FEATURE

Industrial hygiene laboratory for distance education. Part 1: Course development

A college-level laboratory course in the applied science of Industrial Hygiene was created in CD-ROM format and titled "Industrial Hygiene Virtual Laboratory." Content for the course was created de novo but was based on program accreditation requirements and professional judgment of the curriculum necessary. Topics included calibrations, sampling for gases and vapors, particulate sampling, ventilation and indoor air quality, noise, bioaerosols, and thermal stressors. Usability evaluations of the early prototype interface were conducted, and the complexity of the initial selection screen reduced from a possible 40-plus decision elements to 11 sequential modules. As developed, the Industrial Hygiene Virtual Laboratory represents a complete laboratory education opportunity suitable for autonomous distance education. Based on this work, development of the application was finalized for beta testing in comparison with a traditionally delivered laboratory-based curriculum. The benefits of a virtual laboratory are discussed relative to the traditional real-time laboratory experience.

By Timothy J. Ryan

INTRODUCTION

Whereas night school and weekend courses were once the bailiwick of the adult learner, electronic curriculums are increasingly available for such students. Presently, we are at the beginning of an explosion in the development of new educational materials for such learners. Often discussed under the aegis of distance learning or distance education, when delivered in a stand-alone CD-ROM package these programs are more correctly described as autonomous (i.e., stand-alone, self-paced, and unscheduled) education pieces. Regardless of their precise description, technologies employed in this regard include the now commonplace list-serves, email, microwave and compressed video learning networks, as well as rapidly developing Internet-based applications. Within this mix of materials and approaches, there is an increasing volume of rubric-specific multimedia applications software available. Virtually all university fields of instruction can now point to web or CD-ROM software designed to teach key elements of a traditional curriculum. Most problematic among such requisite core competencies are those which heretofore have depended on real-time laboratory experience for instruction. Reports of an increasing number of limited applications in the basic sciences have entered the peer-reviewed literature in recent years. Subjects for which the 'laboratory hurdle' have most recently been broached include entomology,[1] geology,[2] engineering,[3,4] physics,[5] and chemistry (both analytical and chemical engineering).[6,7] This paper describes the development of a virtual laboratory in the area of occupational safety and health. Specifically described is an approach to the study of industrial hygiene (IH) equivalent to a full college quarter laboratory session.

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Nature of the Problem

Industrial hygiene is an applied science, combining elements of chemistry, physics, toxicology, and engineering in dealing with the recognition, evaluation, and control of workplace stressors or hazards.[8] It is a relatively new college major, having evolved in the last 30 years from more traditional programs in chemistry, engineering, physics, and biology in the wake of the passage of the Occupational Safety and Health Act (OSHA) of 1970.[9] Presently there are only five undergraduate IH programs that are accredited in the U.S. by the Accreditation Board of Engineering and Technology, and 27 graduate programs in this field.[10] As a profession,

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industrial hygiene faces challenges in the recruitment or training of competent practitioners. An inability to attract new students, poor retention of international students trained in U.S. schools, and increasing numbers of retirements all combine to limit the number of adequately trained industrial hygienists available to employers in need of such services. As with any profession, there is also a constant pressure for professional growth opportunities in the form of seminars or applicable college-level courses in areas of interest to the employed, aspiring industrial hygienist. The majority of such training opportunities are classroom-based and do not involve an IH laboratory session.

In the traditional laboratory experience, the teacher is available to give instructions, answer questions and demonstrate proper procedures. Since students in this setting are invariably new to the concepts or equipment in question, this approach results in considerable time demands on the instructor and variable waiting for attention on the part of the students. In terms of infrastructure and resources for sciences such as chemistry, engineering, and IH, it is seldom the case that teaching laboratories are equipped with entirely sufficient sets of the latest, properly maintained equipment.[7] Where the use of hazardous materials or physical hazards is employed, live laboratory sessions have the additional issues of student safety or security. For all of these reasons, the time-honored traditional laboratory experience demonstrates problems in terms of decreased accessibility, quality and quantity of instruction, and safety.

Virtually delivered, autonomously operated labs suffer their own potential set of deficiencies and issues. Equipment or technique-intensive topics (e.g., chemistry and IH laboratories) have presented some of the most difficult and obvious issues. How to provide a meaningful laboratory experience for a student at a distance, without the possibility of injury to either the unsupervised student or those around him, is of tantamount importance. Suggestions have included required on-campus lab sessions, the use of expensive commercial laboratory kits, virtual labs, or even the elimination of the laboratory experience.[6] At present it is hard to conceive of an accredited curriculum eliminating laboratory requirements for all but the most basic entry level courses for non-majors, and so the virtual laboratory stands out as the only truly innovative opportunity to address this void. Despite their mention as a possible solution to such problems, based on a review of the literature available there are apparently no such comprehensive chemistry laboratories being offered within the U.S. at this time. Thus, availability is the first and foremost drawback to any virtual laboratory. Secondary problems include those attendant to all autonomously delivered technologies including the lack of state of the art computer platforms capable of running the typically resource-intensive multimedia applications for larger graphics, animations, video or audio files.[11]

Benefits of Innovation

As if in answer to such problems, numerous studies have concluded that the appropriate use of technology can reduce boredom and misbehavior, cut infrastructure costs and, paradoxically, enhance the quality of the student–teacher relationship.[12] Further benefits of new multimedia approaches include improved student attitudes toward the material, boosted achievement and elevated organizational and program retention rates.[13] Media selection is a key step in the effective design of a training experience, and must be carefully considered both in terms of task media fit and media complementary to the core topic presented.[14] So long as a variety of media are appropriately and judiciously utilized, a multimedia approach to teaching a health and safety curriculum is emerging as an overall positive learning tool.[11] In the academic environment, for example, web-based safety training is preferred by 88–91% of the targeted audience.[15] To completely reap the benefits of such technology requires changes to educational models of laboratory instruction, and the necessary development of new curricular materials.[12]

The following section describes the technological and pedagogical development of a college-level laboratory course in IH. Titled Industrial Hygiene Virtual Laboratory (IHVL), the CD-ROM-based course was created as part of an initiative to foster innovation in teaching and learning. The IHVL has been specifically developed as a substitute for a weekly 1 credit-hour traditional laboratory session, and is intended to be utilized in conjunction with a 4 credit-hour weekly classroom lecture. The level and material covered is an upperclassman course described as "IH Sampling and Analysis." Although the IHVL described is CD-ROM-based, its development was undertaken with the recognition that it might ultimately be accessed via the Internet. It contains a number of options (e.g., email tracking, ASCII report generation) amenable to an asynchronous distance learning environment. For these reasons the IHVL is discussed here in terms of a distance learning opportunity for prospective industrial hygienists.

THE VIRTUAL INDUSTRIAL HYGIENE LABORATORY

Content

The initial programming content of the IHVL was based on both national IH program accreditation requirements as well as professional judgment as to the adaptability of the existing laboratory curriculum to a multimedia presentation. Specific topics covered in the 11 laboratory modules are calibration of air sampling equipment, sampling for gases and vapors, total and respirable particulate sampling, ventilation & conducting indoor air quality assessments, noise, bioaerosol sampling, and thermal stressors. The IH program at Ohio University is accredited by the Accreditation Board for Engineering and Technology, Inc. under the category of Applied Science Programs. As such the topics necessary for inclusion in the IHVL were considered sacrosanct in order that ultimate adoption and continued use of the virtual laboratory not jeopardize the accredited status of the IH program. While the IHVL was being programmed, it became evident that entire laboratories could be created on several of the topics covered. For example, ventila-

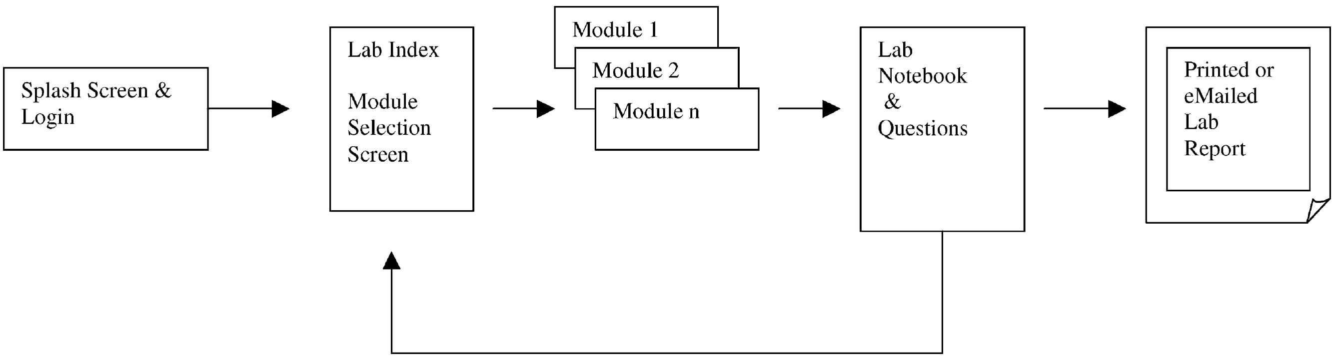

Figure 1. IHVL functional elements.

tion and noise were both seen to be highly adaptable to the multimedia presentations of the IHVL. Because of the curriculum constraints noted, however, the modules developed for the IHVL were limited to those mirroring the existing traditional laboratory.

Organization

Figure 1 illustrates the functional organization of the IHVL material in its current version (1.0.1.). Content for the CD-ROM course was created de novo and includes graphics, data tables, still and video photography demonstrations of field use, animations of techniques, and text pages for instructions. Combinations of some or all of these within a given module are presented to the student as X of Y screens to be progressed through. After the opening "splash" screen presentation, the student is presented with an index to the 11 laboratory modules on the application. By highlighting any one module, the student is presented a short textual description of the module content. The logical progression through the program is then to complete a selected module, and answer a list of questions in the electronic Lab Notebook. Experimental observations and data generated as the result of simulations in a module are entered by the student on-screen, and are automatically recorded in the Lab Notebook. Questions and data in the Lab Notebook can be printed or sent electronically to the course instructor for grading and comment.

Programming & Systems

With the exception of the installation program, the IHVL employs off-the-shelf applications development software. Demonstrations or simulations employing project-built illustrations were programmed using Director 8.0. For those laboratory modules requiring the student to make use of the text-based National Institutes for Occupational Safety and Health (NIOSH) Manual of Analytical Methods, Adobe Acrobat Reader 5.0 was utilized. For the audio or video segments integrated into most modules, QuickTime 5.0.1. is installed to run the application.

In deciding upon system hardware minimums, it was felt that, given the rapid advancements in computer performance, software written for "state of the art" hardware at the projects conception (c. 2000) would give the application the longest shelf life possible. As a result, system requirements are now modest relative to modern platform options. Hardware system requirements for the IHVL vary by platform. For PCs, Windows 95, NT 4.0 or better with a 300 MHz processor speed and 64 MB RAM are necessary. Macintosh computers require OS 7.6 or better (or Mac OS X in "Classic" mode) with a 233 MHz PowerPC and 64 MB RAM. The application can be run directly from the CD-ROM or installed on the hard drive, in which case 50 MB of disk space are essential.

USABILITY TESTING

A properly designed and competently executed multimedia training application can enhance the learning of both traditional students and adult learners.[11,12,16] For any new piece of software there is a time of learning to effectively use the application interface before topical learning can proceed unimpeded by the technology employed. Untested application shells or overly complex navigable paths through an application have been shown to negatively affect learning performance.[17] Students may mistakenly assume themselves to be more knowledgeable of personal computer operations than they truly are. This is particularly true if their proficiency is limited to frequently used software only (e.g., mailers and web browsers). For all of these reasons, the design prototyping and testing of the user interface for the IHVL received considerable attention at an early stage, in accordance with longstanding standards of practice in the computer interface design community.[18]

User-based evaluations of the usability of the early IHVL prototype were conducted with five students who were not presently enrolled in the traditional lecture/lab-based course. All testers were majoring in industrial hygiene or environmental health. Three of these students had previously completed the laboratory course. The grade point averages, sex or age of the students were not factored into their selection or suitability for usability study inclusion.

The initial design of the IHVL employed a "toolbox" approach (Figure 2) to the front-end of the application, in which the student was to look into a virtual IH equipment toolbox, select the appropriate pieces for the intended sampling apparatus, and then properly assemble and operate the equipment. Usability testing of this programming approach consisted of requiring the students to locate and

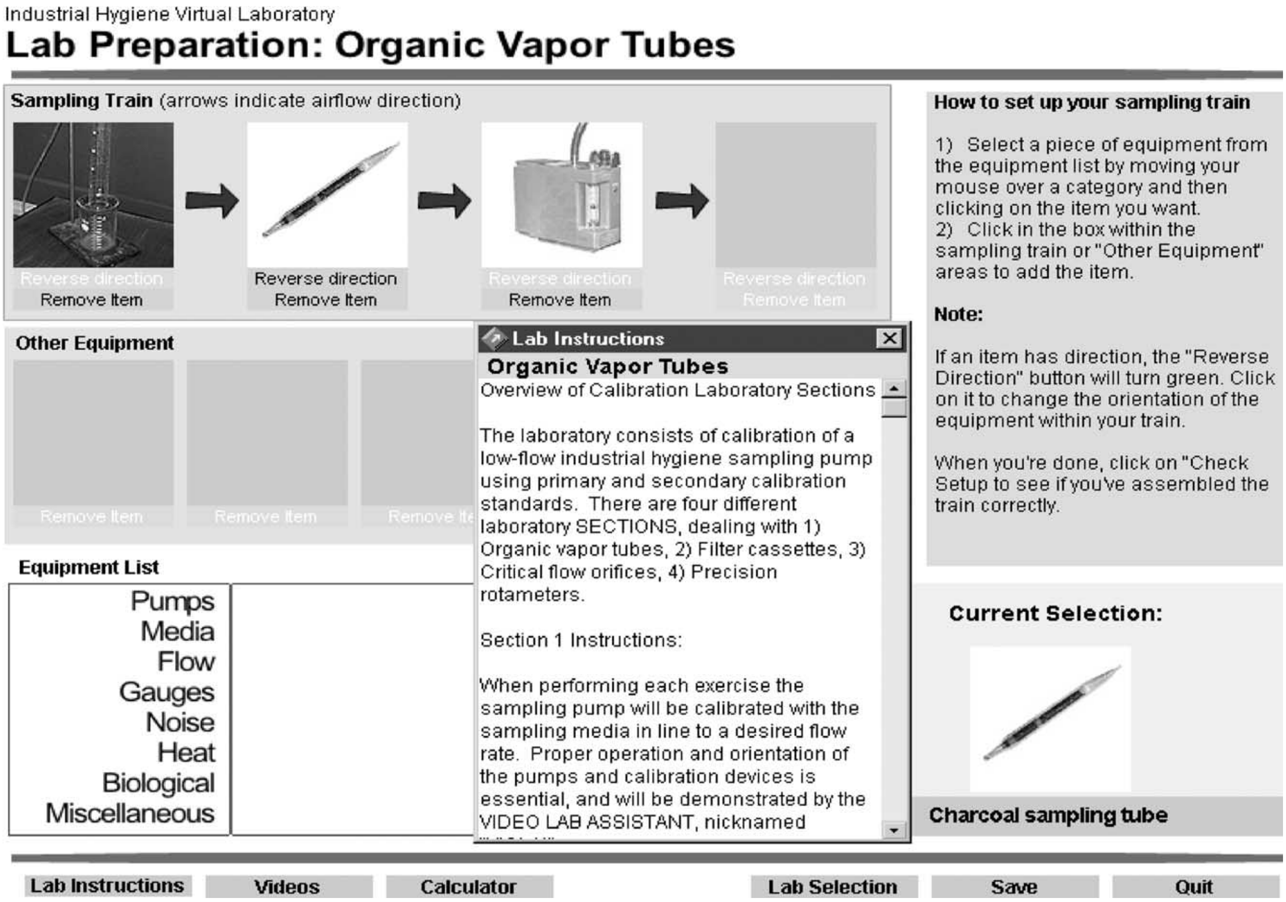

Figure 2. Lab toolbox page. Original application start page, which began with the gas and vapor module. Note the level of complexity and the diversity of choices presented to the user.

open the application on the CD-ROM drive, follow screen instructions to select and assemble a specific subject module (e.g., "Calibrations"), and otherwise freely interact with the program as necessary to complete the laboratory session. The observer did not interfere with the usability testing unless specifically asked a question relating to system operability. Following the completion of their assigned laboratory modules, the students individually completed a questionnaire pertaining to their experience. Complete usability results concerning the toolbox front-end are available online.[19]

Based on users' comments, an IHVL front-end employing a simplified "lab index" concept was designed to replace the "toolbox" model (Figure 3). In addition, revisions were made to all laboratory modules to minimize the operability problems reported. Radio buttons at the immovable bottom taskbar were created to let students see the lab index page, go directly to the electronic Lab Notebook, view NIOSH Manual of Analytical Methods, minimize the IHVL, or exit entirely from the program. The version of the IHVL employing the "lab index" page was then classroom tested among 10 upperclassmen enrolled in a longstanding, university-approved class on the topical material taught by the CD-ROM. Results of efficacy testing of the IHVL are presented in a companion paper.[20]

PEDAGOGY

Traditional laboratory sessions employ a linear teaching pedagogy in which not all aspects of a given technique are to be understood (and occasionally, not controlled). Rather, the student is expected to simply follow instructions to arrive at the desired laboratory endpoint. In this "cookbook" approach, students can readily move forward or backward at any time to repeat or better execute a technique in the lesson. While the linear progression approach has its detractors, from a lesson plan organizational perspective it is the most simple and intuitive approach to learning new material in a hands-on environment.

For these reasons, a linear navigational schema with outcome variability was designed into the IHVL. After the student has recorded his or her name and email address on the application splash screen, he or she is free to select any module within the IHVL program. Once in the selected module, however, progress through the screens is designed to be linear. In certain instances, the student cannot advance to the next program screen until properly completing the current task(s). As an ancillary benefit of the serial progression structure,

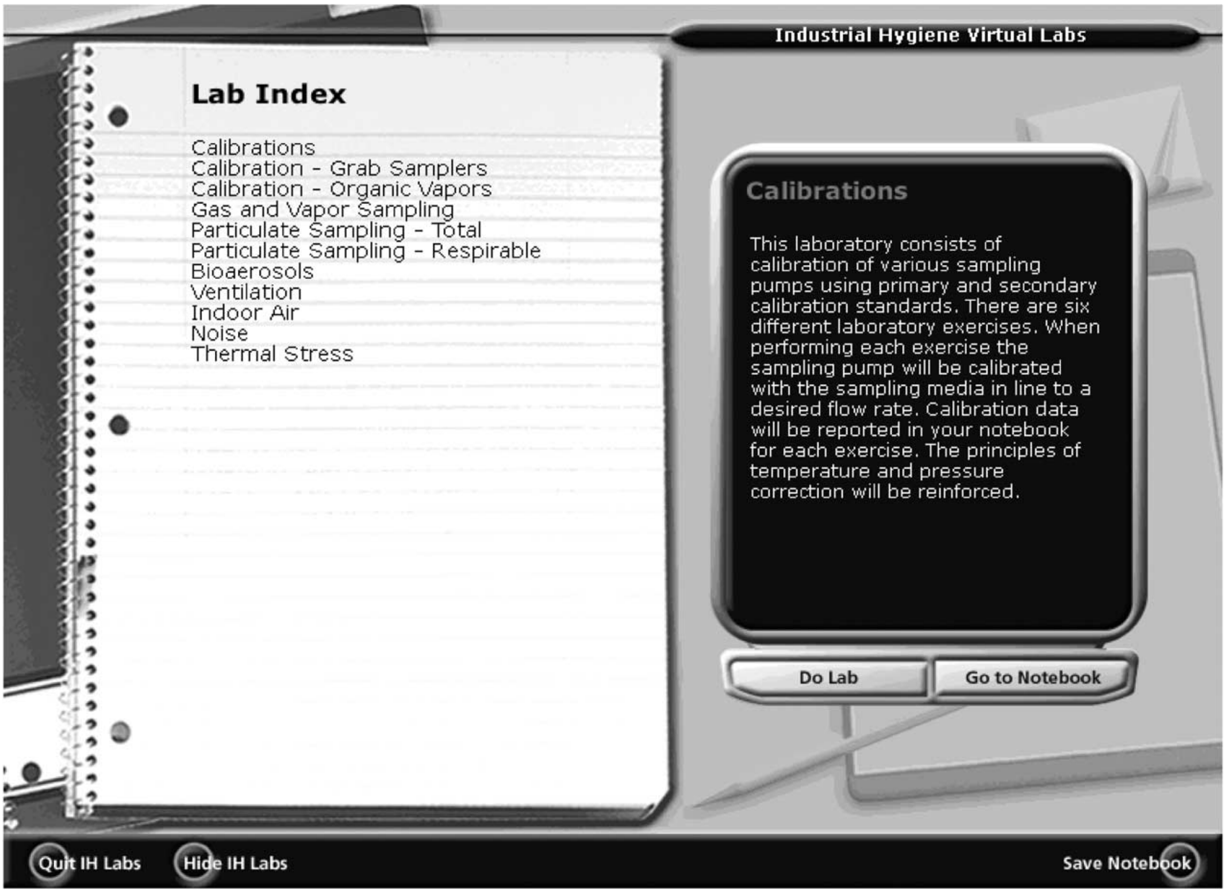

Figure 3. Lab index page. Selection screen ultimately implemented, showing the 11 modules available. The calibrations module has been selected by the user.

student difficulties related to actually using the program are minimized as is attendant frustration at "being lost" within the application shell. Data generated in the IHVL simulations was created to represent realistic value ranges with variability typical of the measurement or device in use.

The traditional chemistry model employing a linear laboratory approach has other pedagogical benefits as well. While learning may not be perfectly enhanced in this approach, such structure does control for issues such as safety and can help reduce the frustration experienced by those struggling to learn new material. Attention is focused on the concepts presented and not on navigating through a complex lesson plan. Furthermore, in this approach students do learn some necessary operational skills (e.g., reading a meniscus) in addition to the key lesson objectives. However, the inherent confusion and lack of a controlled outcome can be serious problems with any live laboratory session. Distractions from other students, large class sizes limiting access to sometimes inappropriately trained teaching assistants, time constraints, and other resources are some of the reasons real-time instructional laboratory sessions are often denigrated by students and faculty alike.[12] In the final analysis, the best that can be stated with any certainty is that the benefits of the traditional teaching laboratory experience are difficult to accurately quantitate, perhaps laying somewhere between the simple quidity of the hands-on experience and the higher-order topical learning intended.

In contrast, within the virtual learning environment everything is controlled. When applied too rigorously this control can negatively affect students' learning by eliminating the randomness and variability that characterize a traditional laboratory outcome. It should be fully appreciated, however, that at the undergraduate teaching level such characteristics may in fact hinder rather than enhance learning, serving only to distract students' attention from the desired outcome. To provide empirical uncertainty while concomitantly minimizing operational difficulty, a virtual laboratory should be designed to provide realistic yet variable data outcomes according to algorithms transparent to the end-user. With few exceptions, each repeated laboratory session should result in an entirely new set of data for the student to analyze and interpret. While such an approach can be more time consuming for the instructor to evaluate in the lab report, it is in fact no more onerous than the reading and evaluation of traditionally completed labs.

Assessment

Testing of the learning facilitated by the IHVL is accomplished by questions posed in the Lab Notebook section of the program. Numerous industrial training applications utilize self-checking program algorithms for measuring the learning of the student, in which the student selects the correct answer from a multiple choice list. While that approach could have been easily implemented with the programming tools available in the IHVL, it was believed that such questions would have to be too limited in scope to adequately present an accredited curriculum in IH. Accordingly, more open-ended questions are asked in the Lab Notebook. For a student to successfully answer all questions he or she would not only have to complete the laboratory exercises proficiently but would also have to conduct rudimentary literature searches (e.g., assigned textbook readings or NIOSH/OSHA web site visits). Drawbacks to this ostensibly more thoughtful approach include the lack of immediate feedback to the student following a laboratory experience, and the need for a qualified instructor to evaluate and grade responses. Benefits of the method are that erroneous conceptual thinking or poor technique demonstration on the part of the student is discretely identified by the course grader. In this design the returned laboratory report can function more effectively as a pedagogical instrument (to the extent the instructor inserts illuminating remarks).

DISCUSSION

As noted earlier, usability studies of the "toolbox" laboratory selection screen prototype clearly indicated that it was too complex for the novice IH student to navigate. Therefore, that complexity was removed by a redesign of the screen into a laboratory "lab index" page. In making this change, the number of possible selections on the front-end of the application was reduced from a possible 40-plus to only 11 (i.e., selection of 1 of 11 laboratory modules). This simplification of the learning experience merits careful consideration. While it is true that the revised approach does not demonstrate all necessary information to a student learning the techniques of air sampling (e.g., necessary orientation of a filter cassette or charcoal tube relative to airflow), neither does the traditional laboratory experience. Traditional lab students also frequently make simple technique errors, even when detailed laboratory instructions are provided. Teaching options to avoid such errors include pre-lab lectures by the on-site instructor, or a companion laboratory guide which more fully explains the importance of key information not included in the laboratory instructions. To address such problems with the IHVL, a users' guide was ultimately developed to fill in information gaps for students when faced with IHVL modules containing less than complete technical guidance on-screen.

Advantages of a virtual laboratory course are numerous. First and foremost among these is that any virtual laboratory is safer than the traditional undergraduate teaching laboratory. To hosting institutions, the minimization or outright elimination of highly hazardous manipulations in favor of virtual exercise counterparts should be attractive. Also of importance to the institution is the lack of a need for expensive teaching laboratory space and equipment, increasingly regulated hazardous materials procurement and security, and the disposal of laboratory wastes. Where a virtual laboratory experience is feasible, the comparatively modest development costs of virtual teaching modules should be given careful consideration.

Attractive as they are to the hosting institution, the benefits of virtual autonomous education are even greater for most students. Whether delivered via the web or in autonomous CD-ROM packages, a multimedia laboratory such as the IHVL offers unprecedented flexibility with respect to laboratory courses. Students-Older-Than-Average (SOTAs) are a special group of learners for whom the autonomy, self-pacing, and convenience of non-campus-based courses are especially attractive. Out of necessity or because of a clearer sense of purpose, SOTAs as a group are more highly motivated than the traditional 4-year residential college student.[21] Older students typically have more time and financial acumen (and obligations) than do their 18–22-year-old counterparts, and so tend to be more efficient in their use of limited and finite resources.[16] For these reasons adult learners are well served by a virtual laboratory opportunity.

Some traditional students attending day classes on campus are also potentially better served by a virtual laboratory approach. In one survey of a lecture-based graduate IH course, almost one-third of the students reportedly preferred the flexibility and convenience of obtaining class content via videotape, as compared with actual class attendance.[11] If Friedlander and Kerns[22] are correct in their assertion that "anonymity breeds apathy," then the large multi-section undergraduate inorganic and organic chemistry labs would be willingly abandoned by motivated students in favor of the one-on-one, student-with-machine setting provided by the IHVL or similar software. Simply put, many of the basic science classes in the university are too large to find acceptance by highly motivated students.[12]

Busy, early-career technicians and specialists represent a student element who may have no continuing education alternative except distance learning. Such persons may be prone to erratic schedules, including frequent and unplanned travel removing them entirely from the campus laboratory for days or weeks at a time. It is difficult for such students to obtain a quality education with a strong continuity element even when class attendance is required only once per week. Similar drawbacks apply to various intensive weekend programs, although mid-career level students will probably be able to more consistently schedule attendance in those experiences.[16] Validated virtual laboratory coursework may successfully fill a niche for aspiring professionals facing these constraints.

SUMMARY

The design elements, decisions, and their rationale in a specific virtual laboratory education program have been described. For all its advantages, an increase in more widespread virtual laboratory education remains uncertain. Croy has concluded that the full acceptance of distance education programs is presently premature.[23] Given the dearth of suitable, full course length virtual laboratory experiences this conclusion seems justifiable with respect to the sciences, at least for the present. Uncertainty exists in the timeframe for the development and testing of new virtual laboratory applications, and for their acceptance in and out of the traditional university setting. Clear advantages to the part-time student or full-time employee are evident from a laboratory experience that can be flexibly arranged. Adoption of new pedagogies such as the virtual laboratory will inevitably occur as a product of evolution from a minority of programs rather than as a wholesale revolution in any particular rubric. However, their development proceeds out of the university and into the autonomous education environment, a necessary next step for all such laboratory sessions is rigorous comparison testing using traditional real-time laboratory experiences as the benchmark.

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