# Assessment of Students' Learning and Perceptions of Task Value of a Physical Pharmacy Laboratory Course

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## Abstract

Objective: To assess student learning and perceived task value of physical pharmacy wet laboratory sessions conducted at two separate campuses within a school of pharmacy.

Methods: Anonymous archival course evaluation and assessment data from 130 students enrolled in a pharmaceutics course were used. The evaluation surveyed students about the task value of five wet laboratory sessions, and assessment data were of pre- and post lab knowledge. Campuses differed in lecture delivery (in-person vs. video-conferencing), but labs were the same.

Results: Most students felt that the quality and organization of the lab sessions were good, that the lab sessions allowed them to better understand pharmaceutics concepts, and that the time spent in lab was worthwhile. Most students also indicated that they preferred wet labs over virtual labs or no labs. The proportion of students achieving mastery on knowledge assessments increased significantly from prelab to postlab. No meaningful differences were found between locations.

Conclusion: Wet laboratory exercises are a useful supplement for learning physical pharmacy concepts.

Key words: physical pharmacy; distance education; wet laboratory; learning achievement; task value

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**Introduction**

"Wet" laboratories have been used by some instructors to assist students in learning basic science concepts. The term *wet labs* refers to classical laboratory experiments in which chemical or biological material is manipulated and analyzed, and are distinguished from computer simulations. These lab sessions can promote learning engagement, by requiring students to apply their knowledge and reflect on its meaning. Learning engagement achieved through active learning is one of the seven recognized principles for good practice in education.[1] Several investigators have noted improved pharmacy student satisfaction and academic performance when active learning strategies were introduced into classes that had used more traditional passive teaching strategies.[2,3] When used as a framework for inquiry-based instruction, wet labs can promote active learning, in which students achieve lower-level cognitive objectives (e.g., knowledge and application skills) as well as higher-level cognitive objectives (e.g., analytical and evaluative skills).[4] Lower-level cognitive objectives largely concern content that can be memorized ("knowing that"), whereas higher-level cognitive objectives provide the tools for constructing new meaning out of rote knowledge ("knowing how").[4] In science education, lower-level cognitive objectives have traditionally been achieved through lecture, and higher-level cognitive objectives have been obtained by actively engaging in research.[4]

It is generally accepted that high quality science education must focus on lower cognitive objectives like factual knowledge,[5] but by themselves, lower-level objectives are not sufficient.[6] For example, Tien et al. found that student-centered active learning that focused on the acquisition of higher cognitive objectives, such as synthesis and evaluation, improved the performance, retention, and attitudes of undergraduates in organic chemistry.[7] The National Research Council has recommended greater emphasis on active learning models in science education, yet there is limited evidence that these models have widespread use at the higher education level.[8] Perhaps one factor is one of the disadvantages of wet labs: they can require significant resources (both human and physical) and time (both for the instructors and students). However, Roche et al. noted that while lab sessions were the least utilized teaching methods in courses addressing chemistry-related content, they should not be abandoned, because they may help the students who have a kinetic style of learning master concepts.[9] The learning styles of students enrolled in a course may differ, and using various teaching methods within the same course increases the likelihood that more students are able to focus more on learning and less on adapting to a particular teaching method.[10] Variation in teaching methods also may encourage the students to adapt new learning preferences.[10] A more flexible learner may adapt better in future situations where the types of teaching methods are restricted.

In helping instructors to meet best practice guidelines in science education, wet lab sessions will also help improve attitudes toward science in pharmacy undergraduates. Law et al. noted that learning motivation and engagement, which are closely tied to attitude, can be affected by the educational approach (i.e. whether active learning is employed).[11] Both Simpson et al. and Koballa and Glynn, found a significant association between student science achievement and attitude toward science.[12,13] The well-established importance of *task value* to learning achievement may explain this relationship.[14] Task value is a motivational factor that refers to how much a student considers something to be important or relevant.[15] For example, task value can be indicated by student-professed perceptions of the quality and relevance of their science education activities, and one would expect students that place a higher task value on those activities to achieve more in learning about the subject. Instructors need to know if the resources required for wet labs are outweighed by improved student satisfaction and academic performance.

Two published studies have systematically investigated the impact of wet labs on pharmacy student perceptions and learning in basic science courses. In the first study, instructors provided students with a lecture on the basics of nuclear receptor action being covered in a laboratory prior to the lab session itself (participation in this lecture was voluntary).[16] These students were either fourth-year exchange students, in their second year of a toxicology program, or in the fourth or fifth year of pharmacy school. Students responding to a survey after completing the laboratory experiment stated that they felt the experiment improved their understanding of the concepts being taught. In the second study, students were required to identify and analyze literature on the subject matter being covered in a lab prior to the lab session.[17]

These students were either honors students enrolled in the early years of the curriculum, or students enrolled in the later years of a pharmaceutical sciences or pharmacy curriculum. After attending the hands-on experiment, the students had an increased ability to define a prodrug, but no increase in their ability to define a false positive or false negative test result.

Whether an educational intervention works is highly dependent on setting or context.[18] Student perceptions may differ depending on the subject matter being taught, the methods used to teach the subject matter, and the characteristics of the students. For example, one important question is whether the mode of content delivery affects student attitudes both about the content and the learning experience. Erickson et al. compared student learning of a clinical intervention (assessment of patient technique with a metered-dose inhaler) between in-person lectures and Web tutorials, and found no difference.[19] Although the Web tutorial had been intended to enhance clinical lab instruction, the authors concluded that it was just as good as lecture delivery. Likewise, Takeda et al. found that streaming video of a demonstration experiment greatly enhanced learning in a chemistry lab, and that student satisfaction with learning was very high.[20] However, the students also expressed a strong preference for keeping the live demonstration experiment rather than relying exclusively on the streaming video demonstration. Some question remains, then, of how delivery modalities other than in-person lecture might affect student learning and attitudes.

## Purpose

The purpose of this study, therefore, was to expand the knowledge of the benefits of wet labs in learning basic science concepts in a different setting. We had three specific goals, the first of which was to determine whether pharmacy students and bachelor’s of science in pharmaceutical sciences students perceived a wet laboratory session, provided in addition to a required lecture, as beneficial in learning pharmaceutics principles. The second goal was to obtain concurrent evidence of the validity of those perceptions in the form of classroom knowledge assessment scores. The third goal was to determine whether the difference in the mode of lecture delivery affected the results.

## Methods

### *Sample*

Anonymous archival course evaluation data were used from 130 students enrolled in a physical pharmacy course at a mid-size public university in a Midwestern US city during the fall of 2008. Ninety-two percent of these students were doctor of pharmacy (PharmD) students and 8% were bachelor of science (BS) in pharmaceutical sciences students. The PharmD students were in the second year of a five year curriculum, and the BS students were in their last year of a four-year curriculum. The students were required to attend a one-hour lecture three times a week, and to participate in five, three-hour, laboratory sessions spread throughout the semester. The class was divided into four groups according to the days of the scheduled lab sessions: Mondays, 34 students; Wednesdays, 33 students; Thursdays, 35 students; and Fridays, 28 students. The Monday, Wednesday, and Thursday sessions took place on the main campus, and the Friday sessions took place on a satellite campus about 125 miles distant. The PharmD students had the following race/ethnicity distribution: White, 85%; Black, 2%; Hispanic, 1%; Asian/Pacific Islander, 5%; Refused to answer, 7%. The BS students had the following race/ethnicity percentages: White, 30%; Black, 0%; Hispanic, 0%; Asian/Pacific Islander, 50%; Refused to answer, 20%. Although both sets of students had the same gender distribution—Male, 30%; Female, 70%—they differed somewhat in age. PharmD students mainly fell in the range of 21-25 years (72%) with a large proportion in the range of 26-30 years (23%), but BS students were mostly 26-30 years of age (60%) with a large number between 21-25 years of age (40%).

### *Course*

The classes/lectures were taught in a traditional manner where the instructor provided information and the students predominately listened and took notes on handouts provided in advance. The instructor delivered lectures to students on the main campus in person, and the students at the satellite campus observed the lecture at the same time via videoconferencing. For the wet lab sessions, eight teaching assistants (two for each lab section), who had successfully passed the Speaking Proficiency English Assessment Kit (SPEAK) (Educational Testing Service, 2002) test required by state law, were trained and supervised on a weekly basis by the course instructor. In each lab session, students typically worked in groups of six on a given laboratory bench equipped with all required materials and supplies specified in the laboratory course syllabus. They began with a review of course concepts, and observed the teaching assistants demonstrate an experiment. Then the students conducted the experiment following instructions in the lab manual. At the end of each experimental session, the students reported their results in written format based on their observations. Overall, the following five experimental topics were covered: 1) a graphing exercise and its application to pKa determination; 2) the importance of pH and buffers; 3) buffers and pharmaceutical formulations; 4) pH and drug solubility; and 5) pH and partition coefficient.

### *Instrumentation*

**Overall Questionnaire of Student Perceptions**. A 28-item, five-part questionnaire was created and administered to the students at the end of the course. The first part of the questionnaire (Part 1) consisted of the same three questions repeated for each of the five wet laboratory sessions. Students were asked about their perceptions of organization and quality, knowledge gained, and relevance. These questions had the following response options: Poor, Fair, Good, Very Good, Excellent. Table 1 lists the items for Part 1, which formed three scales, one for each question: “The organization and the quality of the presentation were,” “The knowledge gained was,” and “The relevance of this topic to my future as a pharmacist is.” Because each question was asked in regard to each of the five wet labs, each scale was comprised of five items.

The next 10 items comprised the next three parts of the questionnaire (Parts 2, 3, and 4) and had the following response options: Strongly disagree, Disagree, Neutral, Agree, Strongly agree. The second part addressed student perceptions of ability to learn certain concepts after attending the lab and fairness of assessments, the third part addressed student preferences for alternative methods of course and/or lab delivery, and the fourth part addressed whether students felt the time and resources used to complete the lab sessions were worth the learning gained. Table 2 lists the items for Parts 2-4. The last part (Part 5) contained three free response questions asking students to list the most and least useful parts of the wet lab sessions, as well as what changes to the sessions they would recommend.

**Classroom Knowledge Assessments**. The instructor developed ten questions for each laboratory session. Five of the questions assessed theoretical knowledge (the principles being demonstrated by the lab) taught in lecture that was relevant that particular laboratory session. The other five questions assessed the practical knowledge (how to do the lab) that was covered in the laboratory session but not in lecture. The instructor administered all 25 questions covering theoretical content and all 25 questions covering practical content prior to the students completing any laboratory work and again after the students completed all five laboratory sessions. The students answered 10 questions (five theoretical and five practical) relevant to that lab session again immediately after completing each lab. It was thought that administering posttest items in this manner would provide the most immediate assessment of knowledge gained from the labs themselves, and lend to the validity of the pretest-posttest comparison.

The assessments themselves were *criterion-referenced tests*, which are tests intended to determine whether examinees have met a predetermined standard for performance. In the present study, the cutoff criterion for mastery of the material was determined to be answering 20 of the 25 items (80%) correctly, and pre-posttest comparisons were conducted on the proportion of students attaining the cutoff. When examining criterion-referenced tests for reliability, the approach recommended by the American Psychological Association is to compute the percentage of examinees who are consistently classified as passing or failing to meet the criterion.[21] For the pretest assessment of practical knowledge, the test was split into alternate forms by separating even-numbered items from odd-numbered items. The two forms classified 60% of the students exactly the same, a proportion that does not indicate very good, but still acceptable, reliability for a classroom assessment. The same procedure was conducted on the pretest assessment of theoretical knowledge, and resulted in 98% of the students being classified the same on both alternate forms, an indication of excellent reliability.[22]

**Institutional Review Board.** The students were asked to fill out the questionnaire anonymously for the purpose of course evaluation. No information was collected that would identify the participants either directly (e.g., name, identification number) or indirectly (e.g., birth date, gender, race/ethnicity). For supplied response items, students were asked to use optical scanning sheets to mark their answers. Optical scanning sheets were processed at the university data administration center, and answers were imported into an Excel spreadsheet. For free response items, students were instructed to write their answers anonymously on the questionnaires themselves. The university's institutional review board determined that the present study was exempt.

**Analytic Strategy and Data Preparation**. To answer the first part of the research question—to determine whether students perceived the wet labs as beneficial in learning pharmaceutics principles—descriptive statistics were calculated for the first 25 items of the questionnaire for the entire group. In addition, evidence of the construct validity of the three scales in Part 1 of the questionnaire was obtained with principle components analysis. As measures of concurrent validity, the proportions of students attaining mastery on the posttest knowledge assessments were compared to the proportions attaining mastery on the pretest measurements using Student *t*-tests. In addition, free response answers to the last three items were examined for emergent themes, and once those themes were identified, responses were categorized accordingly. To answer the second part of the research question—to examine how responses differed between groups receiving different modes of lecture delivery—two different inferential techniques were used. In the case of comparisons of Part 1 scale scores, *t*-tests were used. However, in the cases of the categorical and highly skewed natures of Items 16-25, chi-squared tests of independence were conducted, and in the case of comparing the pre-posttest proportions of students attaining mastery, McNemar's test was used.

## Results

One hundred one students (78%) responded to the questionnaire. Of the 77 main campus respondents, three were missing responses; one for Item 19, and two for Item 25. Because these represented less than five percent of the main campus group, data imputation was acceptable.[22] Because each item had a skewed distribution, the median of each was used as replacement values. None of the 24 satellite students had missing data.

### *Construct Validity of Questionnaire Part 1 Scales*

Evidence for the construct validity of each scale was obtained by conducting a principal components analysis (PCA) of each scale. For each PCA, the Kaiser criterion was used for extractions. For "organization and quality of the presentation," one component was extracted that explained 81% of the variance of the items. All five items had large component loadings of .87 to .91 that translated to communalities of .75 to .83, meaning that the component of organization and quality of presentation accounted for 75% to 83% of the variance in each individual item. Table 1 lists the component loadings, uniquenesses, and inter-item correlations for each scale. Component loadings indicate the strength of association between the item score and the scores on the other items in the scale. Uniquenesses are the percentage of variance in the item scores that are unexplained by the other items in the scale. Psychometrically sound scales—such as those in the present study—have high item loadings (i.e. greater than .50) and low uniquenesses (i.e. less than .75), a pattern that provides stronger evidence than reliability coefficients alone that the items can validly be used together to measure the same construct. The alpha coefficient for this new scale was .94, indicating excellent reliability. Scale scores were computed by averaging the item scores, and the overall mean was 3.53 ($SD$ = 0.81).

For “knowledge gained,” one component was extracted that explained 70% of the variance of the items. All five items had large component loadings of .74 to .89 that translated to communalities of .55 to .78, meaning that the component of knowledge gained accounted for 55% to 78% of the variance in each individual item. The alpha coefficient for this scale was .91, also indicating excellent reliability, and the scale scores had a mean of 3.37 (*SD* = 0.74).

For “relevance of the topic to my future career as a pharmacist,” one component was extracted that explained 78% of the variance of the items. All five items had large component loadings of .80 to .92 that translated to communalities of .63 to .80, meaning that the component of relevance accounted for 63% to 80% of the variance in each individual item. The alpha coefficient for this new scale was .93, also indicating excellent reliability, and the scale scores had a mean of 3.36 (*SD* = 0.89).

### *Overall Student Perceptions and Performance*

Overall, the results of the survey indicated that the students valued the wet lab sessions. When asked in regard to the lab sessions about the organization and quality of presentation, knowledge gained, and relevance to their future careers as pharmacists, Table 2 shows students most frequently responded with “Good” or “Very Good” for all five topic areas covered: graphs and pKa determination, buffer capacity and measurement of pH, buffers and pharmaceutical formulations, pH and drug solubility, and pH and drug partition coefficient. When asked about their agreement that the lab sessions helped them understand the pH of pharmaceuticals and its practical importance, Table 3 shows that students most frequently responded “Agree” or “Strongly agree.”

**Table 1. Component Loadings, Uniqueness, and Inter-Item Correlations[a] of Principal Components Analyses of the Three Scales of Part 1 (N = 101)[a, b]**

| | | | Item | | | |
|---|---|---|---|---|---|---|
| **Organization and Quality of the Presentation (α = .94)** | **Loading** | **Uniqueness** | **1** | **4** | **7** | **10** |
| 1. (Graphs and pKa Determination) | .87 | .25 | —[c] | | | |
| 4. (Buffer Capacity and Measurement of pH) | .91 | .18 | .70 | — | | |
| 7. (Buffers and Pharmaceutical Formulations) | .91 | .17 | .72 | .84 | — | |
| 10. (pH and Drug Solubility) | .91 | .17 | .76 | .74 | .78 | — |
| 13. (pH and Drug Partition Coefficient) | .91 | .18 | .73 | .79 | .75 | .80 |
| | | | Item | | | |
| **Knowledge Gained (α = .91)** | **Loading** | **Uniqueness** | **2** | **5** | **8** | **11** |
| 2. (Graphs and pKa Determination) | .75 | .44 | — | | | |
| 5. (Buffer Capacity and Measurement of pH) | .86 | .26 | .53 | — | | |
| 8. (Buffers and Pharmaceutical Formulations) | .88 | .22 | .51 | .74 | — | |
| 11. (pH and Drug Solubility) | .89 | .21 | .62 | .74 | .71 | — |
| 14. (pH and Drug Partition Coefficient) | .89 | .21 | .60 | .66 | .79 | .72 |
| | | | Item | | | |
| **Relevance of Topic to Future Career as a Pharmacist (α = .93)** | **Loading** | **Uniqueness** | **3** | **6** | **9** | **12** |
| 3. (Graphs and pKa Determination) | .80 | .37 | — | | | |
| 6. (Buffer Capacity and Measurement of pH) | .91 | .17 | .71 | — | | |
| 9. (Buffers and Pharmaceutical Formulations) | .92 | .16 | .62 | .81 | — | |
| 12. (pH and Drug Solubility) | .89 | .20 | .58 | .77 | .82 | — |
| 15. (pH and Drug Partition Coefficient) | .88 | .22 | .64 | .73 | .77 | .76 |

[a]Items are grouped by scale. The title of each scale reflects the wording of the items, and the item labels (in parentheses) reflect the topic area about which the question was asked.
[b]All correlations were significant at the α = .01 level. [c]A correlation of one is indicated by '—.'

**Table 2. Descriptive Statistics for Part 1: Organization, Quality, and Relevance of Individual Lab Sessions (N = 101)**

| | | | | | | | Response frequency[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***M*** | ***Mdn*** | **Mode** | ***SD*** | **Q1** | **Q3** | **1** | **2** | **3** | **4** | **5** |
| Topic 1: Graphs and pKa Determination | | | | | | | | | | | |
| 1. The organization and the quality of the presentation were: | 3.4 | 3 | 3 | 0.9 | 3 | 4 | 2 | 13 | 37 | 36 | 13 |
| 2. The knowledge gained was: | 3.2 | 3 | 3 | 0.9 | 3 | 4 | 3 | 16 | 46 | 30 | 6 |
| 3. The relevance of this topic to my future career as pharmacist is: | 3.0 | 3 | 3 | 1.0 | 2 | 4 | 7 | 24 | 40 | 21 | 9 |
| Topic 2: Buffer Capacity and Measurement of pH | | | | | | | | | | | |
| 4. The organization and the quality of the presentation were: | 3.5 | 4 | 4 | 0.9 | 3 | 4 | 2 | 12 | 33 | 43 | 11 |
| 5. The knowledge gained was: | 3.4 | 3 | 3 | 0.9 | 3 | 4 | 1 | 12 | 47 | 30 | 11 |
| 6. The relevance of this topic to my future career as pharmacist is: | 3.3 | 3 | 3 | 1.0 | 3 | 4 | 3 | 18 | 38 | 31 | 11 |
| Topic 3: Buffers and Pharmaceutical Formulations | | | | | | | | | | | |
| 7. The organization and the quality of the presentation were: | 3.5 | 4 | 4 | 0.9 | 3 | 4 | 2 | 11 | 34 | 46 | 8 |
| 8. The knowledge gained was: | 3.3 | 3 | 3 | 0.9 | 3 | 4 | 1 | 15 | 40 | 38 | 7 |
| 9. The relevance of this topic to my future career as pharmacist is: | 3.4 | 3 | 3 | 1.0 | 3 | 4 | 1 | 16 | 38 | 30 | 16 |
| Topic 4: pH and Drug Solubility | | | | | | | | | | | |
| 10. The organization and the quality of the presentation were: | 3.6 | 4 | 4 | 0.9 | 3 | 4 | 1 | 8 | 32 | 46 | 14 |
| 11. The knowledge gained was: | 3.6 | 4 | 4 | 0.8 | 3 | 4 | 1 | 7 | 38 | 43 | 12 |
| 12. The relevance of this topic to my future career as pharmacist is: | 3.6 | 4 | 3 | 1.0 | 3 | 4 | 2 | 12 | 33 | 30 | 24 |
| Topic 5: pH and Drug Partition Coefficient | | | | | | | | | | | |
| 13. The organization and the quality of the presentation were: | 3.6 | 4 | 4 | 0.9 | 3 | 4 | 1 | 10 | 31 | 43 | 16 |
| 14. The knowledge gained was: | 3.4 | 3 | 3 | 0.9 | 3 | 4 | 2 | 14 | 40 | 35 | 10 |
| 15. The relevance of this topic to my future career as pharmacist is: | 3.4 | 3 | 3 | 1.0 | 3 | 4 | 2 | 16 | 36 | 29 | 18 |

[a]1 = Poor. 2 = Fair. 3 = Good. 4 = Very Good. 5 = Excellent.

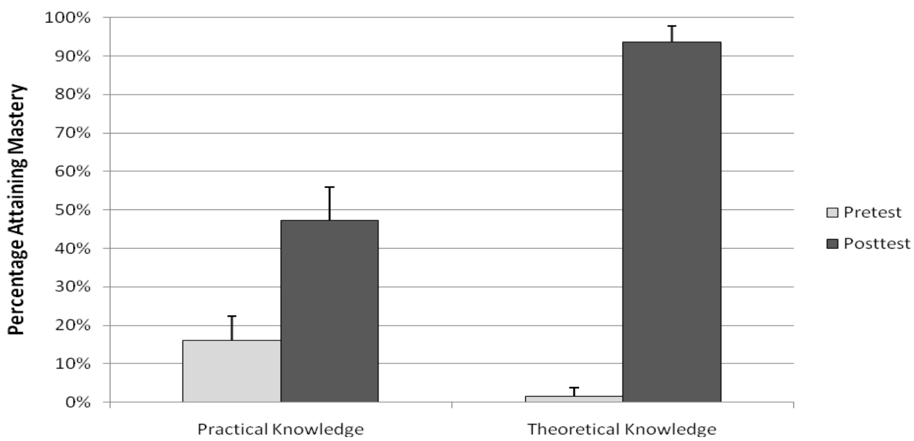
**Table 3. Descriptive Statistics for Part 2: Assessment of Learning and Examination; Part 3: Consideration of Virtual Lab Versus Traditional Laboratory; and Part 4: Overall Assessment of the Pharmaceutics Laboratory (N = 101)**

| | | | | | | | Response frequency[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***M*** | ***Mdn*** | **Mode** | ***SD*** | **Q1** | **Q3** | **1** | **2** | **3** | **4** | **5** |
| Part 2 | | | | | | | | | | | |
| 16. These laboratory sessions enabled me to determine more effectively pH of pharmaceutical drug products. | 3.9 | 4 | 4 | 0.8 | 4 | 4 | 4 | 1 | 14 | 65 | 17 |
| 17. These laboratory sessions enabled me to better understand the practical role and importance of pH in pharmaceutical formulations. | 4.1 | 4 | 4 | 1.0 | 4 | 5 | 5 | 1 | 9 | 47 | 39 |
| 18. These laboratory reports and grading were fair. | 4.4 | 4 | 5 | 0.7 | 4 | 5 | 1 | 1 | 5 | 44 | 50 |
| 19. These laboratory quizzes and grading were fair. | 4.3 | 4 | 4 | 0.7 | 4 | 5 | 0 | 2 | 8 | 50 | 41 |
| Part 3[b] | | | | | | | | | | | |
| 20. I prefer alternative #1 (with practical lab sessions, wet lab) only | 4.1 | 4 | 5 | 1.1 | 4 | 5 | 6 | 4 | 12 | 32 | 47 |
| 21. I prefer alternative #2 (with virtual lab on videos, no wet lab) only. | 2.4 | 2 | 2 | 1.1 | 1 | 3 | 27 | 31 | 26 | 12 | 5 |
| 22. I prefer a combination of alternative # 1 and 2 (videos + practical lab sessions) only | 2.8 | 3 | 3 | 1.1 | 2 | 4 | 16 | 24 | 33 | 22 | 6 |
| 23. I prefer alternative # 3 (all 4SCH lectures, no lab sessions) only | 2.0 | 2 | 1 | 1.1 | 1 | 3 | 46 | 30 | 13 | 6 | 6 |
| Part 4 | | | | | | | | | | | |
| 24. I think the time and resources spent on these exercises have been worthwhile in consideration of learning achieved. | 3.7 | 4 | 4 | 0.9 | 3 | 4 | 2 | 11 | 20 | 53 | 15 |
| 25. I found these laboratory sessions to be useless and they should all be canceled and replaced by more lecture and classroom time instead. | 1.9 | 2 | 1 | 1.0 | 1 | 2 | 46 | 36 | 8 | 9 | 2 |

[a]1 = Strongly disagree. 2 = Disagree. 3 = Neutral. 4 = Agree. 5 = Strongly agree.
[b]Alternative #1: Maintain the 3 semester credit hour (SCH) lecture time + 1 SCH practical lab session. Alternative # 2: Maintain the 3 SCH lecture time + 1 SCH of virtual lab session using synchronous and asynchronus video methods instead. Alternative # 3: Maintain the 3 SCH lecture time + 1 additional hr of lecture time (no lab sessions).

As a check on the validity of the students' overall perception that the knowledge gained from the labs was "Good" to "Very Good," the percentage attaining mastery on the pretest was compared to the percentage on the posttest (Figure 1 displays percentages of students attaining mastery on all tests). McNemar's test was chosen because it accounts for the dependent relationship between pre- and posttest scores. A significant difference was found on the test of practical knowledge ($\chi^2 = 27.65$, $df = 1$, $p < .01$), with the percentage of students attaining mastery increasing from 16% on the pretest to 47% on the posttest. The occurrence of the lab sessions accounted for 47% ($\varphi = .47$) of the difference in proportions, a very large effect size. A significant difference was also found on the test of theoretical knowledge ($\chi^2 = 115.00$, $df = 1$, $p < .01$), with the percentage of students meeting the criterion increasing from 2% to 94%. The lab sessions accounted for 96% ($\varphi = .96$) of the difference, a very large effect size. These results corroborated the students' perception that knowledge was gained from the labs.

**Figure 1. Percentages of Examinees Attaining Mastery on Pre- and Posttests of Practical and Theoretical Knowledge (Error bars represent 95% confidence intervals; N = 125).**




Students also typically responded that they "Agree" or "Strongly agree" with statements that the assessments of lab reports and quizzes were fair. When given several alternatives to the present structure of the physical pharmacy course, the students typically responded with "Agree" or "Strongly agree" to maintaining the current lecture and lab format. Students generally responded with "Disagree" when presented with the option of having virtual labs rather than wet labs, and "Neutral" when presented with the option of a combination of virtual and wet labs. Students responded with "Disagree" when presented with the option of no lab sessions at all.

Two questions were asked of the students about their overall assessment of the wet lab sessions. The first asked how much they agreed that the time and resources spent on the lab exercises had been worthwhile in consideration of the learning achieved, and the most typical answer was "Agree." The second asked how much the students agreed that the labs were useless and should be replaced with more lecture, and the most popular response was "Strongly disagree."

Three free response questions were also asked of the students, the first of which was "What parts of the physical pharmacy laboratories were most useful?" Responses were examined for common themes, and seven categories emerged. Figure 2 shows the number of students giving a response that fit into each category from each campus group (please note that a single student may have a response that was tallied in more than one category). The most frequent type of response from either campus was the actual physical doing of the experiments, and a close second was the discussion section/pre-lab. "Effective TAs" was the third most frequent response, and reviewing equations was a distant fourth.

**Figure 2. Categories and Percentage of Responses by Campus to the Question, "What Parts of the Physical Pharmacy Laboratories Were Most Useful?" (Some students gave multiple responses; N = 90).**

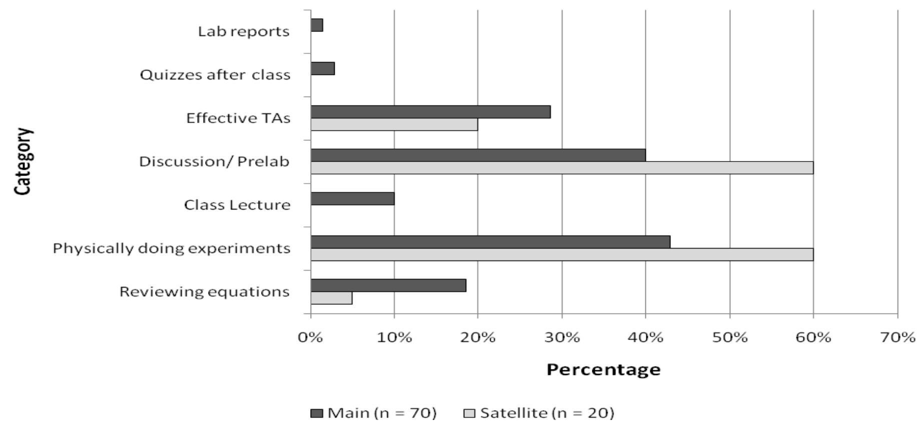
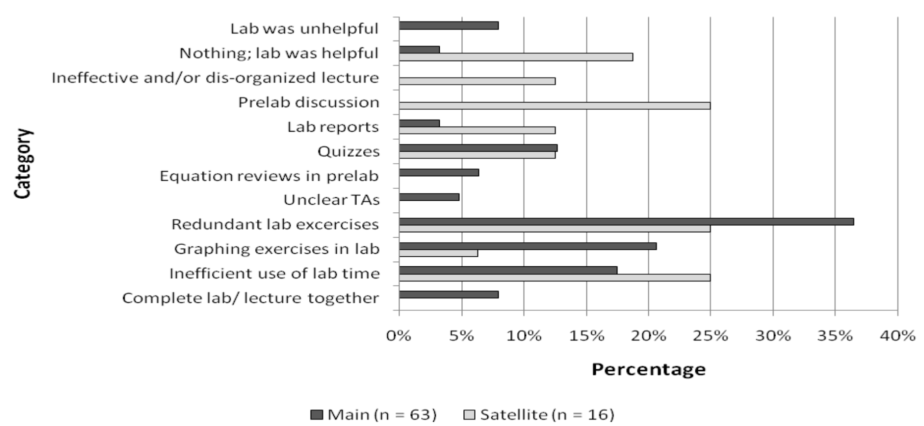


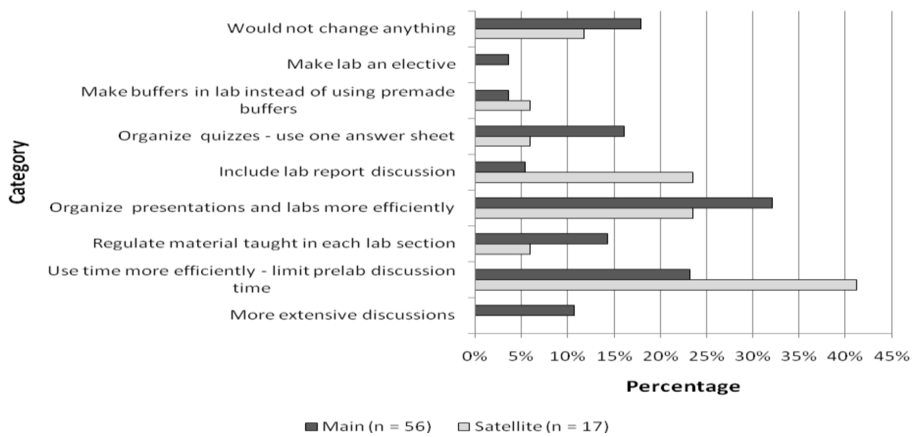

Figure 3 shows the frequency of 12 categories of response to the question, "What parts of the physical pharmacy laboratories were least useful?" The most common response was that the lab exercises were redundant, and the second most common was that lab time was used inefficiently. The third most common response of the main campus group was that the graphing exercises in the lab were least useful, but that of the satellite group was that the prelab discussions were least useful. Five individuals wrote that nothing could be termed "least useful," and that the labs were helpful overall.

**Figure 3. Categories and Percentage of Responses by Campus to the Question, "What Parts of the Psychical Pharmacy Laboratories Were Least Useful?" (Some students gave multiple responses; N = 79).**




The third free response question asked students to "describe any revision or change that can be useful to the instructors of these laboratories." Figure 4 illustrates nine categories that emerged from the responses and the frequency of each. The most frequent response was to organize presentations and labs more efficiently, which was consistent with responses to the second free response question, but contradictory to the overall results of the Part 1 questions about the organization and presentation of the labs. Closely related was the second most popular response, which was to use time more efficiently, perhaps by limiting prelab discussion time. The third most frequent response overall was that students would not change anything about the labs.

**Figure 4. Categories and Percentages of Responses by Campus to the Prompt, "Describe Any Revision or Change That Can Be Useful to the Instructors of These Laboratories." (Some students gave multiple responses; N = 73).**




## Comparison of Site Groups/Lecture Modalities

The Part 1 scales scores of the main campus groups were compared to the satellite group using independent samples *t*-tests. For each of the three scales, scores were distributed normally and met the assumption of homogeneity of variance across groups. The two groups did not differ significantly ($\alpha = .05$) on the organization and quality of presentation ($t = -0.65$, $df = 99$, $p = .51$), but did differ significantly on perceived knowledge gained ($t = -2.14$, $df = 99$, $p = .04$, Cohen's $d = 0.21$) and perceived relevance ($t = -3.12$, $df = 99$, $p < .01$, Cohen's $d = 0.31$). Although the satellite campus had a higher measure of perceived knowledge gained (3.65 versus 3.29), the effect size was small, with a difference of only 0.21 standard deviations. The satellite campus also had a higher measure of perceived relevance (3.83 versus 3.21), but even though the magnitude of the difference was greater, the effect size was still small at only 0.31 standard deviations. Comparison tests of the pre-posttest gains between the campuses were also conducted, and the results supported the students' perceptions. Cochran's test of independence was used because it accounts for the dependency of the pre-posttest percentages for three-way tables. In the present study, a 2 X 2 X 2 three-way table was formed by the following variables: mastery attainment X pre- or posttest X campus. For the test of practical knowledge, the increase in the percentage of students attaining mastery at the main campus was 36%, whereas the increase was 22% at the satellite campus, an insignificant difference (Cochran's $\chi^2 = 1.36$, $df = 1$, $p = .24$). For the test of theoretical knowledge, the increase was the same on both campuses, 92%. Although the students at the satellite campus perceived a slightly larger gain in knowledge, it was a difference of little practical significance, and the mastery test results indicated that there was no objective difference in knowledge gained, either.

The rest of the selected response items on the questionnaire were compared between the two groups using chi-squared tests of independence, and most failed to reveal significant differences. The only question on which the groups differed was Item 23, "I prefer alternative #3 (all 4 semester credit hour lectures, no lab session) only" ($\chi^2 = 14.73$, $df = 4$, $p = .01$, Cramer's $V = .38$). Most of the main campus students (48%) responded with "Strongly disagree," whereas most of the satellite group (58%) responded with "Disagree." The difference in site and/or lecture modality accounted for 58% of the variation in response, a very large effect size.

**Discussion**

The overall descriptive statistics provide good evidence that students perceived that the wet lab sessions had good to very good organization and quality, knowledge gained, and relevance to their future careers as pharmacists. More specifically, there is good evidence that students perceived that the lab sessions enabled them to determine the pH of different pharmaceutical drugs, and to understand the practical importance of pharmaceutical formulations. Pre-posttest results supported the students' perceptions of a gain in knowledge, whether practical or theoretical. Although evidence was found for differences between the site groups in perceived relevance knowledge gained, they were of little practical importance, and objective measures of knowledge gained revealed no differences, either. It is important to note that perceptions of equity in the conduct of the course were equally high in both groups, so perceptions of inequity can be ruled out as an alternative explanation to differences found. Students also indicated a strong preference for continuing wet labs over virtual labs or no labs at all. The vast majority agreed or strongly agreed that the wet labs were worthwhile, and strongly disagreed that they were useless and should be replaced with lecture. The only significant and large difference between the sites occurred over the question of having no lab sessions at all, and it was a matter of how much the students disagreed with the statement.

Answers to the free response questions largely reflected answers to the selected response questions, with one important difference: perceptions of the organization of the labs. Several of the most prevalent themes in the free response answers were that the organization of the labs needed to be improved, but this does not necessarily contradict the overall rating of good to very good on the selected response question. It must be kept in mind that good was the third, and very good the fourth, of five ordered categories of response; excellent was the highest category. Students could very reasonably have indicated that the labs had good or very good quality presentation and yet need improvement to be considered excellent. In addition, there were fewer respondents to the open-ended questions than there were to the selected-response question (90 of the former and 101 of the latter), so it may be erroneous to assume that the open-ended responses were as representative of the overall group of students. However, the responses do suggest that a more efficient use of lab delivery time, perhaps by limiting prelab discussion, would help reduce or eliminate this concern in the future.

**Limitations**

Representativeness of the sample is, of course, one of five possible limitations of the current study. Although the response rate of 78% was good and may be considered representative of the students who took the course, the sample may not be representative of all PharmD and BS students across the US. The second limitation of the study is its reliance on student self-report. The developmental immaturity of these students in the field of pharmacy prevents them from professionally addressing any competency issues relating the course content to their future careers, but their responses provide some insight into their educational experiences. In addition, their perceptions of knowledge gained due to the labs were supported by the timing and results of the pre-posttests. However, the tests themselves present a third limitation, namely, the lack of information offered by criterion-referenced assessments. Although the test results allow valid inferences about the percentages of students meeting the learning achievement standard of the course, they do not allow separate inferences to be made about differences in achievement in the content areas represented by a specific lab, nor do they allow interval-level estimation of learning achievement (e.g. whether the distance between scores of 19 and 20 reflect the same difference in learning achievement as the distance between scores of 21 and 20). Future studies should employ instruments whose scores have greater psychometric precision and accuracy. A fourth limitation is closely related, the possibility of a testing or practice effect in the pre-posttest results. Whenever the same questions are asked of examinees both before and after an intervention, improvement in scores may be explained partly or wholly by familiarity with the items. One way to mitigate this threat to internal validity is to allow enough time between tests for memory to fade, but the intervals between tests in the present study may not have been long enough. The fifth limitation to the study is that it was done, for ethical reasons, using pre-existing rather than randomly-assigned groups. Therefore, we cannot definitively conclude that the lack of evidence for differences between sites means that the modality of lecture delivery (in-person versus video conferencing) has no effect on student perceptions of their experiences in wet lab sessions. For example, the difference in locations may mask any existing effect. However, the comparison of sites acted as a statistical control for an important extraneous variable, and we can confidently state that the good student perceptions are not the result of very good results at one site masking poor results at the other.

An area for further investigation is whether the teaching methods used in the lecture affect the student's perceptions of the wet lab. The lecture portion of the physical pharmacy course was taught using a more traditional lecture format. Previous literature has demonstrated improved student satisfaction when more active learning occurs in the classroom setting.[2,3] Student preference for more or less laboratory time may change with a change in the lecture format.

**Conclusion**

The current study provides evidence of the importance of wet laboratory exercises as a useful supplement for learning physical pharmacy concepts. Such approaches may be applied to other concepts in this discipline and other schools of pharmacy to improve pharmacy students' learning experiences. In recent years, engaging in research (or in other words, conducting basic science) has ceded to clinical practice as the primary focus of pharmaceutical education.[23] One unfortunate consequence of this has been an inability of the US pharmaceutical education system to meet the growing demand for pharmaceutical scientists, because not enough pharmaceutical undergraduates are inspired to pursue the science behind their profession.[23] The use of wet labs, therefore, may also be a useful method of fostering interest in pharmaceutical science.

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