Investigating the Effectiveness of Virtual Laboratories in an Undergraduate Biology Course

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ABSTRACT

In the last 20 years online distance education has become a valuable andragogical tool. The purpose of the current study was designed to investigate student perceptions of biology virtual laboratories. Research findings indicate that students prefer to participate in virtual labs compared to traditional (e.g., face-to-face) labs. Data also indicated that students perceived higher learning gains as a result of participating in virtual labs compared to traditional hands-on labs. Suggestions for future research studies examining virtual laboratory effectiveness in science courses are explored in this article.

INTRODUCTION

There has been substantial evidence over the last several decades that web-based learning interventions have positive effects on student learning outcomes (Allen & Seaman, 2010) and student engagement (Chen, Lambert, & Guidry, 2010). However, there are still very important aspects of online distance education that are not supported in the research literature such as the development and implementation of virtual laboratories in science courses. Virtual laboratories are computer simulations that contain specific instructions, procedures, methods of data analysis, and data presentation algorithms (Flowers, Moore, & Flowers, 2011). While the research literature on the use of virtual laboratories in science courses is scarce, a few research articles have shed light on the effectiveness of this pedagogical strategy in higher education (Dalgaro, Bishop, Adlong, & Bedgood, 2009; Dobson, 2009; Swan & O’Donnell, 2009). Most of the research on virtual laboratory effectiveness has been positive, however, the literature also contains reports that demonstrate student perceptions of virtual labs are less than favorable when compared to traditional labs (Stuckey-Mickell & Stuckey-Danner, 2007). Specifically, previous research on virtual laboratories has focused exclusively on comparing learning gains (e.g., course content) between virtual laboratories and hands-on laboratories. For example, employing a Virtual Physiology of Exercise Laboratory (VPEL) program designed to mimic assay design, data collection, and analysis components of traditional exercise physiology laboratories, Dobson (2009) noted that virtual laboratories are just as effective conveyors of practical knowledge as hands-on laboratories.

In addition to the valuable studies that already exist related to this exciting area of research, the research questions employed in the current investigation also explored student perceptions regarding the ability of virtual labs to effectively teach them how to learn biology laboratory procedures and use biology laboratory equipment. Moreover, this report provides helpful research suggestions for science faculty and science educators. Significant examination of past and current research findings are paramount in order to further develop and implement successful pedagogical strategies employing virtual labs.
METHODS

Student Population Parameters and Course Information

The sample size consisted of 19 undergraduate non-science majors (n=19) enrolled in an introductory biology course at a postsecondary 4-year university from the southeastern region. A total of 6 males and 13 females participated in the quantitative study. Students participated in a traditional course that initially involved participation in standard face-to-face laboratories followed by participation in cognate technology-based laboratories. According to the course catalog, the biology course is an introductory course covering basic biological concepts that provides the student with a comprehensive survey of the biological sciences. Important areas that were investigated in the course are: cell structure and reproduction, energy relationships at the cellular level, genetics, DNA, evolution, microorganisms, plants, and animal organ systems.

Five virtual laboratories (McGraw-Hill) were employed during the semester: Dependent and Independent Variables, Enzyme Controlled Reactions, Cell Reproduction, Punnett Squares, and Pathology. Using the virtual lab computer simulations students designed experiments using computer mouse manipulations (e.g., pointing and clicking). Following the completion of the virtual laboratory and subsequent generation of experimental data, students answered lab-specific questions to measure understanding of scientific material. Additionally, students participated in five 2-hour traditional (face-to-face) laboratories. Student participants covered a variety of academic disciplines including education, criminal justice, psychology, geography, business administration, political science, and sociology. The majority of the respondents reported a cumulative grade point average of over 2.5 (4.0 - 3.5 [3], 3.4 - 3.0 [4], 2.9 - 2.5 [6], 2.4 2.0 [4], 1.9 - 1.5 [2], 1.4 - 1.0 [0], Below 1.0 [0]). A 5-point Likert scale was used to analyze student perceptions of virtual labs. Approximately 78% of the respondents reported to enrolling in 1 or less online non-biology course during their academic career (How many fully online courses have you taken as a student at your university that were not biology courses?). Additionally, over 90% of the respondents have never enrolled in an online biology course during their academic career (How many fully online courses in biology have you taken as a student at your university?).

Procedures

Institutional Review Board (IRB) approval was obtained for the study. Data was collected using a quantitative survey instrument. Demographic items and Likert-type items comprised of the following options: Strongly Disagree, Disagree, Neither Disagree or Agree, Agree, and Strongly Agree were constructed to compare perceived learning outcomes as a result of the virtual laboratory interventions. Data collection procedures were implemented at the end of the semester following student completion of 5 traditional laboratories and 5 cognate virtual laboratories. The current study examined the following research questions:
1. I think I learned more biology concepts participating in virtual labs compared to traditional (e.g., face-to-face) labs.
2. I think I learned more about how to perform biology laboratory procedures in virtual labs compared to traditional (e.g., face-to-face) labs.
3. I think I learned more about how to use biology laboratory equipment participating in virtual labs compared to traditional (e.g., face-to-face) labs.
4. I prefer to participate in virtual labs compared to traditional (e.g., face-to-face) labs.
Data Analysis

Student perceptions were converted to percentages by dividing actual student response numbers for each component of the response scale by the total number of responses for each research question (Table 1). Bar graphs were generated to highlight student results. Raw numbers from student responses for each component of the response scale were used to construct the bar graphs (Figure 1).

RESULTS

Table 1 shows the percentages of research question responses. The majority of the students perceived higher learning gains participating in virtual labs (52.6 - strongly agree and agree). A higher percentage of students either strongly agreed or agreed (47.4) compared to students that strongly disagreed or disagreed (31.6) to the research question designed to determine whether participation in virtual labs was more effective in teaching biology laboratory procedures compared to traditional labs. The majority of the students did not believe that virtual labs were effective in teaching them how to operate biology laboratory equipment (52.6 - strongly disagree and disagree). Table 1 also presents findings that students prefer to participate in virtual labs compared to traditional labs (52.6 - strongly agree and agree). Student response data is further illustrated by bar graphs (Figure 1).

<table>
<thead>
<tr>
<th>Table 1: Percentages of Research Question Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. I think I learned more biology concepts participating in virtual labs compared to traditional (e.g., face-to-face) labs.</td>
</tr>
<tr>
<td>Strongly Disagree</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Disagree</td>
</tr>
<tr>
<td>5.26</td>
</tr>
</tbody>
</table>

B. I think I learned more about how to perform biology laboratory procedures in virtual labs compared to traditional (e.g., face-to-face) labs.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disagree</td>
<td>Neither Disagree or Agree</td>
</tr>
<tr>
<td>10.53</td>
<td>21.05</td>
</tr>
</tbody>
</table>

C. I think I learned more about how to use biology laboratory equipment participating in virtual labs compared to traditional (e.g., face-to-face) labs.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disagree</td>
<td>Neither Disagree or Agree</td>
</tr>
<tr>
<td>10.53</td>
<td>42.11</td>
</tr>
</tbody>
</table>

D. I prefer to participate in virtual labs compared to traditional (e.g., face-to-face) labs.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disagree</td>
<td>Neither Disagree or Agree</td>
</tr>
<tr>
<td>5.26</td>
<td>21.05</td>
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</table>
Figure 1: Undergraduate student virtual lab survey data.

A. I think I learned more biology concepts participating in virtual labs compared to traditional labs.

B. I think I learned more about how to perform biology laboratory procedures in virtual labs compared to traditional labs.

C. I think I learned more about how to use biology laboratory equipment participating in virtual labs compared to traditional labs.

D. I prefer to participate in virtual labs compared to traditional labs.
DISCUSSION

Virtual laboratories are instructional approaches that involve technology-mediated instruction whereby the aim is to facilitate learning on the utilization, function, or purpose of scientific techniques or experimental procedures. The implementation of virtual labs in science courses can enhance understanding of lecture material, teach critical-thinking skills, and improve problem-solving skills (Flowers, Moore, Flowers, & 2011). There are only a few literary sources that examine the use of virtual laboratories in biology college courses (Stuckey-Mickell & Stuckey-Danner, 2007; Weisman, 2003), therefore this article is primarily designed to enhance the research literature in this area. The current study examines student perceptions regarding key learning outcomes related to the use of asynchronous virtual laboratories. Questions were constructed to provide an initial investigation to determine the extent to which participation in virtual laboratories had an effect on understanding biological concepts, learning how to use laboratory equipment, and learning biology laboratory procedures in a general biology course for non-science majors.

Unfortunately, there is a substantial lag in the amount of completely online science, technology, engineering and math (STEM) courses when compared to online courses in education, business, or the social sciences. Traditional science and engineering courses typically involve a hands-on laboratory component designed to mediate technical understanding of specialized laboratory techniques, enhance lecture material, and teach problem-solving skills. A major reason for the delay in acceptance of fully online courses in STEM fields is the difficulty of implementing a sufficient substitute for the in-person laboratory experience. Moreover, a major negative criticism of the use of online instructional strategies involves the lack of instructor contact and ineffective instructional methods.

Data from the current study indicated that the students who participated in the virtual laboratories believe that they generally learned more biology concepts participating in the virtual labs compared to traditional labs (strongly agree and agree > 50%). Moreover, research findings indicated that students preferred to participate in virtual labs compared to traditional labs (strongly agree and agree > 50%) although the rationale for their preference was not clearly resolved based on the method of data collection.

One key issue regarding the use of virtual labs in college science and engineering courses is that computer simulations alone are not able to properly train students on the use of specialized laboratory equipment. To compensate for this deficiency many online biology courses disseminate take-home laboratory kits that contain requisite laboratory equipment, supplies, and literature required to complete experiments. Take-home laboratory kits allow online students to actually work with discipline-specific equipment and supplies as well as interact with the computer-simulated lab activity. Not surprisingly, students believe that traditional labs are more effective pedagogical techniques in terms of teaching them how to use biology laboratory equipment. Interestingly, Maldarelli et al. (2009) demonstrated that visual demonstration of laboratory techniques via instructional videos before the actual physical laboratory was sufficient to mediate significant increases in knowledge, self-efficacy, and experience in basic biology laboratory procedures. While the Maldarelli et al. (2009) study employs a different methodology to the methods described in this report, it lends credence to the viewpoint that virtual instruction strategies can have positive effects on understanding of scientific procedures. Based on previous research I hypothesize that a combination of virtual laboratory educational experiences before and after the traditional hands-on laboratory will ultimately provide the most substantial learning gains, however more research studies must be performed to explore this hypothesis.
While the current study provides important data to a poorly studied area, the author understands that simply comparing traditional instructional methods to online instructional methods to determine which mode of instruction is best is not completely effective (Swan, 2003); and that additional studies examining specific pedagogical strategies employed in both virtual labs and traditional labs are needed to better determine whether the technology or the type of instruction determines student perceptions (Clark, 1983; Phipps & Merisotis, 1999). Moreover, in terms of limitations to the current study, a major limitation is the limited number of participants. Moreover, while the virtual labs and traditional labs had similar learning objectives the precise procedures and methods employed were different for the virtual labs compared to the traditional labs. The differences in laboratory procedures and methods may have accounted for the student responses to the research questions. Additionally, the use of open-ended qualitative questions would have been especially useful. One disadvantage of using discrete scale items is that students are not able to provide in-depth responses to the research questions. The design of specific qualitative questions that explore students’ perceptions of different aspects of the virtual lab (e.g., data table, lab procedures, and assignment submission procedures) would be beneficial to learn valuable information about the use of virtual labs in biology courses. Future qualitative studies either involving student interviews or paper surveys are needed to encourage more detailed responses to the issues under study. Following transcription, coding, and analysis of data the development of emergent themes will lead to student-specific strategies for enhancing both traditional and virtual labs in STEM courses. Also, while not particularly a limitation, additional studies using the same framework involving biology majors may yield more beneficial results.

It should also be noted that all of the virtual laboratory assignments were performed by students on an individual basis. Students were required to read the background information and procedures contained in the virtual lab computer exercise and complete data tables and journal questions. Students then performed detailed electronic submission procedures to facilitate evaluation of the virtual laboratory assignments. In contrast, the traditional biology laboratories involved in-class introductions of pertinent biological concepts and specialized experimental procedures. During traditional labs the entire class was divided into separate laboratory groups (4-5 students). Each group performed the same laboratory exercise. Also, during the traditional labs the instructor provided support as needed. The presence or absence of student collaboration and instructor interaction during the laboratory exercise may have had an affect on student responses and are instructional issues must be given attention on future studies. Implementation of similar instructional approaches for both virtual labs and traditional labs will lead to better comparisons.

The future of online distance education is bright. Many science educators are constantly employing novel strategies to produce quality online environments (Mitchell, 2010). While the next twenty years are sure to produce substantive advancements in technology-based laboratory instruction, additional research studies examining student perceptions of virtual laboratories using a wide variety of research methodologies must be performed in order to generate beneficial data that may lead to enhancements in virtual laboratory instruction as well as the research literature in this area.

REFERENCES


**Acknowledgements**

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