

THE STATUS OF UNDERGRADUATE CHEMICAL EDUCATION

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Contents

1. Introduction
2. Chemistry Curricula and Degree Production
 - 2.1. The Americas
 - 2.1.1. United States
 - 2.1.2. Canada
 - 2.1.3. United States of Mexico
 - 2.1.4. Jamaica
 - 2.1.5. Puerto Rico
 - 2.1.6. Costa Rica
 - 2.1.7. Brazil
 - 2.1.8. Argentina and Venezuela
 - 2.1.9. Chile
 - 2.2. Europe
 - 2.2.1. United Kingdom
 - 2.2.2. Germany
 - 2.2.3. Netherlands
 - 2.2.4. France
 - 2.2.5. Spain
 - 2.2.6. Italy
 - 2.2.7. Poland
 - 2.2.8. Ukraine
 - 2.2.9. Russia
 - 2.2.10. Degree Production in Europe
 - 2.3. Asia
 - 2.3.1. Japan
 - 2.3.2. Republic of Korea
 - 2.3.3. China
 - 2.3.4. Taiwan
 - 2.3.5. Malaysia
 - 2.3.6. Singapore
 - 2.3.7. Thailand
 - 2.3.8. India
 - 2.3.9. Sri Lanka
 - 2.3.10. Pakistan
 - 2.3.11. Israel
 - 2.4. Africa
 - 2.4.1. Egypt

2.4.2. South Africa

2.5. Australia and New Zealand

2.5.1. Australia

2.5.2. New Zealand

3. The State of Chemical Education: Emerging Trends in Undergraduate Curriculum

3.1. Defining Chemistry for the 21st Century: Attracting 21st Century Students to Chemistry

3.2. Designing the Best Chemical Education Systems for Future Generations

3.3. Addressing World Environmental, Health, and Energy Needs

Acknowledgements

Glossary

Bibliography

Appendix

Summary

Many countries are modifying the theory-laden, lecture-based, undergraduate chemistry courses that were abundant during the middle of the last century. While a sound understanding of the theory is still essential, many groups and individuals across the globe have realized the need for chemistry courses that focus on the application of the theories and techniques being addressed. By offering more applied chemical training, developing countries are better able to fulfill their sustainable knowledge base and engineering and industrial workforce. Educational systems in the developed world are joining this trend to increase student interest in chemistry through courses geared towards current environmental and economic issues, such as green chemistry, food chemistry, and biotechnology. This article compares and summarizes the different forms of chemical education in 34 countries. It also highlights the global challenges that are faced by all nations as they strive to produce both academically sound and ethical chemists to carry the field well into this new millennium.

1. Introduction

While students' languages and cultures may differ across the world, their studies in chemistry are remarkably the same. With few exceptions, undergraduate chemistry majors are expected to take coursework in the four traditional divisions—analytical, organic, inorganic, and physical—as well as a general chemistry course and to complete their bachelor's degrees (or equivalent) in three to four years. Programs differ in the emphasis given to coursework outside of a student's major, whether the universities grant more pure or applied chemistry degrees, and in the variety of chemistry topics offered in individual degree programs. Developing nations typically offer more applied chemistry degrees to increase their technological workforce. Topic courses offered by some universities include food chemistry, polymer chemistry, spectroscopy, industrial chemistry, environmental chemistry, archeological chemistry, and chemical technology to name a few. Based on these similarities and differences, we can identify five distinct major systems of chemical education, which we classify as the American, British, Chinese, Spanish, and European systems (Table 1). Table 2 lists examples of countries whose undergraduate chemistry degree programs correlate with these five basic models.

As a prerequisite, all of these systems require students to have completed their secondary education and received a high school diploma or its equivalent.

| System | Entrance Requirements | Undergraduate Degree / Duration (years) / Description of curriculum | Graduate Degrees / Duration (years) |
|--|---|---|-------------------------------------|
| American | High school diploma | BS Chemistry / 4 years / Liberal arts | MS / 3 † PhD / 3 -5 † |
| British | A-level examinations | BSc Chemistry / 4years/ Specialized degree | MS / 2 † PhM / 2 ‡ PhD/ 3 ‡ |
| Chinese | High school diploma Entrance examination | Xueshi / 4 years/ Specialized degree | Shoshi / 2 † Boshi / 3 – 5 ‡ |
| Spanish | Bachillerato Entrance examination | Diplomando / 2 years Licenciando / 4-5 years / Specialized | Magister / 2 † PhD / 3 –5 ‡ |
| European (Eurobachelor) | High school diploma or equivalent Language proficiency | BSc Chemistry / 4 years / Specialized degree | MS / 3 † PhD / 5 † |
| Key: † in addition to a bachelor's degree ‡ in addition to a bachelor's and master's degree | | | |

Table 1: Generalized Undergraduate Chemical Education Systems of the World

| System | Countries Using System |
|-------------------------|--|
| American | US, Canada, Puerto Rico, Costa Rica, Japan, Taiwan, Korea, Pakistan |
| British | UK, Jamaica, India, Australia, New Zealand, Singapore, Egypt, South Africa, Malaysia, Thailand, Sri Lanka, Ukraine, Israel |
| Chinese | China |
| Spanish | Mexico, Brazil, Argentina, Venezuela, Chile, Spain, Italy |
| European (Eurobachelor) | Germany, France, Netherlands, Poland, Russia, UK (converting) |

Table 2: Countries using Educational System

Students in the American system generally take a liberal arts curriculum, which requires courses in the arts and humanities, as well as chemistry, mathematics and supporting sciences. Completion of a bachelor's degree generally requires four years, a master's degree takes an additional two to three years and a doctoral degree may require an average of five years, depending on the type of program offered. Undergraduate courses are taught for full semesters over general topics like introductory, organic, analytical, physical, and inorganic chemistry.

The American system is different from the British system, which generally offers more topical courses that last around three weeks per course. Degrees from universities using the British system are generally more specialized due to the structure of the secondary and university curricula, which allow students to select an area of specialization in chemistry more quickly and cover subjects in greater depth at an earlier grade level than the American system. Bachelor's degrees are offered as a normal bachelor's degree and as an honours bachelor's degree, which can be obtained with the completion of additional research hours. The master's degree lasts two years beyond completion of the bachelor's degree. A Master's of Philosophy can be obtained with two years of study in addition to the masters's, and a Doctorate of Philosophy (PhD) can be obtained three years after the master's degree.

The Chinese system offers separate course work for students wishing to obtain a degree in the chemical sciences (chemistry, applied chemistry, chemical engineering) and those who are specializing in another area of science (biology, engineering, electrical engineering). This system allows for more specialized classes, some of which only serve students in the major while others serve non-majors with chemical content that is applicable to their area of study. The Chinese equivalent of a bachelor's degree (Xueshi) typically takes four to five years to complete in either pure or applied chemistry. Some universities offer both the major's and non-major's coursework, while other universities only offer the major's courses. The master's degree (Shoshi) typically takes three years in addition to the bachelor's degree, while the doctoral degree (Boshi) requires three to five years in addition to the master's degree.

The Spanish system differs from the other systems by offering short-term courses that lead to a professional degree (Diplomado) after three years of study. Students who complete the short-term courses typically do not go on to complete a Licenciando (equivalent to a bachelor's degree) or any graduate level degree. The Licenciando is completed after two years of general studies and between two and three years of chemistry specialization. The chemistry coursework is based on the type of topical courses offered in the British system, instead of the more general liberal arts and humanities courses seen in the American system.

The European system is currently under development as part of a strategy for unifying higher education and job requirements across Europe. It was designed to bring together the undergraduate educational system of twenty-nine countries in the European Union and to allow for easier transfer of knowledge between universities via student exchange. This requires the alignment of the course credit systems used by the universities in each country to a standard form that includes thirty-four five-credit course modules, fifty percent of which must be in a student's major, and prepares students for an additional two years of study beyond the bachelor's degree to receive a master's degree. Each university must identify their courses as transferable or non-transferable under the Eurobachelor system.

2. Chemistry Curricula and Degree Production

An overview of the current requirements for chemistry degrees in 34 countries follows. Portions of this information have also been organized into two tables in the appendix.

Appendix 1 includes a table comparing the names of equivalent degrees by country. Appendix 2 includes a table of admission requirements for university studies by country. Finally, Appendix 3 is a list of the university websites from which data was obtained for each country.

2.1. The Americas

2.1.1. United States of America

Admission Criteria

Admission requirements to colleges and universities vary with institutions and are typically set at the state level. Generally, completion of a high school or general equivalency degree is required. Most schools also require students to complete either the Scholastic Assessment Test (SAT) or the American College Testing (ACT) entrance examinations before admittance and to submit their grade point average and class rank.

Nature of the Degree Program

Chemistry degree programs throughout the United States generally conform to the models outlined by the American Chemical Society's (ACS) Committee on Professional Training. Over 600 colleges and universities nationwide, both public and private, offer ACS approved degrees. Most universities offer two four-year degree programs; the Bachelor of Science and the Bachelor of Arts degrees.

The Bachelor of Science (BS) degree generally requires a minimum of 40 semester-hours of chemistry—including analytical, biological, inorganic, organic, and physical chemistry—taken as part of the typical 125 semester-hours required to obtain a degree. The remaining semester-hours typically include supporting majors-level calculus, physics, and biology courses, as well as general education courses structured to meet the educational guidelines of the host institution. BS degrees are typically viewed as professional preparation for graduate study in science, engineering, medicine, and related technical fields. Students obtaining BS degrees also choose to proceed directly to careers in industry or, after completing certification programs, to teaching in grades 9-12.

A Bachelor of Arts (BA) degree generally requires a minimum of 28 semester-hours of chemistry. The remainder of the typical 125 semester-hours required to obtain a BA degree include supporting science and mathematics courses, and a broad range of general education courses. BA degrees can lead to graduate study, but are more typically thought of as a pathway into business, law, teaching, medicine, and other professional programs. Significant numbers of BA chemists will seek industrial employment after finishing their degrees.

The ACS guidelines also offer approved specialized degree 'options.' In satisfying these options, students typically take six additional hours of coursework that forms a specialization in Biochemistry, Chemical Physics, Environmental Chemistry, Materials, Polymers, or Chemical Education.

The ACS also provides guidelines for students pursuing other majors who wish to obtain a minor in chemistry. Students typically complete 20 semester-hours of chemistry to obtain a minor in chemistry.

The master's degree takes approximately two years to complete. Students are required to complete 30 hours of coursework beyond the bachelor's degree and may be required to submit either a research-based thesis or special project or pass a special examination. The doctoral degree takes between two and five years to complete, depending on the program and the degree held by the student. Some programs are geared toward students with bachelor's degrees wishing to work straight through to a doctorate (five year programs), while other programs start where the master's degrees finished (two to three year programs). Students must demonstrate the ability to produce independent research through the defense of a research-based dissertation. While no coursework is required at this level (when starting from a master's degree), students must pass extensive oral and written examinations before being allowed to defend a dissertation.

Degree Production

The ACS collects data on total degree production from departments with ACS-approved programs. While doctoral degree production has remained at approximately 2000 degrees granted per year over a period between 1999 and 2002, both master's and bachelor's degree production has fallen substantially over the same period (Figure 1). Master's degrees granted by 318 institutions fell in a relatively steady manner by approximately 15% to 1701 new degrees, between 1998 and 2002. The graph below shows a 12% decline in new bachelor's degrees granted by approximately 615 institutions over the same period.

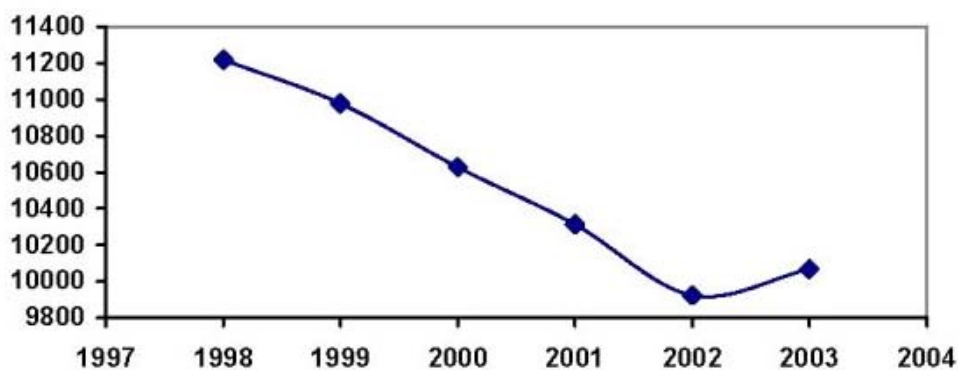


Figure 1: Bachelor's Degrees Granted in the US 1998-2003

Data from the ACS Annual Reports also indicates the following trends in postgraduate study and employment:

Forty-seven percent of current BS graduates are pursuing postdoctoral or graduate study.

Trends in decreasing employment in large companies have continued over the past decade until virtual parity was reached in 2002 between chemists employed by large companies and those employed by small companies.

2.1.2. Canada

Admission Criteria

Admission to colleges and universities vary with institution. Generally, they require students to show language proficiency in the language of instruction through a score on a proficiency exam. They also require a minimum Grade 12 high school course average, usually around 60%.

Nature of the Degree Program

Education in Canada is overseen by individual provinces and territories. To help individual provinces and territories address common concerns, the Council of Ministers of Education was established in 1967. This council sets expectation guidelines for post-secondary institutions that address the quality, accessibility, mobility and portability, relevance and responsiveness, research and scholarship, and accountability standards for these institutions.

The Canadian Society for Chemistry (CSC) provides accreditation for chemistry degree programs to ensure that graduate students will be adequately prepared to practice in their profession upon graduation. With over 120 accredited programs at 36 institutions, the CSC works to identify programs across the country with different curricular strengths, while at the same time offering small student-to-teacher ratios, faculty with strong chemistry backgrounds and experience, and commitment to research.

Accredited bachelor's programs last four years except in the Province of Quebec where they last three years for students who previously completed two years of the Collège d'Enseignement Général et Professionnel (CEGEP) program. Accredited programs require the completion of a total of 1000 hours of laboratory and classroom work in chemistry, including the equivalent of one year (two semesters) in at least three of the five traditional areas—analytical, biochemistry, inorganic, organic, and physical chemistry—and a minimum of a half year of each of the subdisciplines. Programs also typically offer courses in other subjects, such as theoretical chemistry, solid state chemistry, natural products, polymers, advanced instrumentation, and research. In addition to chemistry courses, students are required to take two semesters of calculus, and calculus-based physics, as well as an additional semester of either mathematics, statistics, or computer science.

Universities such as the University of Winnipeg, University of Toronto, and University of British Columbia also offer specializations in environmental chemistry, materials chemistry, chemical geology, chemical physics, and computer science. Students completing these programs typically go into industry, teaching, or graduate programs.

Master's degree programs in Canada last typically two years and follow the same design as seen in the US. Students must complete approximately twelve credits of coursework in their area of interest and defend a research-based thesis. A doctoral degree can be completed from either a BS or MS, as seen in the US. Students beginning with a BS must first complete the requirements for a master's degree before being able to complete an additional six credits of coursework for the doctorate. Students must

complete comprehensive written and oral examinations before being allowed to defend a research-based dissertation.

Degree Production

In 1998, Canadian undergraduate chemistry programs graduated 1125 students, a 17% increase from 10 years earlier. Within two years of graduation, 85% of graduates of chemistry programs had full-time employment and after five years 97% were employed.

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Visit: <http://www.eolss.net/Eolss-sampleAllChapter.aspx>

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