen bonds between hydroxyl groups. Among these alkyl groups, 1-propyl group is the longest and the hydrophobic interaction increases with the length of the alkyl group.

Hence, 1-propanol molecules are most strongly self-aggregated and this effect also strengthens the self-aggregation of water molecules. Consequently, the homo-molecular interactions between 1-propanols and between waters are more dominant than hetero-molecular interactions between 1-propanol and water in the water rich region (The mixture of $V_1 = V_2 = 3.00$ mL corresponds $x_2 = 0.806$) and the dominant homo-molecular interactions must weaken the decrease of volumes of aqueous solutions. Previous papers on the structure of aqueous solutions using the Kirkwood and Buff (1951) theory have reported that the clusters of alkanol and water are formed in solution and that the clustering in the 1-proanol–water mixture is most remarkable in the four alkanol-water mixtures (Matteoli & Lepori, 1984; Nakagawa, 2002, 2006; Shulgin & Ruckenstein, 1999). This explanation supports our theory.

In chemical demonstrations or ordinary scale experiments, 50 mL of alkanol and 50 mL of water have been used. Hence in this study the volumes of alkanols and water are drastically reduced from 50 mL to 2.00 mL (i.e., 1/25), and obviously our method is more cost-effective and environmently friendly than the traditional one.

In our calculation, the estimated volumes of alkanol-water mixtures from densities or excess molar volumes are also smaller than the total ones of alkanol and water. The derivative process is easy for high school or university students because no difficult and complicated mathematics is used in our calculations. In Table 3, the observed values from microscale experiments are in good agreement with the calculated ones, which suggests that our methods are reasonable.

Judging from both our experimental and theoretical results, we find that our methods are useful and informative as teaching materials for high school science and university chemistry classes. We have already demonstrated the procedure of estimating partial molar volumes of binary liquid mixtures (Nakagawa, 2000). Hence, in the future we will develop teaching materials on the partial molar volumes by combining our present results using microscale experiments and theoretical calculations with our previous results.

## 5 Conclusion

Microscale experiments on the decrease in volume when forming four alkanol-water mixtures have been carried out and the observed volumes of the resultant mixtures have been obtained. Calculated volumes of mixtures have also been obtained from densities or excess molar volumes using the theoretical treatment that we have derived. Both are in good agreement. The volumes of alkanols and water are drastically reduced to ca 1/25 using microscale experiments in comparison with traditional ones. Moreover, the theoretical calculations are also easy for high school and university students. The validity of our methods has been confirmed.

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