Learner performance and attitudes in traditional versus simulated laboratory experiences

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Evidence suggests that the physical, expository laboratory, as used in both high-school and college-level science courses, has lost its instructional value while emerging technologies such as simulations can serve as robust replacements. However, certain accreditation processes do not recognise the simulated laboratory as a legitimate alternative to expository high-school and college-level laboratories. This study therefore investigated whether simulated laboratories can achieve the goals of contemporary laboratory instruction as successfully as the expository laboratory paradigm. Using an experimental and quantitative methodology, two experiments were carried out, each of which comprised the completion of a laboratory activity by participants who were assigned to either a control (expository laboratory) or an experimental (simulated laboratory) group. The results revealed significant higher assessment means for the simulated groups. The simulated laboratories were also perceived to be more open-ended, easier to use, and easier to generate usable data, than expository laboratories. The time to complete simulated laboratory activities was significantly less than the time to complete expository laboratory activities. The results suggest that the simulated laboratory can serve as a legitimate alternative to the expository, "hands-on" laboratory and those current accreditation practices requiring online science courses to have "hands-on" laboratories need to be reevaluated.

Keywords: simulated laboratories, expository laboratories, achievement, accreditation

Introduction

The laboratory has been a central component of science instruction since the early 20th century (Singer, Hilton, & Schweingruber, 2006). It has been used to teach experimental methods and techniques that clarify and/or validate existing scientific principles and theories and has typically been considered expository in nature (Lagowski, 2002). Expository laboratories use scripted procedures and directions that are given to students in order to minimise potential equipment damage and injury, while maximising potential for generating usable data. The expository approach to instruction is teacher-centered in that the laboratory activities are carried out in scripted, pre-determined fashion under the direct supervision of the instructor. It is the most widely adopted approach to college chemistry instruction (Lagowski, 2002) and high school chemistry. In such environments, students are not allowed to deviate from the prescribed procedures as to minimise time wasted, injury, equipment damaged, and material wasted. Such approaches are problematic because they do not provide opportunities for students to truly explore the limitations of the equipment, materials, and theory they are trying to validate. Nor do they provide opportunities for students to create their own understanding of the phenomena they are investigating. Rather, the expository environment utilises rote procedures which inhibit students from forming a genuine understanding of the connections between the data they collect and the theories the data describe (Eylon & Linn, 1988).

In the case of science laboratory instruction, technology has reached a threshold where virtual or simulated (learner-centered) approaches can formidably meet or exceed the learning outcomes of expository (teacher-centered) approaches. And research suggests that simulated laboratories can dramatically impact learning in positive ways (Alessi & Trollip, 2001; Clark, 2003a; Hessley, 2004; Huppert, Lomask, & Lazarowitz, 2002; Kennepohl, 2001; Mencer, 2002; Wieman & Perkins, 2005). There also exists a need for the implementation of online or virtual laboratories as supplements or replacements for the traditional high school and college laboratory (Bhargava, Antonakakis, Cunningham, & Zehnder, 2005), which is important given current accreditation processes which stipulate that online science courses have a “hands-on” laboratory, not a simulated one. These accreditation processes continue to oppose the adoption of virtual laboratories as alternatives (College Board, 2006a; National Science Teachers Association [NSTA], 2005).

Therefore this study is designed to investigate the extent to which simulated laboratories can achieve learning outcomes as successfully as the expository laboratory paradigm. Concurrently, this study will address the differences and similarities in possible student attitudes toward using a simulated and an expository laboratory. The results of this study will provide insight into whether or not a simulated laboratory can serve as an effective replacement for the expository laboratory, based on two key questions: (1) what is the instructional value of the expository laboratory in terms of student attitude and learner performance? and (2) what instructional value do virtual or simulated laboratories provide in terms of student attitude and learner performance?

Methodology

This study used a comparative methodology in which students performed laboratory investigations in an expository and a simulated environment. To answer questions of performance (the cognitive domain), comparative assessment data were gathered in the form of a performance assessment (Kennepohl, 2001; Bourque & Carlson, 1987; Rivers & Vockel, 1987; Huppert et al., 2002). To answer attitudinal questions (the affective domain), data were gathered in the form of a questionnaire (White and Bodner, 1999; Harrison, Fisher & Henderson, 1997). Two criteria were used to select the laboratory experience for this study. First, it was established that a “typical” science laboratory should be integrated into the science curriculum (Singer et al., 2006). Therefore the laboratory chosen for this study was also integrated into the science curriculum which, in this case, the high school chemistry curriculum. Second, in the case of general chemistry instruction, the laboratories chosen reflected the central theme of the general high school and college chemistry curriculum which, in this case, was Chemical Stoichiometry, as recommended by Robinson (2003) and Jensen (2003). Specifically, the two laboratory experiences chosen for this study were from the Late Nite Laboratories online simulation library: *Laboratory 1: Empirical Formula of a Hydrate* and *Laboratory 2: Stoichiometry by Loss of* CO_2 (Late Nite Laboratories, 2005). Both of these laboratories are listed as recommended experiences for the college-prep chemistry curriculum (The College Board, 2004).

Sample

Participants were randomly assigned to the experimental (simulated) or the control (expository) laboratory groups (Gall, Gall & Borg, 2003). Once groups were assigned, a computer training session took place for all participants whereby the simulation software was introduced, and students directed to complete an online sample laboratory. Five classes of chemistry students (n = 95) participated in this study and students in all five classes were randomly assigned to one of two groups: experimental or control. Students in Class 1 participated in the pilot study, while students in Classes 2-5 participated in the study.

Experiment 1 was conducted in a 55-minute class period. All students in chemistry classes 1-4 who had been randomly assigned to the control group performed the expository version of *Laboratory 1: Empirical Formula of a Hydrate* during the regularly scheduled class period. Following completion of this activity, students answered the *Laboratory 1 Assessment Question*. Similarly, all students in chemistry classes 1-4 who had been randomly assigned to the experimental group performed the simulated version (online) of *Laboratory 1: Empirical Formula of a Hydrate* during the regularly scheduled class period. Following the completion of this activity, students answered questions on the laboratory assignment for *Laboratory 1* and submitted work at end of class. Experiment 2 was carried out on the day following Experiment 1.All students in chemistry classes 1-4 who were initially assigned to the control group were assigned to the experimental group for Experiment 2. The experimental group performed the simulated version of *Laboratory 2: Stoichiometry by Loss of* CO_2 during the regularly scheduled class period. Following the completion of this activity, students answered questions on the laboratory assignment for *Laboratory 2* and submitted work at the end of class. Similarly, students who were initially assigned to the experimental group for Experiment 1 were assigned to the control group for Experiment 2. The control group performed the expository version of *Laboratory 2: Stoichiometry by Loss of* CO_2 during the regularly scheduled class period. Following the completion of this activity, students answered questions on the laboratory assignment for *Laboratory 2* and submitted work at the end of class.

The rationale for having each group switch experience from expository to virtual or vice versa was to ensure that comparative, attitudinal, and performance data could be collected for each student for each experience, virtual and expository. If students from each group conducted both laboratories using the same approach (i.e., Laboratory 1 virtual, Laboratory 2 virtual; or Laboratory 1 expository, Laboratory 2 expository), comparative data could not be obtained, and Hawthorne effects could not be eliminated. After all experiments were conducted, students in both groups were given a questionnaire that inventoried student attitudes toward the expository laboratory experience and the simulated laboratory experience. The questionnaire that was developed for this study was adapted from the *Science Laboratory Environment Inventory* (SLEI) (Fraser, McRobbie, & Giddings, 1993), the *Computer Laboratory Environment Inventory* (CLEI), and *Attitudes towards Computers and Computer Courses* (ACC), all of which were used in studies involving college students. The questionnaire was comprised of 39-items in a Likert-scale form.

Performance assessment

The assessments originated from laboratory assessment questions that were answered upon completion of the laboratory investigation. The assessment question for *Laboratory 1* came from *Chemistry* by Chang (2003), and the assessment question for *Laboratory 2* came from Late Nite Laboratories (2005). Both of which are used for high school and college chemistry instruction. Each assessment question required the interpretation of collected data along with the application of this interpretation to describe a chemical principle. Each question had a "correct" answer, and student responses were graded based on whether or not the student gave the correct answer. The assessment questions used here specifically addressed the *application competence* of Bloom's Taxonomy where students "use information, use methods, concepts, theories in new situations to solve problems using required skills or knowledge" (Learning Skills Program, 2006). Questions within this competency typically require students to apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, and discover (Learning Skills Program, 2006). Such assessments measure the contemporary goals of science laboratory instruction, in that laboratory experiences should (a) enhance student mastery; (b) develop scientific reasoning; (c) assist in understanding complexities of empirical work; (d) develop practical skills; (e) understand the nature of science (Singer et al., 2006).

Results

To measure learner performance differences, post-laboratory assessment data were analysed, and assessment means, which resulted from the simulated laboratory groups and the expository laboratory groups, were compared. A t-test was used to determine if the difference between means for these groups was significant. To measure learner attitude differences that existed between the simulated and expository laboratory environments, questionnaire data were analysed. Specifically, paired items from the questionnaire were compared in order to determine differences in learner attitudes with respect to the simulated and expository laboratory experiences. These differences were broken into six categories: (a) open-endedness (extent to which the laboratory activities emphasise an open-ended, divergent approach to experimentation (Fraser et al., 1993); (b) equipment usability (how easy equipment was to use); (c) fidelity of experiment (how realistic the experiment/problem was); (d) equipment functionality (how easy it was to generate and collect data); (e) user preference (students preference for simulated or expository); (f) completion time (time to complete experiment) (White & Bodner, 1999). The means for each question were calculated, and a t-test was carried out to determine significant differences between the means for each item (simulated or expository). The data collected to measure learner performance differences between expository and simulated laboratories were expressed as a percent of assessment questions answered correctly. The means were also expressed as percents. The sample sizes (*n*), means ( ), standard deviations (*s*), and variances (s^2) obtained from Laboratory 1 and Laboratory 2 assessments are shown in Tables 1 and 2.

Table 1: Statistical analysis laboratory 1

Laboratory 1	Simulated	Expository
Sample Size (n)	$n_{simulated} = 47$	$n_{expository} = 48$
Mean, Standard deviation, s variances, s^2	$s_{simulated} = .504$ $s^2_{simulated} = .254$	$s_{expository} = .494$ $s^2_{expository} = .240$

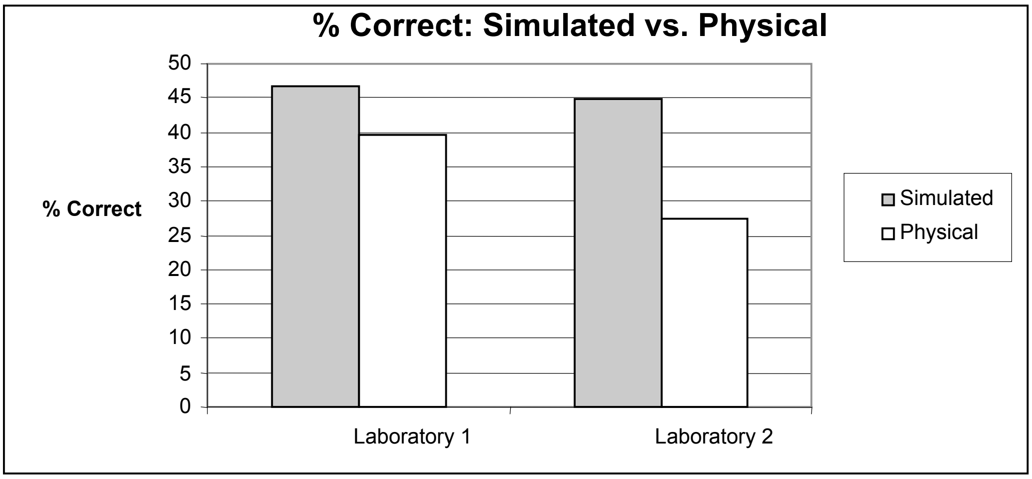
Table 2: Statistical analysis laboratory 2

Laboratory 2	Simulated	Expository
Sample Size (n)	$n_{simulated} = 41$	$n_{expository} = 49$
Mean, Standard deviation, s variances, s^2	$s_{simulated} = 1.37$ $s^2_{simulated} = 1.88$	$s_{expository} = 1.05$ $s^2_{expository} = 1.11$

Test statistics

To analyse the instructional value of the expository laboratory with respect to learner performance, comparisons of the mean assessment scores between the control groups and experimental groups for Laboratory 1 and Laboratory 2 were carried out. Figure 1 presents the assessment means for Laboratory 1 (simulated and expository) and the assessment means for Laboratory 2 (simulated and expository). T-tests were conducted to determine difference of means between simulated laboratories and expository laboratories. Table 3 presents the null hypothesis (H_0), alternate hypothesis (H_1) and test statistics ($t_{crit.}$, $t_{calc.}$, d.f.) for learner performance components.

Figure 1: Assessment means for laboratory 1 (simulated and expository) and the assessment means for laboratory 2 (simulated and expository).



Learner performance data

Upon reviewing the data resulting from the t-tests, it was evident that there were significant differences between the assessment means of the simulated laboratory groups and the expository laboratory groups for both Laboratory 1 and Laboratory 2. The t-test analyses clearly showed that not only were there significant differences in the assessment means between the simulated laboratory and expository laboratory groups but also that the assessment means for the simulated laboratory groups were significantly higher than the assessment means of the expository laboratory groups. Learners who conducted the simulated laboratory version outperformed, on performance assessments, those who conducted the expository version of the same laboratory. Therefore the following conclusions were made regarding learner performance:

- The instructional value of the expository laboratory in terms of learner performance was that the expository laboratories were of lesser value when compared to the simulated versions.
- The instructional value of simulated laboratories in terms of learner performance was that students who conducted the simulated laboratories outperformed students who conducted the expository laboratory versions. Virtual or simulated laboratory experiences were of greater value from a learner performance standpoint.

Table 3: Hypotheses and test statistics – learner performance component

	Laboratory 1	Laboratory 2
Hypotheses		
Null Statement	The mean assessment scores for the simulated version of Laboratory 1 are the same as the mean assessment scores for the expository version of Laboratory 1.	The mean assessment scores for the simulated version of Laboratory 2 are equal to the mean assessment scores for the expository version of Laboratory 2.
t-values ($t_{calc.}$; $t_{crit.}$)	$t_{calc.} = 7.35$; t_{crit} was 1.99 at a = .05	$t_{calc.} = 7.20$; T_{crit} was 1.99 at a = .05
Degrees of Freedom (d.f.)	d.f. = 100	d.f. = 100
Test	$t_{calc} = 7.35 > T_{crit} = 1.99$	$t_{calc} = 7.20 > T_{crit} = 1.99$
Outcome	Reject the null hypothesis that	Reject the null hypothesis that

Questionnaire data

The items on the questionnaire measured learner attitude with respect to the simulated and expository laboratory experience. Specifically, participants evaluated each questionnaire item as: (1) almost never; (2) seldom; (3) sometimes; (4) often; (5) very often. Of the 39 questionnaire items, 12 questions (6 pairs: simulation-specific and expository laboratory-specific) were included in the attitudinal analysis. Each pair of questions addressed one of six categories specific to both the expository and simulated laboratory environments: (1) open-endedness (the extent to which the laboratory activities emphasise an open-ended, divergent approach to experimentation) (Fraser et al., 1993); (2) equipment usability (how easy equipment was to use); (3) fidelity of experiment (how realistic the experiment/problem was); (4) equipment functionality (how easy it was to generate and collect data); (5) user preference (whether students preferred simulated or expository); (6) completion time (time to complete experiment) (White & Bodner, 1999). Table 4 displays the question category in relation to the paired items used, simulated and expository.

Table 4: Question category in relation to the paired items used, simulated and expository

Category	Relevant Questionnaire Item
I. Open-Endedness	#2 There is opportunity for me to pursue my own experimental interests in the simulated laboratory. #3 There is opportunity for me to pursue my own experimental interests in the regular laboratory.
II. Equipment Usability	#12 It was easy to learn and operate the computer simulation. #27 The regular laboratories were easier to learn and operate than the computer equipment.
III. Fidelity of experiment	#33 Regular laboratories give me a better sense of the kinds of problems likely to be encountered in “real-life”. #25 Computer simulations allow me to study problems that are more complex and realistic than regular laboratories.
IV. Functionality	#11 The regular experiments worked better than the computer experiments. #29 Computer simulations work better than regular experiments.
V. User Preference	#9 I liked using computer simulations. #10 I like the regular laboratory.
VI. Completion Time	#22 The simulated laboratory experiments took less time to perform. #35 A higher percentage of our time was spent planning the design of the computer experiments.

Hypothesis testing

The means for questionnaire pairs *2 & 3, 12 & 27, 33 & 25, 11 & 29, 9 & 10, and 22* & *35* were calculated. T-tests were then carried out to determine significant differences between the means for each item (simulated or expository).

Upon review of the questionnaire items, the instructional value of the expository laboratory in terms of *learner attitude* was determined to be the following. First, the *open-endedness category* of the expository laboratories received a score of 3.4, indicating that, in the students' view, the expository laboratory was open-ended *sometimes*. Second, the *equipment usability category*, which measured the degree to which students were able to use the requisite experimental equipment, scored 2.6 for regular laboratories, indicating that the ease with which the equipment could be used was between the scales of *sometimes* and *seldom*. Third, the *fidelity of experiment category*, which measured how realistic the experiment was, scored a 3.2 for regular laboratories. Students responded that expository laboratories *sometimes* give a better sense of the kinds of problems likely to be encountered in "real-life." Fourth, the *functionality category*, which measured the degree to which a particular laboratory "worked," scored 2.8 for expository laboratories. This score indicated that students believed the "regular" laboratories worked between the scales of *sometimes* and *seldom*. Fifth, the *user preference category*, which measured the preference students had for a particular environment (simulated or regular) scored 3.8. for expository laboratories. This indicated that students' preference for the expository laboratory was between the scales of *often* and *sometimes*. Sixth, the *completion time category*, which measured the time necessary to complete a laboratory activity, scored 2.4 for expository laboratories. This indicated that, in the students' view, the simulated laboratories *seldom* took longer than the expository laboratory; the expository laboratories frequently took longer time to complete. Therefore, when considering the instructional value of expository laboratories in relation to learner attitude, expository laboratories had less value than simulated laboratories.

The instructional value of the simulated laboratory in relation to learner attitude was determined to be the following. First, the simulated laboratories received a score of 3.8 for the *open-endedness category*. This score indicated that, in the students' view, the simulated laboratories were open-ended *often* and provided students opportunities to pursue their own experimental interests. Second, with respect to the *equipment usability category*, simulated laboratories scored 4.1, indicating that the equipment could *often* be used with ease. Third, with respect to the *fidelity of experiment category*, simulated laboratories scored a 3.6. Students responded that simulated laboratories *often* gave a better sense of the kinds of problems likely to be encountered in "real-life." Fourth, with respect to the *functionality category*, simulated laboratories scored a 3.5, indicating that students believed the simulated laboratories worked *very often*. Fifth, with respect to the *user preference category*, simulated laboratories scored a 4.1. This score indicated that students *very often* preferred the simulated laboratory version over the expository laboratory version. Sixth, with respect to the *completion time category*, the simulated laboratories scored a 4.3. This score indicated that, in the students' view, the simulated laboratories *very often* took less time to complete when compared to expository laboratories. Therefore, when considering the instructional value of simulated laboratories in relation to learner attitude, simulated laboratories had equal or greater value to students than expository laboratories.

Discussion

While the findings of this study clearly showed that simulated laboratories resulted in learner performance gains over expository laboratories and that student attitudes regarding simulated laboratories were markedly greater than expository laboratories, exactly why these differences occurred and what they mean in a broader context must be further explored.

The finding that students using simulated laboratories outperformed students who used expository laboratories suggests that there were learning differences between the two environments. The differences may have been that the simulated laboratories reduced the cognitive load typically found in the "hands-on" laboratories. This is consistent with the literature in that simulations have been shown to reduce cognitive load (Clark, 2003b) by controlling the progression of complex elements of a model (Huppert et al., 2002). Furthermore, the possibility that simulated laboratories reduced cognitive load is consistent with Mencer's (2002) findings which showed that students can control the time, location, and pace of their interaction with the simulation. This is also consistent with questionnaire data from item 12, which stated, "It was easy to learn and operate the computer simulation." Seventy-three percent of respondents stated that it was easy to learn and operate the computer simulation "very often" or "often." Hence, one reason why post-laboratory assessment scores were higher for simulated laboratories may be due to their ability to reduce cognitive noise.

The finding that simulated laboratories were perceived to be more open-ended than expository laboratories suggests that students could more easily explore and experiment with the virtual equipment than the expository equipment. In such environments, the learner has the freedom to explore, experiment, and deviate from prescribed procedures (Bhargava et al., 2005). This finding is consistent with the literature in that simulated laboratories provide students more freedom to explore and experiment, which may yield more time to engage in higher-level thinking and data analysis (Powell et al., 2002). Similarly, this finding is consistent with claims made about the lack of open-endedness found in expository laboratories. For instance, expository environments emphasise lower-cognitive skills (e.g., rote learning, algorithmic problem-solving, recall, and rule application) and give little attention to higher-level thinking like investigation planning and interpretation of results (Bhargava et al., 2005; Domin, 1999). The finding that the simulated laboratories were more *open-ended* than the expository laboratories is also consistent with the contemporary goals of the science laboratory. Specifically, the laboratory should provide students with the ability to interact directly with the material world or with data derived from it. In their interactions, students should be instructed in the tools and techniques of data collection and analysis, along with guidance in how their interpretations reflect the underlying model under investigation (Singer et al., 2006). The open-endedness of the simulated laboratories is congruent with these goals.

The findings that simulated laboratories were perceived easier to use than expository laboratories and that students preferred using simulated laboratories over expository laboratories suggest that laboratory simulations may be more motivating. These findings are consistent with Towne's (1995) claims that simulations are motivating and can enhance transfer of learning and suggest that simulations can effectively serve the "hands-on" role of the traditional laboratory, an activity which has historically been cited as being motivating. Moreover, this finding refutes claims that the expository laboratory increases student interest in science. For instance, claims that the expository laboratory may increase student interest in science (Singer et al., 2006) and can also improve student attitudes toward science (Bhargava et al., 2005; Renner et al., 1985; Denny & Chennell, 1986) are not in agreement with the finding that simulated laboratories were perceived easier to use than expository laboratories. Hence, there are indications that the simulated laboratory may have been more motivating than the expository laboratory, even though one reason for requiring "hands-on" laboratories is the claim that they are motivating. The reasons why simulated laboratories were perceived easier to use may be due to the "hands-on" way in which students interact with the environment. In such environments, learners explore, experiment with, and deviate from prescribed procedures (Bhargava et al., 2005). "Hands-on" in the virtual world may actually mean "hands-on" the learning objects within that environment.

The findings have implications regarding the design of simulated high school and college-level laboratories for the 21st century. According to Singer et al. (2006), the role of the laboratory in 21st century science instruction is to (a) enhance mastery of subject matter, (b) develop scientific reasoning, (c) assist students in understanding the complexity and ambiguity of empirical work, (d) develop practical skills, and (e) understand the nature of science. However, no single laboratory experience is likely to achieve all these learning goals. Laboratory design for the 21st century should take into account the aforementioned goals of 21st century science. The design implications of this study were compared to the prescribed goals of the 21st century laboratory.

First, the findings of this study reveal that simulated laboratories may not effectively enhance the mastery of subject matter. This was evident in the mean post-laboratory assessment scores for Laboratory 1 and Laboratory 2, which were 45% and 47%, respectively. Although the overall goal of these laboratories was not to enhance mastery of learning, future designs should consider ways to accomplish this. Potential design improvements could include tutorial sections which provide necessary information that guides the learner through the sequence of the simulation. Recent studies on laboratory simulations such as Linn and Hsi (2000) have suggested that students can learn scientific concepts along with graph interpretation from using real-time data collection tools. Future versions may include intelligent tutors (e.g., peer tutors and expert agents) who can assist learners in their laboratory investigation. Second, this study found that the simulated laboratories used here may have assisted students in the process of developing scientific reasoning skills--an aforementioned goal of 21st century laboratories. This evidence stems from the questionnaire categories which were discussed earlier in this chapter, namely the ability of simulations to generate usable data and the ability of students to spend more time problem solving and interpreting/analysing data. For instance, questionnaire item 24, which stated, "In simulated laboratories, we have more time for problem solving and data analysis/interpretation," resulted in 68% of respondents stating that there was "very often" or "often" more time for problem solving and data analysis/

interpretation in simulated laboratories. Hence, there is evidence that the simulated laboratories used in this study may have assisted students in the process of developing scientific reasoning skills, such as generating usable data and analysing and interpreting such data.

Third, simulated laboratories were found to be mediocre in providing instruction consistent with the 21st century laboratory goal of teaching the complexity and ambiguity of empirical work. For instance, questionnaire item 25, which stated "The computer simulations allow me to study problems that are more complex and realistic than regular laboratories," provided some insight. Of the 94 students who answered this question, 0 answered *very often*, 24 (25.5%) answered *often*, 39 (41.5%) answered *sometimes*, 8 (8.5%) answered *seldom*, and 1 (1.1%) answered *almost never*. From these data, it is apparent that the simulation design could be changed to create an environment where students can investigate more complex and realistic problems. Fourth, while this study involved high school science students, the labs, assessment items and questionnaire items were adapted from college-level chemistry texts, and laboratory activities, (Chang, 2002; Late Nite Laboratories, 2005; Lagowski, 2002, College Board, 2006b). Therefore, the findings may have implications to laboratory science as used in higher education. Lastly, the findings of this study refute claims that simulations may promote a lack of human contact and may lead to boredom in students (Kennenpohl, 2001). For example, questionnaire item (31), which stated "I would be comfortable performing laboratories at home, online," attempted to measure this. Of the 94 students that responded to this question, 32 (34.0%) answered *very often*, 24 (25.5%) answered *often*, 21 (22.3%) answered *sometimes*, 10 (10.6%) answered *seldom*, and 7 (7.4%) answered *almost never*. Therefore, the findings of this study suggest that simulated laboratories should be made available online for access at home.

The findings of this study, that the simulated laboratory is a legitimate alternative to the traditional "hands-on" laboratory with respect to learner performance and learner attitude, are contrary to the accreditation process for online science courses. According to the College Board (2006a) and NSTA (2005), the science laboratory experience should be "hands-on," not virtual. The findings of this study show the contrary: simulated laboratories *are* effective alternatives to the traditional "hands-on" laboratories. These findings are consistent with the literature in that a need exists for the implementation of online, virtual laboratories, as alternatives to the traditional (expository) laboratory (Bhargava et al., 2005). It has been shown that simulated laboratories can dramatically impact learning in positive ways (Wieman & Perkins, 2005; Clark, 2003c; Mencer, 2002; Hessley, 2004; Huppert et al., 2002; Alessi & Trollip, 2001; Kennepohl, 2001; Linn & Hsi, 2000; Towne, 1995). The findings of this study are consistent with such claims. Therefore, regarding the accreditation process for face-to-face and online science classes, the findings of this study demonstrate that simulated laboratories should be regarded as effective alternatives to the traditional "hands-on" laboratories. Furthermore, the current use of "hands-on" should be revisited in light of the characteristics of 21st century learning environments.

Conclusion

This study shows that the simulated laboratory can serve as a legitimate alternative to the expository, "hands-on" laboratory which is frequently used in science courses. The current accreditation practice of requiring online science courses to have "hands-on" laboratories should be reevaluated to include simulated laboratories as alternatives. Requiring "hands-on" laboratories in online science classes denies the neediest students access and equitability to science classes (The National Academic Council for Online Learning [NACOL], 2006).Recent position statements from the College Board (2004, 2005, 2006a, 2006b) and the NSTA (2005) should be changed to reflect simulation laboratories as legitimate alternatives to the required "hands-on" laboratories used in science classes, both face-to-face and online. Furthermore, this study indicates that the simulated version of a "hands-on" laboratory may actually provide more freedom for students to explore and deviate from prescribed procedures. Such approaches are consistent with 21st Century learning environments whereby students construct their understanding of the expository world in learning environments that are active, digital, virtual, and online (Oblinger & Oblinger, 2005).Therefore, the very nature of simulating "hands-on" laboratories, making the equipment and materials virtual, may change the nature of the experiments from prescribed and expository to open-ended.

It is apparent that technology has reached a threshold where virtual or simulated approaches can meet or exceed the learning outcomes of expository (teacher-centered) approaches. While simulations are frequently used in science research, they are rarely used in science education (Zurn, Piotto & Nesper, 2003). The laboratory of the 21st century must embrace the changes that have occurred over the last century in terms of laboratory goals, student needs, job skills, and technology. The implications found here suggest that contemporary laboratory instruction should consist of environments which generate usable data, albeit virtual, thereby focussing student attention on analysis and interpretations of how data support or refute understanding of scientific processes and principles. The 21st century laboratory environment must be a learner-centered space which fosters higher-level thinking skills through the manipulation of ideas in virtual spaces: a virtual "hands-on" environment for the “millennials.” Could it be possible that “hands-on” for the online world has forever meant “hands-on” the mouse, rather than “hands-on” the Bunsen burner?

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