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Keywords

Student Attitudes, Lab Design, Science Education, Biology

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Introduction

Characteristics of science labs can vary in delivery (teacher demonstration, computer simulation, hands-on observation, hands-on experimentation), approach (inductive, process-based, constructivist -- Hodson 1996; implicit, explicit, explicit and reflective – Toh and Woolnough 1993, Khishfe and Abd-El-Khalick 2002), style (expository, discovery, problem-based, inquiry – Domin 1999) and a host of other miscellaneous features. Likewise, student-learning outcomes (Table 1) vary in a similar manner, as do student learning-style preferences (Dunn et al. 1982, Kolb 1985). Different combinations of lab characteristics should result in variations in student-learning outcomes. Two fetal pig dissection labs provide an example. The first is a hands-on observational lab utilizing an expository style that has students identify structures and know functions. The second is an inquiry style experiment utilizing fetal-pig

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dissection as the avenue for gathering data, in which students derive a question and then design and carry out an investigation to test the question. Both labs address the same general content and lab skills, but the first may help students more with term recognition and conceptualization associated with discipline content, while the

second may help students more with science process and reasoning skills and improving students' attitudes toward science. This example illustrates the existence of trade-offs in learning outcomes resulting from labs with different designs.

Table 1. A set of potentially desired learning outcomes resulting from lab classes in science.

Domain	General Category	Specific Learning Outcome
Cognitive	Bloom's Taxonomy (Bloom 1956)	Knowledge
		Comprehension
		Application
		Analysis
		Synthesis
		Evaluation
	Science Process Skills (German et al. 1996)	Identify, Define Problem
		Derive Hypothesis
		Define Variables
		Derive Methods
		Perform Experiment
		Analyze, Present Data
		Draw Conclusions
		Make Extensions
	Miscelaneous	Nature of Science
Psychomotor	Discipline Specific	Lab Skills
		Use of Equipment
	General	Lab Skills
		Use of Equipment
Affective	Attitude and Motivation	Toward Science
		Toward Discipline
		Toward Lab

Theoretically, for a given set of student-learning goals, there should be an optimal lab design that maximizes student-realization of those goals. Determining the "optimal lab design" for a set of learning goals or even tougher, an "optimal curriculum design," is virtually impossible. However, quantifying differential influences of lab characteristics on various learning goals can bring lab and curriculum designs much closer to the optimal design.

Research in this area is difficult to evaluate for several reasons

- Relatively few studies experimentally compare the effects of different characteristics of hands-on science labs on student learning outcomes. Most of these studies only examine two or three lab characteristics, and with the exception of understanding the nature of science (NOS), utilize unique assessments that cannot be compared on relative scales between studies

(Holcomb 1971, Jackman et al. 1987, Sundberg and Moncada 1994, Tamir et al. 1998, Booth 2001, Anders et al. 2003, Luckie et al. 2004).

- Studies often do not delineate learning outcomes (especially higher and lower order cognition) in the assessment so tradeoffs cannot be evaluated for different learning outcomes (Johnson and Lawson 1998, Lawson and Johnson 2002, Luckie et al. 2004).

- Studies commonly examine specific adjustments to labs or curricula rather than broad theoretical categories such as lab style (Cox and Junkin 2002, Flora and Cooper 2005).

- Terminology and evaluation criteria in relation to lab characteristics such as lab style vary tremendously, making comparisons between studies difficult (Purser and Renner 1983, Ajewole 1991, Sundberg and Moncada 1994, Domin 1999, Booth 2001, Lawson and Johnson 2002).

In this paper we outline a different approach for research addressing optimal lab design and provide an example of how to quantify relative influences of several lab characteristics on students' attitudes toward labs. We chose attitudes toward science labs as the primary learning goal on which to focus for several reasons. First, this is a starting point to demonstrate a new approach to examining impacts of lab design on student learning outcomes. Second, positive attitudes toward science and science classes are well recognized as desired learning outcomes (Gardner and Gauled 1990, Domin 1999). Third, research consistently supports hands-on lab experience as one of the best ways to positively influence students' attitudes toward science, both as a discipline and a lab class (Ajewole 1991, Freedman 1997, Killerman 1998). Fraser et al. (1993) demonstrated that a positive attitude by students toward the learning environment of a science lab is a strong and representative factor in student learning. Hofstein and Lunetta (2004) argued that recent research on science lab education has not adequately dealt with student attitudes toward lab class and more research is needed in this area. Finally, although there has been a recent push to include student attitudes toward class in studies examining impacts of lab design on student learning (Anders et al. 2003, Luckie et al. 2004, Flora and Cooper 2005), more research on attitudes is needed.

What Lab Characteristics Influence Students' Attitudes Toward Science Labs?

Fraser et al. (1993) developed and validated The Science Laboratory Environment Inventory (SLEI) to assess the learning environment in science classes. The SLEI has five scales: student cohesiveness, open-endedness, integration, rule clarity and material environment. Of the five scales we focus on open-endedness and integration in this study. Open-endedness refers to the degree to which a lab allows students to plan and design lab inquiry. Integration refers to the degree to which labs are integrated with non-lab activities and material (e.g. lecture). Fraser et al. (1993) showed that of the five scales, integration had the best positive correlation with student affective and cognitive learning outcomes.

One major learning goal from the cognitive domain is science process skills (deriving hypotheses, designing experiments, analyzing data, drawing conclusions) and science reasoning (inductive and deductive). Many sources contend that labs mirroring real science, in which students test hypotheses by gathering and assessing data, and challenge ideas and answer questions first-hand rather than reading about them – should be more satisfying, engaging and enjoyable for students (NSF 1996, Sundberg and Moncada 1994, Flora and Cooper 2005). The degree to which a lab is investigative may be a lab characteristic with a strong influence on students' attitudes toward labs.

Level of difficulty is another important characteristic to consider in optimal lab design. The cognitive congruence model of motivation (Klausmeyer, 1980) proposes that reducing difficulty of a learning task should improve motivation of students to accomplish the task. Increased motivation should have a positive influence on learning goals in general and attitude toward the lab specifically.

A fifth important lab characteristic in optimal lab design comes from theory in behavioral ecology that utilizes evolution through natural selection as a major theoretical force shaping behavior in animals (see Krebs and Kacelnik 1991). According to this theoretical framework, students are genetically adapted to want labs that are time efficient, such that, they maximize their own desired learning outcomes per unit time they invest.

Informal interviews conducted by JB with students in lab over the last fourteen years indicates an additional category that should be included in this analysis -- students dislike labs that are "boring" and like labs that are "exciting". Thus, how exciting the lab is can have a major impact on students' attitudes toward lab.

To summarize, the following is a list of lab characteristics we will examine in this study:

- The degree to which the lab is open ended (open-endedness)
- The degree to which the lab is integrated with lecture (lecture help)
- The degree to which the lab is investigative (experimental)
- The degree to which the lab is easy for students to understand (not difficult)
- The degree to which students perceive they learn for the time they invest (time efficiency)
- The degree to which the lab is exciting (excitement)

Overview of this Investigation

In this investigation we examined relative impacts of the six lab characteristics previously listed on students' attitudes toward lab. Quantifying relative impacts of six variables at once requires a different experimental design than the usual controlled experiment with separate treatment groups and a before to after assessment. In order to assess relative impacts, students need experience with all of the lab characteristics they are comparing and the lab characteristics need to change in their degree of association or involvement. Thus, instead of a before/after lab or class assessment and a comparison of change, this study needs an end-of-semester assessment that compares relative attitudes.

Methods

Location and Sample

This study was carried out at the University of Colorado at Boulder (CU), USA from 2001 through 2007. CU is a relatively large, public research university. Three lab classes were used in the study: first-semester general biology lab (GBLI), second-semester general biology lab (GBLII), and general biology lab utilizing a human approach (HAL). GBLI and GBLII are part of the science-majors yearlong introductory sequence. Both labs run concurrently with a lecture covering similar content and topics. HAL is designed for non-science majors and runs for one semester, and repeats itself the second semester. The associated lecture is a yearlong sequence so only 50% of the content of lab is consistent with the concurrent lecture (½ in fall and ½ in spring). Class sizes of GBLI and GBLII ranged between 400 and 750 students comprised of approximately 60% freshmen (13^{th} grade), 30% sophomores (14^{th} grade), 5% juniors (15^{th} grade) and 5% seniors (16^{th} grade). Class sizes of HAL ranged from 85 – 112 students comprised of approximately 20% freshmen, 40% sophomores, 20% juniors and 20% seniors. In all three classes students were grouped into lab sections of approximately 16 students each and instructed by a graduate student teaching assistant (TA). The number of TA's varied from 12 to 21 depending on enrollments for GBLI and GBLII and 2 to 3 for HAL. Each TA taught 2 to 3 lab sections.

Treatments

Treatments were the labs utilized in the curricula of the three classes (e.g. lab #4 was photosynthesis). The labs exhibited a mixture of the six characteristics being examined. Eleven different labs were examined for GBL1, twelve for GBL2, and eight for HAL.

Assessment 1

Assessment 1 was an end-of-semester survey. In the survey, students were asked to indicate the best and worst lab and respond to 48 associated questions, half with the best lab and half with the worst lab using a Likert type scale (strongly agree, agree, neutral, disagree, strongly disagree). Each group of 24 questions was divided into six subgroups addressing the six lab characteristics – 2 of which were positively worded and 2 of which were negatively worded (Table 2). Reliability of the assessment was first determined with Cronbach's alpha in fall 2002. Each question was then individually examined with respect to the three associated questions for internal consistency and wording changes were made where needed. Reliability was again examined with Cronbach's alpha in spring 2003. The assessment was used in GBLII in spring 2005, GBL1 in fall 2006 and HAL in spring and fall 2006.

Table 2. An overview of the second part of the assessment. For this assessment students were first asked to choose the lab they thought was best. For the lab they thought was best they were asked to use a Likert scale (1 = agree stronly, 2 = agree, 3 = neutral, 4 = disagree, 5 = disagree strongly) to rate the following -- I rated this lab as the best because... Sample answers are listed in the table. The same questions were repeated for the lab students thought was the worst.

Lab Characteristics	#	Samples
Open-Endedness	2 (+)	I was free to examine what I thought was most important. (+)
	2 (-)	the procedure of the lab was provided for me (-)
Experimental	2 (+)	I was able to test a hypothesis with an investigation (+)
	2 (-)	I did not have to run an experiment. (-)
Easy to Understand	2 (+)	the concepts were easy to understand. (+)
	2 (-)	the material in the lab was difficult to comprehend (-)
Lecture Help	2 (+)	the lab helped me learn lecture material better than other labs. (+)
	2 (-)	the material in lab did not help me with lecture exams (-)
Time Efficient	2 (+)	I learned a great deal for the time I invested. (+)
	2 (-)	the lab was too time consuming for what I learned. (-)
Exciting	2 (+)	the subject was exciting and interesting. (+)
	2 (-)	the subject covered in the lab was boring (-)

To evaluate assessment 1, we reasoned characteristics that best promote a positive attitude toward lab are most likely a combination of reasons students chose the lab as best and reasons students chose the lab as worst. Thus, for the evaluation of assessment 1, we combined both reasons for best and reasons for worst into one mean value for each student. Negatively worded questions were quantitatively reversed and were combined with positively worded questions to attain the mean. Means less than three indicated preferred lab characteristics. Means greater than three indicated non-preferred characteristics. We used a one-sample t-test with a comparison mean of 3 to determine which lab characteristics influenced students' choices of best and worst lab.

We performed general linear modeling using SAS statistical software (SAS Institute, Cary, NC) to determine the effects of major status (science major vs. non-major), curriculum (GBI, GBII, HAL) and lab characteristic (lecture help, exciting, time efficiency, difficulty, experimental, open ended) on student attitudes. Attitude toward lab was predicted by major and lab characteristic using a two-way, Model I ANOVA. Pair-wise comparisons were made between all combinations of lab characteristics with major status and curriculum (e.g. majors with fall curriculum guided vs. non-majors with spring curriculum experimental). To examine the effect of major status alone, pair-wise comparisons on students' attitudes were made between majors and non-majors for each lab characteristic while disregarding curriculum. Finally, students' attitudes on lab characteristics were compared, irrespective of major and curriculum. All p-values were adjusted for multiple comparisons based on the *Bonferroni inequality*; Finn, 1997 pp. 702).

Assessment 2

Assessment 2 was designed over the course of several years. The first form of the assessment was administered at the end of the fall 2001 semester in GBLI. For each lab exercise, students were asked to rate on a scale of 1 – 10 how much they enjoyed the lab, how much the lab helped them on lecture material, how much they learned from the lab in general and what they perceived as the value of the lab. To assess reliability, we used a test-re-test format. Since several labs were modified between fall 2001 and fall 2002 and modifications may have impacted student attitudes, 2001 to 2002 student ratings for each lab were compared with t-tests (a = 0.0125 using the adjustment for multiple comparisons based on the *Bonferroni inequality*).

Since assessment goals changed after 2001, assessment 2 was modified to fit the new goals and used in GBL2 (spring 2007). Students were asked to rate each lab on a scale of 1 – 10 with 10 as the best for each of the following categories: overall rating (i.e. which lab was the best), lecture help (i.e. how much the lab helped with lecture), exciting (i.e. not boring), time efficient (i.e. how much was learned for the time invested) and how easy the lab and concepts were to understand. For open-endedness and experimental ratings, two separate scales were derived to estimate relative proportions of each characteristic in each lab. For open-endedness, every task students did during lab was examined and open-endedness of each task was rated as a 0, 1, or 2. Zero was given to a task in which students had no choice in how they completed it, 1 was given to a task in which students had limited choices, 2 was given to a task in which students had several choices in how they approached and completed the task. For each lab, open-endedness scores were converted to a proportion. One problem was still present; students displayed individual variations in their rating scales (e.g. one student had a range from 7 to 10 points while another had a range from 1 to 10 points). To circumvent this problem, we normalized each proportion of open-endedness for each student with the following equation

$$O_s = (P_o * S_r) + S_m \qquad \text{Eq. 1;}$$

where O_s = score for open-endedness, P_o = proportion of lab that was open ended, S_r = student score range for the total assessment and S_m = student score minimum. For example, suppose a lab had 50% of the tasks scored as open ended, and an individual student's ratings ranged from 5 – 10, then P_o = 0.5, S_r = 5 and S_m = 5. The O_s for this student is calculated as (0.5 * 5) + 5 = 7.5 relative rating units. For the degree to which a lab was experimental, each lab was evaluated utilizing the checklist from Basey et al. (2000) designed specifically to quantify the extent to which a lab is experimental. These values were again converted to a proportion for each lab and normalized for individual student scoring variations with a slightly adjusted Equation 1. For experimental O_s was replaced with E_s (score for experimental), and P_o was replaced with P_e (proportion of lab that was experimental).

For each lab, we estimated the degree to which the characteristic rating deviated from the overall rating with the following equation:

$$R_d = \left(\sum_{i=1}^{N} \left| R_{oi} - R_{ci} \right| \right) / N; \qquad \text{Eq. 2;}$$

where R_d represents the difference rating of each student, R_{oi} represents the student overall rating for lab "*i*", R_{ci} represents the student characteristic rating for lab "*i*", and N = the number of labs in the curriculum. Each student rated 12 labs (N = 12). We used a one-way ANOVA followed by a Tukeys HSD test to evaluate assessment 2.

Quantifying Relative Impacts

To quantify the relative impacts of the 6 lab characteristics on students' attitudes toward lab, we subtracted the student rating from the neutral rating for each assessment. For assessment 1 the neutral rating was 3. For assessment 2, we estimated the neutral rating by calculating the total rating range for each individual student and averaging that range. We then converted these differences to a relative proportion for each of the 6 characteristics. We compared the relative proportion ratings of each student for a given characteristic between assessment 1 and assessment 2 with a t-test (α levels were set using the adjustment for multiple comparisons based on the *Bonferroni inequality*).

Results

Reliability of Assessments

We used Cronbach's alpha to assess reliability of assessment 1 for fall 2002 (Cronbach's alpha -- favorite = 0.95 and least favorite = 0.83). Following revisions, Cronbach's alpha in spring 2003 indicated slightly improved reliability (favorite = 0.97 and least favorite = 0.83).

For assessment 2, there was a significant difference in student ratings between fall 2001 and fall 2002 in 1 of 20 ratings when the labs were not changed and 7 of 12 ratings when labs were changed (Table 3). A Chi-Square test comparing the number of significant differences versus those not significantly different for changed and unchanged labs was significant ($X^2 = 16.67$, *d.f.* = 1, $P < 0.001$). In addition, changes to labs resulted in differential changes in student ratings between categories (Table 3).

Table 3. Test re-test measure of reliability for assessment 2. In the assessment students were asked to rate each lab on a scale of 1 - 10 based on how much they enjoyed the lab, how much the lab helped with lecture, how much they learned in general, and how valuable they thought the lab was. Ratings were compared between fall 2001 and fall 2002 in GBLI with a t-test (α adjusted for multiple comparisons based on the Bonferroni inequality). Exercise numbers indicate the order of labs in the semester. Some exercises were not present both years and were not assessed. (One asterisk indicates 0.05 > adjusted P > 0.01; two asterisks indicates 0.01 > adjusted P > 0.001; three asterisks indicates adjusted P < 0.001.)

Lab Change	Lab #/ Topic	Enjoyment			Lecture Help			Learned (general)			Value (general)		
		2001	2002	P	2001	2002	P	2001	2002	P	2001	2002	P
Not Changed	1/Sci. Meth.	5.58	5.69	.481	5.26	5.31	.799	5.90	5.90	.966	5.65	5.52	.440
	3/Osm./Dif.	6.08	6.38	.031	6.93	7.02	.531	6.70	6.82	.361	6.42	6.57	.297
	4/Plant Pig.	6.24	6.5	.073	6.71	6.80	.590	6.72	6.80	.563	6.42	6.52	.460
	7/Diss. 1†	7.67	7.31	.040	7.23	7.09	.270	7.79	7.57	.140	7.65	7.47	.232
	8/Diss. 2†	7.57	7.03	.003*	7.28	6.91	.035	7.69	7.36	.025	7.57	7.24	.038
Changed	2/Micr./Cells	6.18	6.54	.017	5.94	6.46	.001**	6.28	6.72	.001**	6.01	6.38	.018
	5/Phot./Resp.	6.14	6.71	<.001***	6.97	7.37	.005*	6.82	7.11	.030	6.56	6.82	.070
	6/Stud. Proj.	5.87	6.39	.004*	4.52	4.86	.128	5.48	6.26	<.001***	5.33	6.17	<.001***

† For dissection labs in fall 2002, fetal pigs were from a different source than in fall 2001. In fall 2002 pigs were not as well preserved and definitely had a more unpleasant odor.

Assessment 1

The one-sample t-test indicated that of the characteristics for all of the classes (GBLI, GBLII, HAL spring 06, HAL fall 06), only "open-ended" for GBLII was not significantly different from neutral ($P < 0.05$). All other comparisons were significantly different from neutral (Figure 1).

The two-way, Model I ANOVA showed that the curriculum had no significant effect on students' attitudes toward lab; lab characteristics did significantly impact students' attitudes toward lab, but there was a significant interaction between the two (curriculum - $F = 1.56$, *d.f.* = 3, $P = 0.197$; characteristics $F = 318.46$, *d.f.* = 5, P <

0.0001; interaction – $F = 6.55$, $d.f. = 15$, $P < 0.0001$). Of the 24 pair-wise comparisons on students' attitudes between majors and non-majors for each lab characteristic while disregarding curriculum, only one was significantly different – experimental for HAL Fall 06 vs. GBLII ($F = 6.14$, $P = 0.03$, Figure 1). When curriculum was added (GBLI vs. GBLII vs. HAL fall or spring), experimental for HAL Fall 06 and GBLII was still the only comparison (of 36) that demonstrated a significant difference. Pair-wise comparisons of characteristics holding the curriculum and major constant revealed the following order (< indicates a significant difference, $P < 0.05$): GBLI – exciting < time efficient < not difficult = lecture help = experimental < open ended; GBLII – exciting < time efficient < not difficult = lecture help < experimental < open-ended. For HAL the trends were similar, but with the smaller sample size there was more overlap. The order of explanative power for both semesters (HAL spring 06 and fall 06) was: exciting, time efficient, experimental, lecture help, not difficult, open-ended. Characteristics were significantly different in every other category. For instance exciting was not significantly different from time efficient, but was significantly different from experimental ($P < 0.05$).

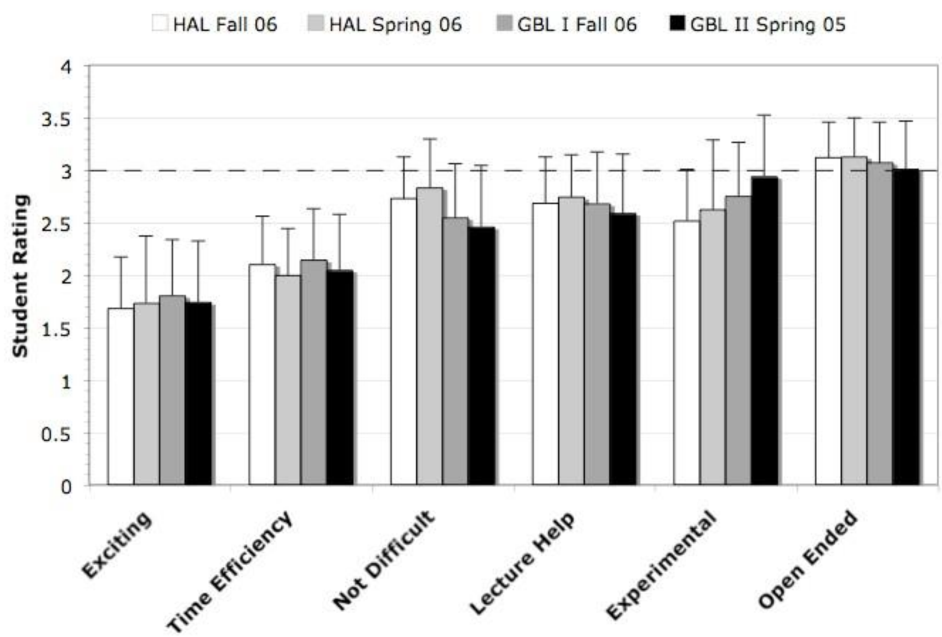

Figure 1. Relative influences of lab characteristics on student choices for best and worst lab combined. A student rating of 3 (dotted line) indicates students did not think the characteristic impacted their choice of best or worst lab. The smaller the student rating the more students thought the characteristic impacted their choice. Student ratings are shown for three curricula (GBLI, GBLII, and HAL) and a replicate class (HAL Fall 06 and HAL Spring 06). Only the mean student rating for GBLII was not significantly different from neutral ($P > 0.05$). The only pair-wise comparison holding characteristic constant that was significantly different was between HAL Fall 06 and GBLII for the experimental characteristic ($P < 0.05$). There were significant differences between lab characteristics holding curriculum and class constant (see text). Error bars indicate 1 standard deviation from the mean.

Assessment 2

The average student rating range for the assessment was 7.22 points. Thus, the neutral difference rating (R_d) is 3.61 points. The one-sample t-test indicated that mean difference ratings for each characteristic were significantly different from neutral ($P < 0.001$, Figure 2).

The ANOVA indicated a significant difference was present in the difference ratings (R_i) between lab characteristics ($F = 128.19$, $d.f. = 5, 1{,}240$, $P < 0.0001$). The Tukeys HSD test indicated the following order (< indicates a significant difference, *P*

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< 0.05): exciting < time efficient = not difficult < lecture help < experimental = open ended (Figure 2).

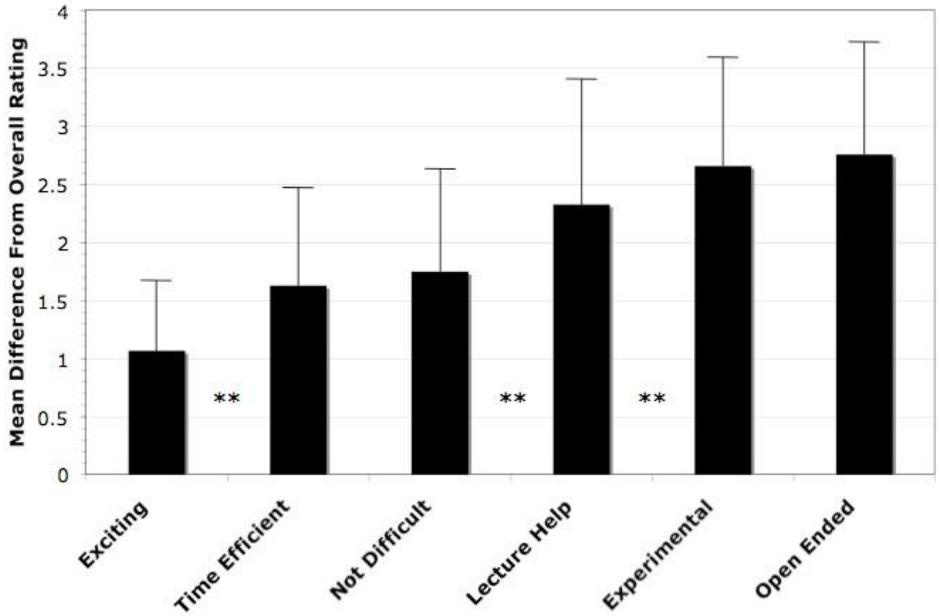

Figure 2. Mean difference in student rating of lab characteristic from overall student rating of lab (Rd) on a scale of 1-10 for GBLII Spring 2007. A value of 0 indicates a perfect match in rating and that a lab characteristic explained 100 % of the variance in overall ratings. The larger the value of mean difference in rating, the less the lab characteristic explained student overall rating. Asterisks between bars represent between lab-characteristic comparisons with a Tukeys HSD test. Significance is indicated as follows: **, P < 0.01; no asterisks, P > 0.05. Error bars indicate 1 standard deviation from the mean.

Quantifying Relative Impacts

The final estimates of relative percent rating deviations from neutral among the six characteristics are listed in Table 4. Only "time efficient" and "open-ended" showed a significant difference in the relative percent rating deviations from neutral between assessment 1 and assessment 2 (Table 4).

Table 4. Estimates of and a comparison of relative impacts of the 6 lab characteristics on students' attitudes towards lab between assessment 1 and assessment 2. Values represent mean deviation of student ratings from neutral normalized into relative proportions. Relative proportions between assessments were evaluated with a *t*-test (α levels were set using the adjustment for multiple comparisons based on the Bonferroni inequality). One asterisk indicates 0.05 < *P* < 0.01, and two asterisks indicate 0.01 < *P* < 0.001.

	Exciting	Time Efficient	Easy to Understand	Lecture Help	Experimental	Open Ended
Assessment 1	0.426	0.277	0.121	0.098	0.081	-0.003
Assessment 2	0.348	0.220	0.178	0.102	0.082	0.070
T	1.465	2.913	-1.758	-0.186	-0.017	-3.847
P	0.144	0.004*	0.080	0.852	0.986	0.0001**

Overall students' attitudes toward lab based on these 6 characteristics can be explained in three ways: from assessment 1 alone, from assessment 2 alone, or from an average for the two assessments. For example, if an average of the two assessments better explains student attitudes toward lab than either assessment alone, then the following equation would be used from values in Table 4: Total Student Attitude = 0.39 Exciting + 0.25 Time Efficient + 0.15 Not Difficult + 0.10 Lecture Help + 0.08 Experimental + 0.03 Open-Ended.

Discussion

Assessment Reliability and Validity

Evaluation of assessments 1 and 2 supports their reliability and validity. We used assessment 1 with three different lab curricula (GBL1, GBLII, and HAL) and two different groups of students (science majors and science non-majors), and we assessed one group of students twice to verify consistency (HAL spring 06 and Fall 06). Not only did the two HAL groups provide the same reasoning for their ratings, but the two GBL groups and GBL I and II vs. the HAL groups did as well (Figure 1). Out of all pair-wise comparisons between classes for the same characteristic (N = 36), only one showed a significant difference in student attitudes. This indicates that even with different groups of students and different lab curricula, students' reasons for rating a lab as best or worst are resilient to changes in these other parameters. For assessment 2, comparing students for the same curriculum between years showed that when labs were unchanged, students consistently rated the labs the same across several different rating questions, and when labs were changed, students differentially changed their ratings depending on the rating question (Table 3).

To evaluate validity, we compared results of the two assessments. Both assessments 1 and 2 revealed the same order of power for influence of the lab characteristics on students' attitudes, with the exception that in assessment 1 "time efficient" was not grouped with any other characteristic (Figure 1), and in assessment 2 "time efficient" was grouped with "not difficult" (Figure 2). In addition, in assessment 1 for 3 out of the 4 classes, students significantly disagreed that "open-ended" was a reason they chose the lab as best or worst, but in assessment 2, "open-ended" was significantly associated with student overall rating of the lab. Despite these differences, both assessments resulted in very similar quantitative estimates for relative impacts of the 6 lab design characteristics (Table 4).

Educational Implications

"Excitement" had an estimated 39% relative impact on students' attitudes toward lab. What makes a lab more exciting? Unfortunately, "excitement" is not easily defined and may vary from one student to the next. Furthermore, no studies that we know of have examined what lab components make a lab more or less exciting to students. Logic dictates that hands-on labs should be more exciting for students than watching a demonstration by a teacher, and research consistently indicates students' attitudes improve with hands-on labs compared with teacher demonstrations (Ajewole 1991, Freedman 1997, Killerman 1998). Among hands-on labs, lab style may have an impact on excitement. Logic again dictates that the standard verification style of lab (expository) should be one of the least exciting lab styles. The teacher tells the students what will happen and they verify it in class. Problem-based labs with interesting and intriguing questions for students to answer should be more exciting than expository labs. Discovery style where students discover a general principle for themselves should also be more exciting. In inquiry labs, students choose their own topic and theoretically choose a topic that excites them. Few studies have examined students' attitudes in relation to different lab styles. Of those studies, several authors conclude that students' attitudes improve with alternate lab styles over expository (Booth 2001, Anders et al. 2003, Luckie et al. 2004, Flora and Cooper 2005), while other authors allude to alternate lab styles decreasing students' attitudes toward biology and science when compared with expository labs (Sundberg and Moncada 1994).

"Time efficiency" had an estimated 25% relative impact on students' attitudes toward lab. The theoretical framework for time efficiency is based on a cost/benefit analysis where the cost is time and the benefit is perceived learning. Theoretically, either reducing the time relative to perceived learning, or increasing perceived learning relative to time can improve attitude toward a lab. One good way to reduce time investment is to have better equipment, such as: electronic balances that tare instead of triple-beam balances; equipment attached to computer interfaces and software that automatically calibrate and graph, such as new spectrometers and gas probes; equipment with higher resolution so the experimental time to expose the influence of a treatment can be reduced; etc. Unfortunately, improved time efficiency from the student's perspective is not necessarily the best for the cognitive domain. For instance the expository style of lab is likely the most time efficient for content learning and application, but does not necessarily help students with science reasoning, understanding the nature of science, reversing misconceptions and higher-order cognition like analysis and synthesis. Additionally, many students may not perceive the learning that comes from actually doing science as valuable. This may be why Sundberg and Moncada (1994) allude to decreased attitudes with full inquiry labs. One approach that may counterbalance the perceived time efficiency in expository labs versus alternate lab styles and improve students' attitudes toward lab is to allocate time in discussions or lecture explicitly addressing with students what they learn by doing inquiry labs (Anders et al. 2003).

"Not difficult" had an estimated 15% relative impact on students' attitudes toward lab. Unfortunately this lab characteristic may be in direct conflict with desired learning outcomes in the cognitive domain. Again, expository labs are probably less difficult for students than the alternate lab styles because they will mainly deal with lower order cognition of memorization, conceptualization and application (see Table 1). Problem-based and discovery labs challenge students with higher-order cognition and inquiry labs challenge students with inductive reasoning. One potential way to keep attitudes positive without decreasing difficulty is to run a problem-based or expository lab instead of full inquiry and add reflection (Cox and Junkin 2002). This way the higher order cognitive tasks happen at the end of the lab instead of the beginning and students do not get stuck and frustrated at the beginning of the lab; thus, students should enjoy the lab experience more.

"Lecture help" and "experimental" had an estimated 10% and 8% relative impact on students' attitudes toward lab, respectively. Almost any type of lab can be converted from an observational lab into an experimental lab. We can return to the example in the introduction of this paper. A hands-on, observational, fetal-pig-dissection-lab can be converted to an experimental lab by having students measure and quantify certain parts of the fetal pig during its dissection in relation to some question or hypothesis. However, by making this change the amount that the lab helps with lecture may be reduced as time is spent measuring and analyzing data instead of dissecting and exploring new anatomical features. Still, this study indicates that the influences of an experimental lab and a lab providing lecture help, on students' attitudes towards lab are similar.

Even though the relative impact of "open-endedness" was significantly different between assessment 1 and assessment 2, both assessments indicated that "open-endedness" had at best a minor relative influence on student's attitudes toward lab (mean of 3%).

Future Research

This study provides an example of how multiple characteristics that differentially influence one potential learning outcome (i.e. attitude toward lab) can be investigated relative to one another. By continuing to examine relative impacts of various characteristics on different learning outcomes, a more complete cost-benefit analysis can be incorporated into lab design. As previously demonstrated, lab characteristics examined in this study can be linked with various lab styles, which can be linked with other learning goals listed in Table 1. The main difference in this approach versus other approaches is that with the "optimal-lab-design" approach, relative impacts of several independent variables are quantified simultaneously rather than the traditional approach of isolating one independent variable at a time. Ultimately, as more relative information using this approach is gathered, we can use mathematical modeling to individualize the optimal lab design so that it meets a variety of differential learning goals.

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References

Ajewole, G. A. (1991). Effects of discovery and expository instructional methods on the attitude of students to biology. *Journal of Research in Science Teaching*, 19, 233 - 248.

Anders, C., Berg, R., Christina, V., Bergendahl, B., Bruno, K., & Lundberg, S. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. International Journal of Science Education, 25(3), 351-372.

Basey, J. M., Mendelow, T. N., and Ramos, C. N. Current trends of community college lab curricula in biology: an analysis of inquiry, technology and content. *Journal of Biological Education* 34(2): 80–86.

Bloom, B.S., Engelhart, M.D., Furst, E.J., Hill W.H., and Krathwohl, D.R. (1956). *Taxonomy of educational objectives: Part I, cognitive domain.* (New York: David McKay Company Inc.)

Booth, G. (2001). Is Inquiry the Answer? *Science Teacher*, 68(7), 57–59.

Cox, A. J., & Junkin, W. F. III (2002). Enhanced student learning in the introductory physics laboratory. *Physics Education* 37(1): 37–44.

Dunn, R., Dunn, K., & Price, G. E. (1982) *Productivity environmental preference survey.* Lawrence. Kansas: Price Systems.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education*, 76, 543 - 547.

Finn, J. K. (1997). Analysis of Variance and Covariance. In (Ed.) Keeves, J. P. *Educational research, methodology, and measurement: an international handbook 2nd ed.* (pp. 696–703). Cambridge: Cambridge University Press.

Flora, J. R. V., & Cooper, A. T. (2005). Incorporating inquiry-based laboratory experiment in undergraduate environmental engineering laboratory. *Journal of Professional Issues in Engineering Education and Practice,* 131(1), 19–25.

Fraser, B. J., McRobbie, C. J., & Giddings (1993). Assessment of the psychosocial environment of university science laboratory classrooms: a cross-national study. *Higher Education*, 24, 431–451.

Freedman, M. P. (1997). Relationship among laboratory instruction, attitude toward science and achievement in science knowledge. *Journal of Research in Science Teaching*, 34(4), 343-357.

Gardner, P., & Gauld, C. (1990). Lab work and students' attitudes. In E. Hagarty Hazel (Ed.), The student laboratory and the science curriculum (pp. 132-156). New York: Rutledge.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: promoting scientific inquiry. *Journal of Research in Science Teaching*, 33, 475-499.

Hodson, D. (1996). Laboratory work as scientific method: three decades of confusion and distortion. *Journal of Curriculum Studies*, 28(2), 115-135.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: foundations for the Twenty-First Century. *Science Education*, 88, 28–54.

Holcomb, C. M. (1971). The effect of degrees of direction in the qualitative analysis laboratory on retention of learning. *Journal of Research in Science Teaching*, 8(2), 165-169.

Jackman, L. E., Moellenberg, W. P., & Brabson, G. D. (1987). Evaluation of three instructional methods for teaching general chemistry. *Journal of chemical education,* 64(9), 794–796.

Johnson, M. A., & Lawson, A. E. (1998). What are the relative effects of reasoning ability and prior knowledge on biology achievement in expository and inquiry classes? *Journal of Research in Science Teaching*, 35(1), 89-103.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, 39(7), 551-578.

Killermann, W. (1998). Research into biology teaching methods. *Journal of*

Biological Education, 33(1), 4-9.

Klausmeyer, H. J. (1980). *Learning and teaching concepts,* New York, New York: Academic Press.

Kolb, D. A. (1985). *Learning Style Inventory: self-scoring inventory and interpretation booklet.* Boston, MA: McBer & Company.

Krebs, J. R., & Kacelnik, A. (1991). Decision-making. In (Ed.) Krebs, J. R., & Davies, N. B. *Behavioural Ecology: An Evolutionary Approach*. Boston MA: Blackwell Scientific Publications.

Lawson, A. T., & Johnson, M. (2002). The validity of Kolb learning styles and neo piagetian developmental levels in college biology. *Studies in Higher Education,* 27(1), 79–90.

Luckie, D. B., Malezewski, J. J., Loznak, S. D., & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of "Teams and Streams." *Advancements in Physiology Education,* 287, 199–209.

National Science Foundation, Advisory Committee to the Directorate for Education and Human Resources, Melvin D. George (Chair) (1996) Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology. Volume I. Arlington, Virginia: National Science Foundation, NSF 96 - 139.

Purser, R. K., & Renner, J. W. (1983). Results of two tenth-grade biology teaching procedures. *Science Education,* 67(1), 85-98.

Sundberg, M. D., & Moncada, G. J. (1994). Creating effective investigative laboratories for undergraduates. *Bioscience*, 44, 698 – 704.

Tamir, P., Stavy, R., & Ratner, N. (1998). Teaching science by inquiry: assessment and learning, *Journal of Biological Education*, 33, 27-32.

Toh, K. A., & Woolnough, B. E. (1993). Middle school students' achievement in laboratory investigations: explicit versus tacit knowledge. *Journal of Research in Science Teaching,* 30(5), 445-457.