Advancements in curriculum and assessment by the use of IMMEX technology in the organic laboratory

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The use of web-based software and course management systems for the delivery of online assessments in the chemistry classroom is becoming more common. IMMEX software, like other web-based software, can be used for delivering assessments and providing feedback, but differs in that it offers additional features designed to give insights and promote improvements in problem solving strategies. This report describes some of the features offered with IMMEX software and provides a detailed description of how IMMEX problems are best implemented into the organic laboratory.

Keywords: laboratory, assessment, technology/computers, problem solving

Introduction

Web-based software and course management systems such as Web-Assign (Webassign, 2007) and WebCT / Blackboard (Cole, 2000; Charlesworth, *et.al.*, 2003; WebCT, 2007) are commonly used for delivering online assessments. The IMMEX system (Interactive MultiMedia EXercises) is also a web-based software package that can be incorporated with large enrollment courses (Stevens and Palacio-Cayetano, 2003), but this software offers unique assessment features not commonly available (Stevens, 2004; Cox, 2006; IMMEX, 2007; Cooper *et al*., 2008). For example: IMMEX allows the use of case-based problems that mimic real-life situations students may encounter. The IMMEX system has its origins in medical schools where the use of case-based problems is quite common (Wilkerson, 1989). Each IMMEX problem is equipped with multiple problem clones which have different answers with the same embedded content, but typically require different problem solving strategies to reach the final result. While problem *variations* can be created using other packages, for example, by substituting different numbers in calculations, different problem solving approaches are rarely required to successfully solve such variations thereby promoting problem solving by analogy or algorithm (Underdahl, *et.al*., 2002).

IMMEX software is designed as a tool to develop a greater understanding of student problem solving strategies, while promoting improvements in student problem solving ability. We have developed a wide range of problems for use in general and organic chemistry. This report briefly discusses how IMMEX problems can be implemented in the organic laboratory environment and describes four problems concerning organic separations, qualitative organic analysis, thin layer chromatography, and spectroscopic analysis.

All IMMEX problems begin with a prolog statement that defines the problem's goals and objectives. After reading the prolog statement, students may then navigate through the problem space selecting items they deem relevant for solving the problem (Palacio-Cayetano and Stevens, 1999, Underdahl, *et.al.*, 2002; Cox *et al*., 2006). A sample prolog statement is shown in Figure 1. The problem space consists of all items that are available for students to view, for example: chemical tests, physical tests, spectra, and background information. The inclusion of reference material was designed to allow students to look up needed data or information within the confines of the problem, rather than using outside sources such as the web or the textbook, since these external sources cannot be tracked by the IMMEX software (Cox, 2006). Figure 2 provides an example of a problem space. Each IMMEX problem has between two and sixty clones (Underdahl, *et.al*., 2002), and consequently, some problem space items may be relevant for one clone but not for another.

Immediate feedback is provided in a number of different ways. For example, most IMMEX problems allow two attempts at finding the correct solution. Upon submitting their initial answers students are provided with a complete list of the problem space items they have viewed, regardless of whether their answers are correct or incorrect. Therefore, if their answers are incorrect, they can review the items they have used on the solve page, and then refine their methods by either reviewing the problem space items again or viewing items that were not previously viewed (Cox *et al*., 2006). This kind of immediate feedback has been proposed

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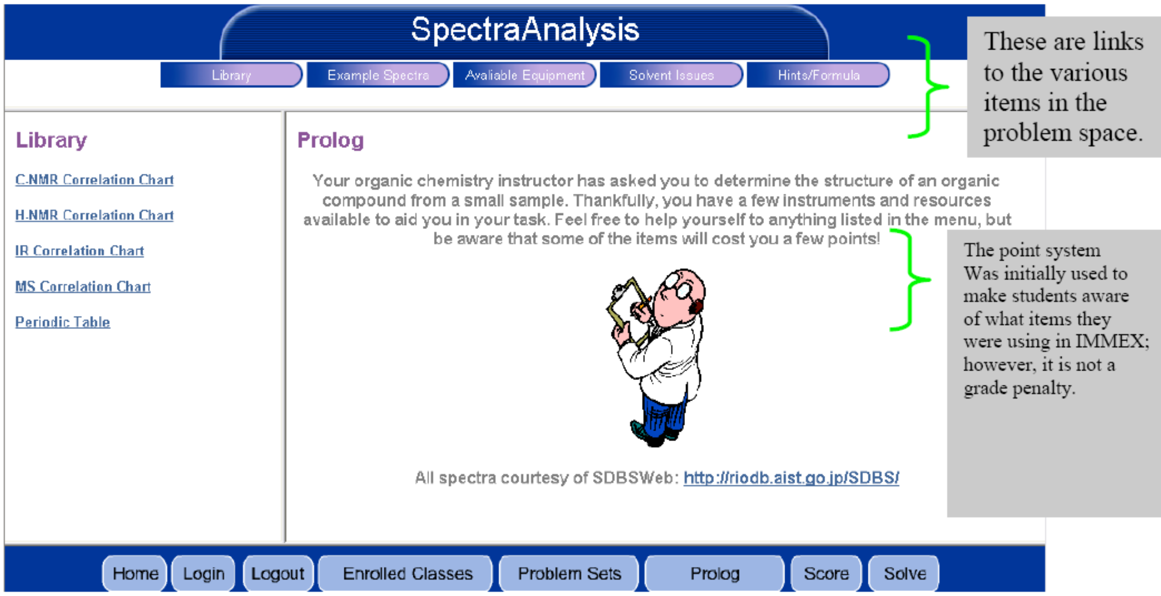

Fig. 1 The prolog statement for *Spectra Analysis*. This prolog provides the objective of identifying an unknown using NMR, IR, and MS data.

Fig.2 The problem space for *Chromatography Challenge.*

to foster the development of expertise (LaJoie, 2003). Many problems also have an epilog that reviews the important features of the problem, and outlines a general strategy that would lead to a correct solution. In addition, students may download a visual representation of the path that they took through the problem, a Search Path Map (SPM), as illustrated in Figure 3, which provides a different way of viewing the student's progress through the problem.

Implementation and grading

IMMEX problems have been designed so that they fit in well with most organic laboratory curricula. The problems can be used either as a tutorial to help students familiarize themselves with a particular technique, or as an assessment. They can be given as homework (typically as a pre-lab

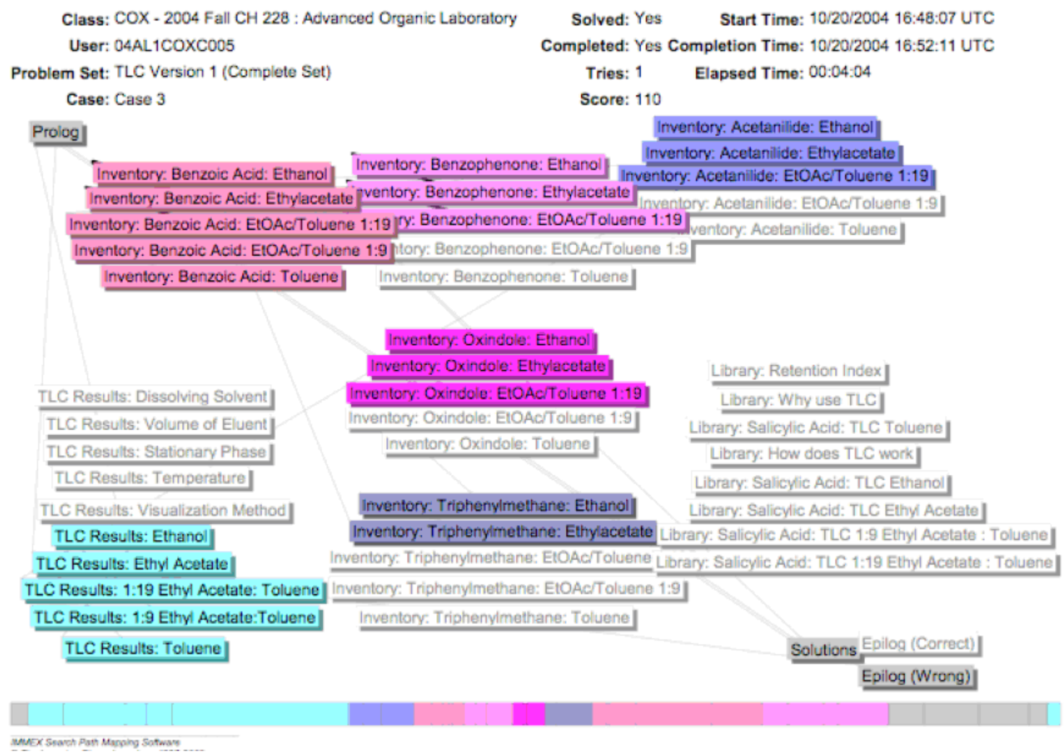

Fig.3 Search Path Map for TLC. The colored items are ones the student used to solve the problem. Students have access to the search path maps as a way of reviewing what items they viewed in the problem space. The colored boxes indicate problem space items students viewed as they were completing the problem For instance, in this case, the student moved from the Prolog statement to the TLC results, then to the inventory, and finally to the solutions page.

assignment), in–lab assignments, or even as part of the laboratory examination. Indeed, they have been used for all these purposes at a south-eastern university. The results of the IMMEX assignments can be used in many different ways. The instructor is provided with a summary of the number of problems completed and the number correct for every student, and, of course, may use these values in any way they seem appropriate. For example: students are required to answer correctly four or five problem variations (or clones) for full credit. With the exception of Separation, all the problems presented in this paper have a minimum of at least five variations, all providing students with a similar scenario, yet most requiring different problem solving strategies. Students were required to complete both variations available for the separation problem. The grade was based upon the number correctly answered as a percentage of the minimum required.

The average solved rates reported were computed from the number of correct attempts out of the total number of attempts. Students in the organic laboratory included both chemistry majors and non majors, and over 90% of the students in the study were majoring in a science-oriented field.

Sample of organic laboratory IMMEX problems

Finding carbon's neighbors – a qualitative organic analysis problem

The content of this problem focuses on the use of qualitative organic tests to identify an organic unknown without the use of spectroscopic data. *Finding Carbon's Neighbors* contains twenty-four cases with a wide variety of functional groups ranging from alkenes to carboxylic acids; some cases contain two or more functional groups. In order to aid in the identification, combustion data for carbon and hydrogen are provided, and physical tests such as solubility in water, acid, base, and organic solvents is provided as well. However, the most pertinent information is contained within the chemical tests.

This problem is best implemented during the second semester organic laboratory in conjunction with synthesis experiments. It can be used as a pre-lab introduction to qualitative analysis, and/or for assessment. The average solve rate at for this problem is 75%.

Cooperative learning laboratories are used for organic laboratory at this university, and a separate stand-alone experiment is not conducted specifically on qualitative organic analysis. However, within most of the cooperative experiments, these qualitative analyses are emphasized. Before this problem was implemented, students often demonstrated difficulty with understanding the array of different chemical and physical tests available for their in-lab analyses. As the number of tests was increased throughout the semester the corresponding author noted that students had more difficulty with the laboratory projects. Following the implementation of the problem set, the average on the lab assessment questions relating to qualitative analysis increased by 20%. Furthermore, students were observed to be more efficient in completely laboratory experiments after working these problems, presumably because they were more familiar with the array of analyses and the interpretation of their results.

Spectroscopic analysis

This problem focuses on the elucidation of an organic unknown structure using spectroscopic data including: ^{1}H NMR, ^{13}C NMR, IR, and MS. The program provides actual spectra for the unknowns, and students have a range of other information, including sample spectra, for a wide variety of functional groups, correlation tests, peak locations for various solvents, MS fragment interpretations, and various hints that may be useful in solving the problem.

There are fifteen cases for this problem, and students are given two attempts at each case. As with *Finding Carbon's Neighbors*, the cases are representative of the entire range of functional groups, and some cases have more than one functional group. The problems were designed such that the integration is not needed for the NMR—hence, we have opted to omit that piece of information. The average solved rate is around 52% for *Spectra Analysis*,. The problem was assigned after completing the unit on spectroscopy, and used for formative assessment. Since student performance on this problem is typically quite low, we have investigated the question of how to improve student strategies for solving the problem; this will be reported elsewhere. These studies included incorporation of interventions such as collaborative grouping, including web-based collaboration using the collaborative IMMEX feature (Stevens *et al*., 2005). Furthermore, the Cox conducted studies that required students to provide detailed analyses of their search path maps, as a tool to gain a richer understanding of students' reasoning when solving problems. IMMEX strategies for this sample of students were analyzed using the modeling features available (Stevens *et al*., 2004; Stevens *et al*., 2005) to develop an understanding of the key features of successful strategies versus unsuccessful strategies.

Chromatography challenge

Chromatography challenge provides students with a real-life scenario and requires that students understand how to perform a TLC analysis, and how TLC data is related to the structure of the compound and the nature of the solvent. Students are provided with an unknown compound and asked to identify it using only TLC data. Students can obtain TLC results using a variety of solvents with a wide range of polarities, and then compare these with the results obtained when using an authentic sample.

Actual TLC figures are provided within the problem, therefore, students must interpret the markings and determine the R_f value. An example of the TLC plate is shown in Figure 4.

There are five cases for TLC and the average solve rate is 84%.Most students experienced difficulty on the questions related to TLC on the laboratory assessments with the average correct answers ranging from 45 to 60% on these questions. After working through the TLC problem, the average increased to 70 to 75% correct on similar items. The TLC questions were conceptually oriented, and students

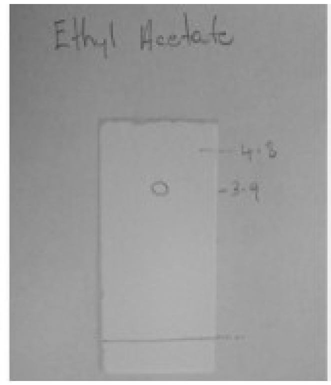

Fig. 4 An example of the TLC data as it is presented to students.

were asked to rank three compounds of differing polarities in order of increasing retention factor (R_f) for a given solvent. Other questions involved predicting how the R_f would change following a chemical reaction or providing detailed descriptions of the relationship between the R_f value and the polarities of the respective solvent and stationary phase. All these questions were open-ended, giving students the opportunity to explain their answers and how they arrived at their conclusions.

Separation

This problem requires students to understand and predict how the structure of a compound affects its properties, and how those properties may be used to separate a mixture. The problem is best used as a tutorial that provides students with an excellent introduction to separation schemes. Students are given a list of possible extraction steps such as filtration, distillation, addition of water, acid, or base. After selecting a separation method, students identify which of the components in the mixture will be separated, and the process continues. The problem allows students to make errors, but in order to proceed and complete the problems students must eventually select the appropriate option in the separation scheme. There are two clones for the separation problem. This problem was used prior to the organic extraction experiments. Laboratory instructors noted that after completing this problem students are more equipped to do similar tasks in the laboratory, are more successful with the separation experiment, and come to lab better prepared and ask fewer questions.

Crystallize it! This problem was designed to serve as a tutorial for recrystallization. There are four clones for the recrystallization of benzoic acid, benzophenone, naphthalene, and indole. Toluene, ethanol, and water are the three possible recrystallization solvents. Digital photos of the recrystallization process in all three solvents are provided, as well as, the percent recovery and melting points of the pure and recrystallized products. This information is provided in order for students to determine which of the three possible solvents is the best choice for recrystallization. Photos are provided from start to finish in order to reinforce written descriptions often provided in the textbook. Feedback is provided for students based upon their selections of the best recrystallization solvent, including potential problems associated with their choices. This problem is best used as a pre-lab for a laboratory where crystallization is introduced.

Terpene tizzy! This problem was designed to serve as a tutorial about the combined use of reactions, reaction mechanisms and spectral data to identify a specific molecule within a family of molecules – specifically terpenes. There are sixteen clones that differ according to the presence of functional groups. All molecules are found in nature, and the prolog of the problem provides the motivation by noting the sample to be studied comes from smoke particles down wind from a forest fire. The practicality of the exercise is thus rooted in solving a question about what type of plant may have been burned to have that terpene in the smoke. The conceptual exercise for pedagogical value lies in using various tests, both wet chemistry and spectroscopy, to analyze an unknown.

Murder in the laboratory! This problem was designed to serve as a tutorial for carbohydrate chemistry. The scenario paints a forensic science oriented problem where an individual has been found murdered by poisoning. The specific form of toxin is a carbohydrate, and students must carry out both spectroscopic analysis and functional group reaction chemistry to determine the specific poison used. There are six clones for this problem. This problem would serve as a pre-lab for carbohydrate chemistry.

Microreactor madness! This problem is another version of qualitative analysis using a combination of spectroscopic analysis and wet chemistry. The premise is that the microreactor in a laboratory is malfunctioning, so that unknown, but interesting molecules are being produced. This is a more general qualitative analysis scheme with ten clones. This exercise would be useful as a pre-lab assignment for a general qualitative analysis experiment.

The advantages of using IMMEX in the laboratory

Traditional written pre-lab exercises are limited in their ability to simulate a true laboratory environment. For example, the number of qualitative organic methods presented on written pre-labs is often limited to a smaller subset in comparison to the problem space presented in *Finding carbon's neighbors*. Students become accustomed to working with smaller subsets of chemical tests by implementing traditional pre-labs in lieu of a wider array of tests and have difficulty 'chunking' (Johnstone, 1983) information when faced with more realistic expectations.

A second advantage of IMMEX over traditional written pre-lab exercises lie in the interactive features of these assignments. Since IMMEX provides immediate feedback, errors in understanding of techniques or concepts can be detected before the lab. Commonly, when written pre-labs are used, feedback is only provided after the experiment is completed; therefore, students may in-fact complete portions of the experiment incorrectly because of alternative conceptions about correct procedures or expected results. While there are web-based pre-labs that provide immediate feedback, they are also often quite limited because they provide only minor variations on a particular theme, instead of providing activities that require different problem solving strategies. For example, with *Chromatography challenge*, students are presented with an array of possible solvents and products with differing polarities. Course management systems and most web-based assessments typically cannot assess students' true understanding by providing the complete array of possibilities. With IMMEX-based pre-labs, students are required to complete four to five different variations which will provide a much larger combination of possibilities; thereby exposing the student to a wider range of conditions and promoting improvement of problem solving skills needed for success in the laboratory (Cooper 2008).

IMMEX also has the capability to simulate laboratory results. *Crystallize it!* and *Chromatography challenge*, for example, provide students with pictures and animations to promote student understanding. These animations promote the development of mental visualizations of the various scenarios students may confront in lab. The video demonstration provided with *Chromatography challenge* can reinforce and promote the development of correct laboratory technique.

Conclusions

The use of IMMEX in the organic laboratory offers a number of advantages over traditional assignments. Students and faculty are provided with immediate feedback, and students have the opportunity to evaluate their strategies using the problem space summaries. IMMEX problems have multiple cases allowing students multiple opportunities to work related yet unique problems allowing for the development of problem solving skills. Overall, improvements in laboratory problem skills have been observed as a result of implementing IMMEX based activities.

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