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Progressively Fostering Students' Chemical Information Skills in a Three-Year Chemical Engineering Program in France

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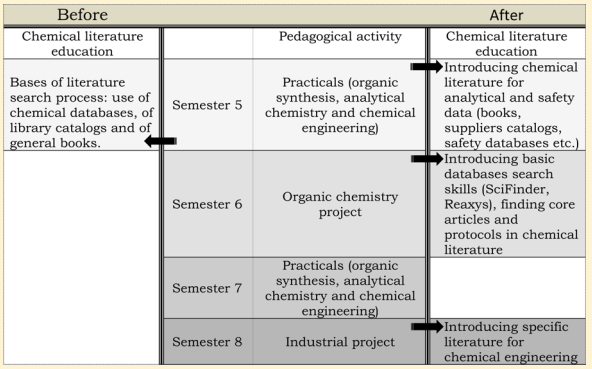
Supporting Information

ABSTRACT: Literature searches are essential for scientists. Thus, courses on how to do a good literature search have been integrated in studies at CPE Lyon for many years. Recently, we modified our pedagogical approach in order to initiate students progressively in the search for chemical information. In addition, this new teaching organization is now based on a "learn and prompt practice" concept.



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BACKGROUND

Presently, with online research databases and articles, accessibility to literature and information has dramatically increased in all domains. In contrast to the past where the difficulty was finding information, it could be considered that the main problem today is to find specific, reliable and relevant information among the huge amount of data available.[1] Navigating through the literature and finding specific resources is a skill which has to be mastered by all scientists.

Thus, students need to become familiar with data recorded in specialized books, catalogs, and databases.[2] At CPE Lyon, a French Grande Ecole[3] which offers a Master's degree in chemistry and chemical engineering, the technique for how to do a literature search has been integrated in the course for many years.

Studies at CPE Lyon begin after two years of higher education in mathematics, physics, and chemistry. The engineering course lasts three years and is divided into 6 semesters numbered 5−10.

During semesters 5−7, students have three different pedagogical activities requiring different chemical information skills. In semester 5, students have 4-h laboratory sessions in organic synthesis, analytical chemistry, and chemical engineering every week. In preparation for these experiments, students have to search for physicochemical and safety data for the reactants and products. In semester 6, students have a project in organic chemistry and need to search for both general information and chemical procedures in the literature. Finally, a chemical process project involving information concerning thermodynamic and kinetic data and industrial process design is assigned during semester 7. After that, students choose a specialization based on their knowledge and skills. The last year is dedicated to this specialization and includes a semester of academic courses and a six-month internship (Figure 1). (For a more detailed program of the course, see the ref 3.)

INCORPORATING SEARCH SKILLS IN THE CURRICULUM

During their studies, students should acquire good skills in finding chemical information in all fields of chemistry. Previously, during a 4 h session in the library at the end of semester 5, students were initiated in literature searches using books, handbooks, databases, and so forth. The first problem was that students lacked the ability to find the right information for preparing their laboratory work during semester 5, that is, finding the physical properties as well as analytical information (mp, bp, nDT, IR and NMR spectra) and safety data. In addition, some of the information search tools were presented too early and were then forgotten by the students. Consequently, we modified our pedagogical approach three years ago and divided this course into three 2-h sessions dedicated to data searches consistent with the following pedagogical activities (Figure 2). The idea was to gradually

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Higher Education 1 & 2	Semesters 1 to 4	Two years of higher education in mathematics, physics and chemistry
Higher Education 3 & 4	Semesters 5 to 7	Engineering course - complete education in organic and inorganic chemistry, analytical sciences, polymers, catalysis, and process engineering
Higher Education 4	Semester 8	First specialization
Higher Education 5	Semester 9	Specialization
	Semester 10	Academic or industrial internship
Master's degree in chemistry and chemical engineering		

Figure 1. Synopsis of the course sequences for CPE Lyon. Course program details can be found in ref 3.

Before			After
Chemical literature education		Pedagogical activity	Chemical literature education
Bases of literature search process: use of chemical databases, of library catalogs and of general books.	Semester 5	Practicals (organic synthesis, analytical chemistry and chemical engineering)	Introducing chemical literature for analytical and safety data (books, suppliers catalogs, safety databases etc.)
	Semester 6	Organic chemistry project	Introducing basic databases search skills (SciFinder, Reaxys), finding core articles and protocols in chemical literature
	Semester 7	Practicals (organic synthesis, analytical chemistry and chemical engineering)	
	Semester 8	Industrial project	Introducing specific literature for chemical engineering

Figure 2. Modification of our pedagogical approach to introduce literature search skills for students.

integrate specific literature search skills in the course so that students could apply them directly.

The aim of the first "literature search" session is to help students prepare for laboratory work in organic or analytical chemistry in the fifth semester. Thus, it begins with a presentation of how to find physicochemical, analytical, and safety data for the reactants and products. To do this, there is a 2-h session, where 25 students are supervised by three teachers.

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The students are asked to find specific data from a list of books (e.g., *Handbook of Chemistry and Physics, The Merck Index, Sax's Dangerous Properties of Industrial Materials, Perry's Chemical Engineers' Handbook, The Ullmann's Encyclopedia of Industrial Chemistry, Kirk-Othmer Encylopedia of Chemical Technology,* Charlot, and Skoog)[4−10] or in Web databases (NIST Chemistry WebBook, suppliers Web sites, Handbook of Chemistry and Physics Online, and SDBS).[11−13] In this session, students have to answer three questions: where and how do they find the information, and is the source reliable? For one molecule, for example, oxalic acid or toluene, students look for physicochemical data, such as the pK_a value or boiling point, in each book, Web site, and database, and make a note of how they proceed. For example, for the boiling point of toluene in the *Handbook of Chemistry and Physics*,[4] they can use the index chapter "Boiling Point of Organic Compounds". In this chapter, molecules are classified in alphabetical order. Data is available with literature references and pressure values so the boiling point can be considered as reliable. (Another example of an exercise based on oxalic acid is shown in the Supporting Information.) This work is a good way to introduce the importance of various concepts such as CAS RN, source reliability, data accuracy, and the difference between experimental and calculated data.

At the beginning of semester 6, the second 2 h literature search session is devoted to using databases such as Scifinder[14] and Reaxys,[15] and to general chemical literature (books, publications and Web sites).[16] Groups of 18 students work on different exercises, in the presence of two teachers. First, students have to find general information in the literature about the Finkelstein reaction, for example from the reference of the original publication, the mechanism, scope, common experimental conditions, and applications of this reaction in total synthesis. Then, students look for a particular Finkelstein reaction procedure within a specific publication and learn how to use supporting information to find both experimental details and spectroscopic data. On this occasion, the importance of noting references carefully and accurately is pointed out by giving students an incomplete reference and thus showing them the difficulty in finding the corresponding article. Concerning databases, the different search tools (by topic, reaction or substance) are applied in several exercises. For these, students have to look for publications describing and discussing the S_N2 mechanism of the Finkelstein reaction. Afterward, they must find both an experimental procedure on specific substrates and physical and spectroscopic data of the so-formed products. Finally, the session is completed by searching for a patent related to the Finkelstein reaction using the platform "espacenet".[17] (See the Supporting Information for this exercise.)

All the above skills are then applied in an organic chemistry project during semester 6. In groups of six, students work on a subject such as "Acid catalysis in organic chemistry". Six references of reaction procedures are associated with the subject. Two 4-h sessions are dedicated to literature searches, and there are then four 4-h sessions of laboratory work. After having performed the reactions, students write a scientific report (including a bibliography, results and discussion, and experimental section), and finally, present their work in English to industrial chemistry researchers from GSK (U.K.) using a scientific poster for the communication.

For the whole of semester 7, students apply the tools seen and used in semesters 5 and 6 in their organic chemistry practicals. Students study reactions, for example, the influence of reactants or catalysts in a Suzuki coupling,[18] and write scientific reports.

The third literature search session is scheduled at the beginning of semester 8. Here, students are involved in an industrialization project. From a laboratory procedure, they have to calculate and design an industrial process of about 100 T/h. A large part of the project consist in calculating the material balance of the different unit operations and students have to use the tools seen and used previously to find reagents and product data. They also need many thermodynamic and kinetic data. This third and final session, therefore, mainly uses databases such as Scifinder and Reaxys but also Detherm[19] or Chemsafe[20] and thermodynamics books. Students, in groups of 5, work on their projects with a teacher helping them to discover new databases. The objective is to successfully define the problem and the solutions. For example, for scaling a reactor, they need to know the reaction enthalpy and must search for the value or the method in the databases in order to calculate or estimate the data (an example is given in the Supporting Information). This project allows them to use all the resources available as well as those discovered in semesters 5−8. This is a good exercise in order to check if students have acquired the necessary skills to find chemical information in different literature data.

CONCLUSION

To improve our students skills in finding reliable chemical information in different fields, we have organized teaching based on a "learn and prompt practice" concept. As chemical information management is about cumulative knowledge, we initiate students progressively. Each new tool is directly applied in a pedagogical activity.

We were pleased to find that this improvement in our teaching method was positively received by students as they can apply these new skills directly. More importantly, we also observed a real improvement in the preparation of laboratory sessions particularly in analytical chemistry where reports had often been incomplete before. As students are now more confident about doing literature searches and also more independent, it gives us the opportunity to create new activities. For example, the last laboratory session on solution chemistry is now devoted to a project where students are free to choose their own procedure for a titration such as the redox titration of ascorbic acid in lemon juice, or a complexometric titration of calcium ions in mineral water. Concerning the organic chemistry project in semester 6, we can now raise our standards concerning the bibliographic part of students' reports. In addition, laboratory sessions in semester 7 are now much more formative as students do not have to carefully follow each instruction on a described procedure but are now able to step back and compile the data found in the literature to choose relevant parameters that they want to study for their report. Finally, during the industrial process design in semester 8, students have become more efficient and they quickly learn to use new tools like the Chemsafe database.

Through these different activities, we hope that they will be able to remember and apply the proverb of "A week in the library can save a month in the lab."[21]

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00414.

Students' literature searching exercise 1 (PDF)
Students' literature searching exercise 2 (PDF)

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Notes

The authors declare no competing financial interest.

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