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The Analytical Sciences Digital Library: a resource to promote active learning

Abstract: The Analytical Sciences Digital Library (ASDL) collects, catalogs, links, and publishes peer-reviewed web-based materials pertinent to innovations in curriculum development and supporting technical resources in the analytical sciences. The library has four primary sites: the ASDL collection, the Journal of the Analytical Sciences Digital Library, a community site, and an active learning site. This article describes the nature of the materials on each of the four primary sites and shows their utility to the analytical sciences community. Additional materials for the Active Learning site are currently under development by a group of more than 20 analytical chemistry faculty members in the US interested in the utilization of evidenced-based teaching. The different collections within ASDL provide instructors of courses and practitioners within the field a wealth of resources to facilitate learning in the analytical sciences.

Keywords: active learning; education; web resources.

Introduction

The Analytical Sciences Digital Library (ASDL; http://www.asdlib.org) grew out of a series of workshops held in the mid-1990s that examined curricular reform in the analytical sciences. Chaired by Ted Kuwana and sponsored by the US National Science Foundation, the workshops brought together stakeholders from academia, industry, and funding agencies to examine the current practice of analytical chemistry instruction and explore ways to improve the practice. The report that resulted from the workshops, Curricular Developments in the Analytical Sciences (Kuwana 1998), provided a number of important recommendations related to instruction in the analytical sciences, some of which are the following:

- That the academic community develop context-based analytical science curricula that incorporate problem-based learning.
- That more students be offered hands-on learning opportunities.
- That the analytical community develop a list of appropriate and well-developed technologies that faculty may consider for classes and laboratories.
- That faculty strive to incorporate today’s technology into classrooms and laboratories and to use technology to access real-world learning experiences.
- That analytical faculty drive the revisions to undergraduate analytical curricula and help spread the word about the need for these revisions.
- That the community of analytical educators take an active role in the design, assessment, and purchase of technology as it applies to education and in their own continuing education.
- That everyone involved in undergraduate education look for ways to share information about curricular reform.

In light of the final recommendation, individuals involved in the workshops undertook a series of activities aimed at promoting the recommendations in the report, one of which involved the establishment of ASDL. Initially supported through grants from the digital library initiative of the US National Science Foundation, funds to sustain ASDL are now provided by the Analytical Division of the American Chemical Society. Another factor in the impetus for starting ASDL involved the realization that information is now disseminated primarily through the web. Generalized keyword searches (e.g., mass spectrometry) undertaken using common web search engines usually turn up many more websites than are feasible to search, and sorting out sites with significant educational value from those that are not useful is difficult. ASDL collects, catalogs, links, and publishes peer-reviewed web-based materials pertinent to innovations in curriculum development and supporting technical resources in the analytical sciences.
Collections in ASDL

The library has four primary sites: the ASDL collection, the *Journal of the Analytical Sciences Digital Library* (*JASDL*), a community site, and an active learning site. The ASDL collection, *JASDL*, and the community site will be discussed in this section of the article. The active learning site is described separately. Materials in the ASDL collection, *JASDL*, and the active learning site undergo a peer-review process by experts in the field similar to what occurs with items published in peer-reviewed journals. Reviewers must agree that the materials selected have important educational value to the analytical sciences community. Each web resource listed in these three collections has an annotation that describes the resource and its useful attributes.

Each of the four primary sites has a managing editor. Associate editors who span a range of areas of disciplinary expertise function much like editors at peer-reviewed journals. They assign websites under consideration for inclusion in the ASDL collection for peer review and, based on the reviews, solicit revisions of the site if warranted or make decisions about whether to include the site in the collection. They also develop the annotations that accompany each website. As of November 2013, there were 492 accepted websites in the collection.

ASDL collection

Table 1 shows the four broad headings that are used to catalog items in the ASDL collection and the various subcategories that are associated with each heading. Using mass spectrometry as an example, there are two ways to access information on mass spectrometry in the collection. One is to use the search box on the home page and type in the term mass spectrometry. Another is to hover over the Techniques link, which brings up a list of methods, one of which is Mass Spectrometry. Clicking on this link brings up all the sites in the collection that have been considered by the editors to have a significant component on mass spectrometry (in November 2013, there were 40 sites in the collection listed under Mass Spectrometry). Hovering over the Mass Spectrometry link brings up four additional subcategories within this topic: Basics, Hyphenated-MS, Spectral Interpretation, and Applications.

The collection on mass spectrometry includes sites that cover a range of interests and topics. Several are broad in scope and provide an introduction or overview of mass spectrometry (e.g., a glossary of terms or the history of the method). Several of the sites are structured as tutorials. Other sites provide an overview of hyphenated techniques such as GC-MS, HPLC-MS, and ICP-MS. Others provide videos or animations on the basic principles of mass spectrometry or, more specifically, on the functioning of mass analyzers or a GC-MS. One site provides virtual laboratory experiences that students without access to an instrument can undertake to appreciate the value of mass spectrometry as an analytical method. Another group of sites focuses on the interpretation of mass spectral data obtained from electron impact or electrospray devices. Databases of mass spectra are available through the library as well. Other sites focus on applications of mass spectrometry, some of which are broad in scope, others of which are specific to the analysis of biological systems, foods, polymers, and proteins. There are highly specialized sites that focus on issues of accuracy, resolution, and Fourier transform processes. Websites that provide information on other methods listed under the Techniques heading would be similarly diverse and encompassing in scope.

The Applications section of the collection incorporates many websites that are listed under the Techniques section but also includes additional sites that are not focused on a specific technique. Most of the subtopics in the Applications section are divided into additional categories that characterize the focus of the website. For example, websites within the Bioanalytical heading are further categorized into areas such as biosensors, bioseparations, genomics and molecular biology, immunoassays, lipids, method validation, protein analysis, and microscopy/imaging. The Scientist’s Guidelines section provides information on copyright and patents, ethics
and mentoring, poster guidelines, safety and compliance, writing practices, and notebook and authorship.

Some of the items under Resources by Formats are also categorized into additional subtopics. The Animations category includes materials that are illustrative of concepts in bioanalytical, chemometrics, electrochemistry, equilibrium, mass spectrometry, NMR spectroscopy, separations, spectroscopy, surface analysis, and X-ray techniques. Websites within the Teaching Resources category focus on active learning methods including the use of case studies, cooperative learning and problem- and inquiry-based learning.

Journal of the Analytical Sciences Digital Library

JASDL is an online journal that publishes peer-reviewed resources. A key feature of JASDL is that resources are archived by and served from ASDL, providing greater stability than one typically encounters with web-based materials. Resources are catalogued as Courseware, Labware, and Educational Practice. Many of the JASDL Courseware and Labware items emphasize active learning pedagogies. The Educational Practice section is a venue for sharing pedagogical models. JASDL is an un gated, open-source site that operates under the Creative Commons copyright. In the Creative Commons system, the author retains the copyright to the materials. The licensee has the right to distribute the material without limit. Web users can read, download, and hot link the material without limit. Copies can be made and distributed to students as long as the original author is cited as the creator of the material. Any copies must be distributed at cost and no one other than the author of the materials is allowed to profit from them. Submissions to JASDL can include materials in traditional manuscript form and in nontraditional formats such as software, webpages, and simulators.

The number of items in JASDL is considerably fewer than in the ASDL collection, but there are items with educational value to instructors and analytical scientists. Items in JASDL are also cross-listed with the general ASDL collection. The Courseware section includes instructional items on data analysis, electrochemistry, chemical equilibrium, separation science, affinity chromatography, kinetic capillary electrophoresis, atomic emission spectroscopy, X-ray fluorescence and diffraction, scanning probe microscopy, and lasers. The Labware section includes exercises involving analog-to-digital conversion, capillary electrophoresis, analytical electrochemistry, analysis of paintings, and forensic science. One exercise describes how to make a spectrophotometer out of a cell phone. The Educational Practices section has items describing the utilization of active learning in an advanced analytical chemistry course for first-year graduate students and the development of a team-taught course on mass spectrometry that involves an industry-university collaboration.

JASDL is an ideal venue through which instructors may disseminate interesting new course or laboratory exercises related to the analytical sciences. Many instructors who develop new course or laboratory activities put them up on their own website; however, these sites usually have few visits, often with no indication whether anyone used or was inspired by the material. ASDL has seen steady growth in the number of times people access the site, with the most recent data indicating over 14,700 visits to the site in October 2013. Items published through JASDL are often more likely to be seen by members of the analytical science community than those put up on personal websites, and because they are archived and served by ASDL, authors are relieved of the responsibility for assuring web availability.

Community site

The community site provides a forum for sharing user-generated content and materials for teaching analytical chemistry at the introductory and advanced levels. Unlike the other sections of ASDL, information can go onto the community site without first going through peer review. Materials shared through the community site are done so under the Creative Commons license.

The Image and Video Exchange forum provides a repository for user-generated media – including images, photos, videos, and animations – illustrating important topics in analytical chemistry. The forum currently houses over 300 items, many of which are from the eText Analytical Chemistry 2.0, a freely available Analytical Chemistry textbook of more than 1000 pages.

The Data Set Exchange forum provides a repository for user-generated data sets illustrating important topics in analytical chemistry. Data files are provided in the form of Excel spreadsheets (or other suitable formats) and accompanied by examples illustrating ways to use the data. For example, one data set available through the site provides a set of 20 UV spectra for benzene recorded under different combinations of scan rate, instrument response time, and monochromator slit width, allowing students to evaluate how each variable affects the signal-to-noise ratio, spectral resolution, and absorbance.
The Laboratory Experiment forum provides a place for discussing and sharing pedagogical innovations for laboratory courses in analytical chemistry. Posts at this site include both original content in the form of laboratory experiments and descriptions of innovative laboratory curricula, and descriptions of and links to interesting experiments published in *The Journal of Chemical Education* and *The Chemical Educator*.

The Problem Exchange forum provides a repository for sharing user-generated problem sets that illustrate important topics in analytical chemistry in a form suitable for in-class exercises, out-of-class assignments, or examinations. The current inventory includes 38 problems in areas ranging from statistics to sampling, equilibrium chemistry to quantitative analysis, and classical wet chemistry to instrumental methods of analysis.

People can also use the community site to create common-interest groups that can share information and engage in discussion. The community site welcomes suggestions for additional forums that meet the needs and interests of its users. One forum currently in development will provide space for sharing instructional materials, applications, and user-generated code using R (http://www.r-project.org/index.html), an open-source statistical analysis and graphics package.

The ASDL active learning initiative

Participants at the workshops on the teaching of analytical chemistry held in the mid-1990s recommended the adoption of problem- and context-based learning strategies because of the considerable volume of educational research that demonstrated their effectiveness at promoting student learning. Research has shown that lecturing is an ineffective way to facilitate learning (Bligh 1972, Rowe 1980, Penner 1984, Johnson et al. 1991, Wenzel 1999). Effective learning involves a construction of knowledge, where new information is categorized into and builds onto concepts the individual already understands (Bodner 1986, Bransford et al. 2000, Nieswandt 2007, Mayer 2011, Singer et al. 2012, Rugg 2013). Stating and explaining things in a lecture environment are ineffective at facilitating this construction of knowledge because it is too passive a process.


Studies of student learning in the laboratory, a very important component of the learning that occurs in many analytical chemistry courses, show that exercises where students are provided a recipe to follow has little measurable effect on educational achievement (Hofstein and Lunetta 1982), whereas laboratory activities in which students are involved in more autonomous investigations that mimic the practice of science result in higher-order cognitive outcomes (Wheatley 1975, Raghubir 1979, Reif and St. John 1979). In the laboratory, students should be given problems to explore – ideally working in teams – and be expected to use existing primary literature, make decisions, design experiments, collect samples, perform the analysis, interpret data, draw conclusions, and present the data in oral and/or written form. Today, the use of group learning in the classroom and investigative projects in the laboratory is often referred to as evidence-based teaching practices, since research studies show their enhanced effectiveness at promoting learning.

Bloom’s taxonomy of learning in Table 2 provides the types of skills that students need to develop (Bloom 1956, Anderson et al. 2000). The items within Bloom’s

| Knowledge | – recall and memorize (define, describe, draw, identify, label, match, recall, state) |
| Comprehension | – translate from one form to another (classify, convert, describe, explain, summarize, translate, transform) |
| Application | – apply or use information in a new situation (apply, calculate, construct, extend, operate, predict, produce, sequence, solve, transfer) |
| Analysis | – examine a concept and break it down into its parts, develop conclusions by making inferences, find evidence to support conclusions (analyze, correlate, determine, differentiate, discriminate, illustrate, recognize) |
| Synthesis | – put information together in a unique or novel way to solve a problem (adapt, build, design, device, incorporate, modify, revise, validate) |
| Evaluation | – make a judgment (appraise, compare and contrast, critique, defend, interpret, justify, recommend) |
taxonomy represent a hierarchy of learning achievement progressing from lower-order (e.g., knowledge) to higher-order (e.g., evaluation) learning outcomes. The higher-order skills in Bloom’s taxonomy are especially important for success in a career after college. A classroom environment that involves lecturing and a laboratory environment that involves cookbook experiments may promote some student achievement within the lower-order skills of Bloom’s taxonomy, but evidence from many research studies show that these approaches will fall short in developing higher-order skills (Bligh 1972, Rowe 1980, Hofstein and Lunetta 1982, Johnson et al. 1991, Penner 1984, Wenzel 1999).

A hindrance to the wide-scale utilization of evidence-based teaching practices by instructors of analytical chemistry courses is the paucity of materials available to support such an approach. Traditional textbooks are written in a form that promotes utilization of a lecture approach rather than small-group discussion and problem solving. Most laboratory manuals and experiments for undergraduate analytical chemistry courses provide the information to students in a recipe where all of the steps are spelled out and the students merely follow the directions. A group of more than 20 analytical chemistry faculty members in the US interested in the utilization of evidenced-based teaching has assembled over the past few years to develop active learning materials and disseminate them free of charge through ASDL. This effort is currently supported through the US National Science Foundation. Materials undergo peer review prior to inclusion on the Active Learning site. These materials are under the Creative Commons copyright; thus, anyone can download and use them as is or in a modified form in their courses without charge, provided they acknowledge the original author.

The institutions represented by faculty members currently involved in the active learning project range from research universities that have analytical chemistry courses and laboratories with large enrollments to public and private 4-year institutions, many of which have courses with substantially lower enrollments. These institutions also serve a wide range of student populations as several are characterized as historically black or Hispanic serving institutions.

Four categories of materials are included on the Active Learning site: In-class Activity, Laboratory Activity, Contextual Module, or Textual Material. Instructors are able to use all of an activity or part of an activity or modify the activity in a way that best suits their environment. Table 3 lists the criteria that are used in determining whether

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<th>Table 3</th>
<th>Criteria used to define the meaning of an active learning exercise.</th>
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<tbody>
<tr>
<td>Class activity</td>
<td>1. The activity includes stated learning objectives.</td>
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<td>2. The activity is designed so that students work in teams.</td>
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<td>3. Students are given a question or problem to solve.</td>
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<td>4. Students have prior knowledge that informs their initial response to the problem.</td>
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<td>5. Students are given time free of instructional input to discuss the problem within their group.</td>
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<td>6. The activity is structured in a way that students are informed either through oral or written prompts whether they are on the right track with their initial response.</td>
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<td>7. The initial problem usually leads to additional questions that must be addressed.</td>
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<td>8. Solving the problem involves a back-and-forth exchange between the students and the instructor and requires active facilitation on the part of the instructor.</td>
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<tr>
<td>Laboratory activity or contextual problem</td>
<td>1. The activity begins with an open-ended question or problem (e.g., complete the analysis of lead in soil samples; why are the flamingos dying at Lake Nakuru).</td>
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<td></td>
<td>2. The activity is designed so that students work in teams.</td>
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<td></td>
<td>3. The instructor may or may not know the outcome of the problem in advance.</td>
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<td></td>
<td>4. Students must use prior knowledge and/or consult the literature to address the question or problem.</td>
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<td>5. Students must use critical thinking skills to develop a hypothesis and/or devise a procedure to solve the problem following appropriate aspects of laboratory safety.</td>
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<td>6. Students will either carry out the procedure by observing and collecting information or be provided data when they have determined the correct measurements to make.</td>
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<td>7. When experiments are performed, students must make decisions in their design and execution, taking into account aspects of safety.</td>
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<td></td>
<td>8. Students will use appropriate methods to validate their measurements.</td>
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<td></td>
<td>9. Students will process the information that is collected or provided (e.g., describe, tabulate, summarize, calculate).</td>
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<td></td>
<td>10. Students will draw conclusions from the information that is collected or provided and support those conclusions.</td>
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<td></td>
<td>11. Students will usually report on their findings in written and/or oral form.</td>
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materials being considered for inclusion as an in-class activity, laboratory activity, or contextual module repre-
sent an active learning exercise. The goal of the project is
to eventually develop active learning materials that cover
the entire range of topics typically included in undergrad-
uate analytical chemistry courses.

The development and utilization of active learning
exercises do not preclude the need for text resources.
Therefore, the group involved in this curricular effort has
also been writing or assembling already-available textual
materials and including them on the Active Learning
site. These textual materials support the variety of topics
included in an undergraduate analytical chemistry cur-
riculum and are also available at no charge. Many are
resources published through JASDL.

### In-class activities

In-class, collaborative learning activities that address
topics commonly covered in chemical equilibrium, sepa-
ration science and chromatography, and molecular and
atomic spectroscopy are available on the Active Learning
site of ASDL. A unit on electrochemistry is under develop-
ment. Each of these units consists of a series of in-class
questions/problems for students to work on in groups,
textual material that supports the in-class question sets,
a series of learning objectives, and an instructor’s manual.

Table 4 provides examples of some questions/prob-
lems that students are given to work on in groups within
each of the units. The role of the instructor in this type of
group learning is especially important. Students should
be given some uninterrupted time to discuss the question,
after which the instructor must interact with the groups.
One reason for interacting with the groups is to ensure
that the students have not misinterpreted the question
being asked. If one group needs help interpreting what
the question is asking, others probably have the same
confusion, and it is advisable to call the entire class to atten-
don and clarify what is being asked. Correctly answering
the questions will require the students to draw on prior
knowledge. Another reason to interact with the groups is
to listen to what prior knowledge they have thought of in
response to the question and to let them know whether or
not they are on the right track. If the students are off track,
instead of telling them the answer, it is better to prompt
them with a question or something else to consider. When
every group appreciates the concept needed to answer the
question, the instructor should summarize the topic for
the entire class.

The instructor’s manual for each unit gives insights on
common misconceptions that students have in response to
questions. Prompts that can be used to guide the students
through the questions are also provided. Since it is prefer-
able to have the students explore concepts and draw on
prior knowledge, appropriate portions of the text should
be provided to students only after they have discussed the
question or problem in class.

### Laboratory activities

The Active Learning site currently has three modules
that describe active learning laboratory exercises. One
of these describes a series of projects developed in the
instrumental analysis laboratory at Indiana University

| Table 4 | Sample in-class questions from the units on chemical equilibrium, separation science, molecular spectroscopy, and atomic
spectroscopy. |
<table>
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<tr>
<td>Calculate the pH of a solution that is 0.155 M in ammonia.</td>
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<tr>
<td>Calculate the pH of a solution that is prepared by mixing 45 ml of 0.224 M 1,3-chlorobenzoic acid with 30 ml of 0.187 M ethylamine.</td>
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<tr>
<td>Calculate the concentration of free calcium(II) ion in a solution prepared with initial concentrations of calcium of 0.020 M and total EDTA of 0.10 M. The solution is buffered at a pH of 2.</td>
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<tr>
<td>Consider a packed chromatographic column:</td>
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<tr>
<td>Consider different molecules have different path lengths as they passed through the column?</td>
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<tr>
<td>Is the difference in length between the shortest and longest path dependent at all on the diameter of the particles?</td>
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<tr>
<td>Some packed columns exhibit channeling. What do you think is meant by this term?</td>
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<tr>
<td>What would be the order of retention for the ions Li(Ⅰ), Na(I), and K(Ⅰ) on a cation exchange resin? Justify your answer.</td>
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<tr>
<td>Compare the UV absorption spectrum of 1-butene to 1,3-butadiene.</td>
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<tr>
<td>Describe a way to measure the phosphorescence spectrum of a species that is not compromised by the presence of any fluorescence emission.</td>
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</tr>
<tr>
<td>Consider the molecular vibrations of carbon dioxide and determine whether or not they are Raman active.</td>
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<tr>
<td>Flame noise (either emission from the flame or changes in the flame background as a sample is introduced) may present a significant interference in atomic methods. Can you design a feature that could be incorporated into an atomic absorption spectrophotometer to account for flame noise?</td>
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</table>
in which students undertake quality control analyses for a local brewery. The particular analyses performed in a given year are determined by the needs of the brewery. Students work in groups. After meeting with a representative of the brewery, each group receives a letter from the brewery outlining the analyses of interest that they will measure. Examples of species that have been measured in the past include calcium, magnesium, chloride, oxalate, bitterness units (α and β acids), percentage alcohol, diacetyl, and total and individual polyphenols. Groups use the literature to identify potential analysis methods. After comparing and identifying an acceptable method, the groups carry out the analysis. Results are reported in written and poster form. The instructor’s manual for this project gives advice about the utilization of project-based learning pedagogy and specific recommendations about the implementation of such a teaching strategy in large courses. Topics such as project selection, budgeting, team selection, grading, communication between student groups, and training of teaching assistants are covered. Copies of assignments and grading rubrics used in the laboratory including the brewery letter, group contract, literature search assignment, choosing the best method assignment, progress report, written report, and poster presentation are provided.

A second module describes a series of thematic laboratory activities used in smaller laboratory sections at Butler University. Students in the course undertake semester-long projects organized around a single theme. Themes included in the module involve forensics analyses, environmental analyses, bioanalytical chemistry, and analyses of art objects using molecular spectroscopy. Students work in small groups on specific facets of the project or collectively on a series of analyses. They must identify possible methods for the analysis, carry them out, and then report on their findings in oral, poster, and written forms. The instructor’s manual provides advice on choosing themes and projects, making effective use of student time and managing group dynamics. Appendices provide guidelines and rubrics that are given to students for the project proposal, report writing, oral report, poster presentation, and peer review. Grading rubrics for different facets of the project are provided as well.

A third module describes a series of chromatography projects used in the laboratory component of an undergraduate separation science course at Bates College. Students work in groups of two or three and undertake a single, semester-long project. Table 5 lists projects that students have undertaken in the course. Groups perform a literature search and, partway through the semester, submit a proposal that explains why it is important to analyze the target species, compares prior analysis methods and procedures reported in the literature, describes a rationale for which methods and procedures have been selected for use, and provides a detailed experimental plan including any associated costs of chemicals and supplies needed to complete the project. Once the proposal is approved, the group undertakes its analysis. Every group gives an oral presentation on the project and each student writes a final report that takes the form of a scientific manuscript. The instructor’s manual includes the handouts provided to the students for the project proposal and final written report, peer- and self-assessment instruments that students complete after submission of the proposal and at the end of the term, and specific comments about each project in Table 5 that will be helpful to instructors considering their use.

### Table 5  Projects undertaken by students in the laboratory component of an undergraduate separation science course.

<table>
<thead>
<tr>
<th>Analysis method shown in parentheses.</th>
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<tbody>
<tr>
<td>Caffeine, theobromine, and theophylline in chocolate (HPLC-UV)</td>
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<tr>
<td>Catechins (polyphenols) in green tea, wine, and chocolate (HPLC-UV)</td>
</tr>
<tr>
<td>Amino acid analysis (HPLC-fluorescence)</td>
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<tr>
<td>Volatiles in coffee (GC-MS)</td>
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<tr>
<td>Trihalomethanes in drinking water (GC-MS)</td>
</tr>
<tr>
<td>Methylbenzenes from car exhaust in air (GC-MS)</td>
</tr>
<tr>
<td>Nitrate and nitrite in sausages and cured meats (ion chromatography)</td>
</tr>
<tr>
<td>PAHs in charred meats or creosote (GC-MS)</td>
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<tr>
<td>Chloride content of frozen foods (ion chromatography)</td>
</tr>
<tr>
<td>DNA restriction fragment analysis (capillary electrophoresis)</td>
</tr>
<tr>
<td>Additives in soft drinks (capillary electrophoresis)</td>
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</table>

Contextual modules

Contextual modules are learning activities that develop fundamental aspects of analytical chemistry within the context of a real analytical problem. There are currently two completed contextual modules on the ASDL active learning site, both of which explore the question of why flamingos that feed at Lake Nakuru in Kenya are experiencing higher than usual mortality rates. Lake Nakuru has no outlet, so pollutants such as pesticides and heavy metals that get into the lake through run off and other processes can accumulate. The reason(s) for the higher rates of flamingo death at the lake is still unknown, but two possibilities include elevated levels of pesticides or heavy metals. Another possibility is that algal toxins, the formation of which may be promoted through changes in the water chemistry of the lake, may now be present, and the target species, compares prior analysis methods and procedures reported in the literature, describes a rationale for which methods and procedures have been selected for use, and provides a detailed experimental plan including any associated costs of chemicals and supplies needed to complete the project. Once the proposal is approved, the group undertakes its analysis. Every group gives an oral presentation on the project and each student writes a final report that takes the form of a scientific manuscript. The instructor’s manual includes the handouts provided to the students for the project proposal and final written report, peer- and self-assessment instruments that students complete after submission of the proposal and at the end of the term, and specific comments about each project in Table 5 that will be helpful to instructors considering their use.
Each module is composed of several sections. The pesticide module includes sections on sampling, sample preparation, gas chromatography, pesticide analysis by mass spectrometry, and method validation. The heavy metals module has sections on X-ray fluorescence, anodic stripping voltammetry, and atomic spectroscopy. Each section provides background information that is interspersed with questions that students answer while working in small groups. The contextual modules are intended as guided activities that are performed with an instructor present. Students must draw on prior knowledge to answer some of the questions. For other questions, students must look up information in primary literature articles or documents like a US Environmental Protection Agency analysis method. The modules are written in such a way that it is possible to use only some of the sections and not necessary to use the complete module. Instructor’s manuals that provide answers to the questions and advice on using the modules are available on request from the authors.

Textual materials

A wide variety of free textual materials are available on the Active Learning site of ASDL. Perhaps most notable is Analytical Chemistry 2.0, a comprehensive textbook that includes chapters on all the topics typically covered in a quantitative analysis course as well as many topics incorporated into instrumental analysis courses.

More specialized textual materials cover areas such as chemical equilibrium, chromatography and separation science, molecular and atomic spectroscopy, electrochemistry, X-ray diffraction and X-ray fluorescence, NMR spectroscopy, scanning probe microscopy, lasers, the use of kinetic measurements in chemical analysis, data analysis, and signal-to-noise ratios. Many of these resources have been published through JASDL.

Summary comments

The different collections within ASDL provide instructors of courses and practitioners within the field a wealth of resources to facilitate learning in the analytical sciences. Readers are encouraged to bring websites that would be especially useful to the analytical community to the attention of the appropriate ASDL editor. Readers are further encouraged to submit items for publication through JASDL, to join the community site, and to use exercises provided on the active learning site. Development of additional items for the active learning site is currently underway through support provided by the US National Science Foundation. Readers are encouraged to monitor the active learning and other collections within ASDL on a regular basis for new resources.

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