Design labs: Students' expectations and reality

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Abstract. In a study reported in PERC 2004 [1] the authors described how introductory physics labs in which students design their own experiments help them develop scientific abilities. These include the ability to design an experiment to solve a problem, to collect and analyze data and to communicate the details of the experimental procedure. The goal of the present study is to investigate the social aspect of student learning in these labs: whether students' expectations are consistent with the goals of the labs, whether student assessment of their learning in the labs matches the goals, and whether students perceive the labs as helpful in learning useful skills.
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"The problem is to provide students with enough guidance to lead them into thinking and the forming of insights but not so much as to give everything away and thus destroy the attendant intellectual experience."
—*Arnold Arons*

INTRODUCTION

Experts in physics education suggest that student learning in introductory physics labs should resemble the work of scientists. For example, students can use lab observations to construct concepts and then test them experimentally guided by hypothetico-deductive reasoning [2]. The AAPT noted that experimental design, data analysis, understanding the difference between evidence and claims, and development of the ability to work with others are goals that introductory labs should strive to achieve, in addition to improvement of the understanding of content [3]. Workplace studies suggest that introductory courses should address these goals so that students who pursue science-related professions can be prepared for the future [4,5]. Specifically, such students need to learn how to design experimental investigations, how to evaluate experimental results, and how to work in groups. The Investigative Science Learning Environment (*ISLE*) [6] incorporates the above goals into students' learning experiences naturally. The essence of *ISLE* is that it replicates some of the processes that scientists use to construct knowledge. In each unit students construct concepts by analyzing patterns in experimental data, then test their ideas by using them to predict the outcomes of new experiments and finally apply these concepts to solve practical problems. Much of this is done in labs, where students work in groups to design their own experiments and evaluate the results. Write-ups for *ISLE* labs do not contain instructions on how to perform the experiments; instead they guide students through various aspects of a typical experimental process. Thus the labs address the goals discussed earlier. See the example of a lab write-up in Figure 1.

Relationship between current and voltage
Design an experiment to determine a mathematical relationship between the current through a resistor and the voltage across the resistor.
Available equipment: Voltage source, resistor, light bulb, voltmeter, ammeter, wires. Include in your report:
a) Devise a procedure for your investigation and describe your design. Include a circuit diagram.
b) What important physical quantities change during the experiment? What are the independent and dependent variables in your experiment?
c) What assumptions are you making? Explain how these could affect the results.
d) List sources of experimental uncertainties. Evaluate how these will affect the outcome.
e) Connect the circuit according to your diagram and perform the experiment.
f) Record your data in an appropriate manner.
g) Describe the pattern you found between the current and the voltage as a mathematical relationship.
h) Test whether the relationship you found is applicable to a light bulb. *Make a prediction based on the relationship you constructed.* Connect the circuit and perform the experiment. Determine the outcome.

FIGURE 1. Example of a lab write-up.

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We have evidence that students performing such labs improve significantly on their ability to design an experiment, devise a mathematical procedure to solve an experimental problem and communicate the details of the procedure [1]. We now wish to investigate the following questions: how do students perceive their learning in the labs? Are the goals of the labs as conceived by us (the authors are also the designers of the labs) consistent with students' expectations of the goals of an introductory science lab? Do students understand what the actual goals of the labs are?

MOTIVATION

Why is it important for the students to understand and appreciate the goals of the instruction and be aware of what they are learning? The motivation for this study comes from the fields of educational theory and science education research. In a theoretical approach to complex learning called "contextual modules" [7], Bereiter suggests that learning is a more complex process than a simple acquisition of declarative knowledge (physics concepts) and procedural skills (experimentation and design abilities) by a learner. According to Bereiter, goals and feelings of a learner are important contributors to learning, especially for difficult topics. More recent theoretical developments in education focus on intentional learning [8], suggesting that learner's motivation is strongly related to conceptual change. Science education research presents evidence of the correlation between student attitudes towards science with their science achievement [9]. However, PER indicates that students' expectations of physics instruction are different from those of instructors [10]. In particular, a study done by Lippmann [11] of students performing Scientific Community Labs (SCL) developed by the University of Maryland PER group, in which they designed their own experiments showed that students' perceptions of the goals of the labs do not match the goals of instructors. While the goals of the designers of the SCL were to help students design experiments and learn how to interpret data, only 14% and 8% students respectively identified these as important goals of the labs. As the *ISLE* labs have goals similar to those of SCL, but are more structured and explicitly focus students' attention on the development of scientific abilities, we want to investigate whether *ISLE* students understand the goals, share them and think that the labs achieve the goals.

DESCRIPTION OF STUDY

The study was conducted in a large enrollment (200 students) introductory two-semester physics course for science majors (pre-med, pre-vet, biology, environmental science, meteorology). There were two 55-min lectures, one 80-min recitation and a 3-hour lab per week. In each semester students performed ten labs and had two lab practical exams. A lab usually contained two experiments: the first had some guidance and in the second, students designed their own experiment with almost no instructions. A write-up similar to the example in Fig. 1 provided scaffolding to help students focus on certain elements of the lab. Students designed, performed and wrote a report of their procedure and findings in the allotted 3 hours. Throughout the labs, students used scientific abilities rubrics [12] to help them design, perform and report the experiment. The rubrics contain descriptors on a scale of 0-3 of individual scientific abilities. A portion of the rubric (for one ability) is shown in Table 1. In each lab students described real life situations where they might need to solve similar problems.

TABLE 1. Portion of a rubric.

Ability/Score	0	1	2	3
Is able to make a reasonable prediction based on a relationship or explanation	No attempt to make a prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it doesn't follow from the relationship or explanation being tested, or it ignores or contradicts some of the assumptions inherent in the relationship or explanation.	A prediction is made that follows from the relation-ship or explanation and incorporates the assumptions, but contains minor errors, inconsistencies or omissions.	A correct prediction is made that follows from the relationship or explanation and incorporates the assumptions.

At the end of the second semester, students responded to an anonymous survey on the goals of the labs. The survey contained both open response questions (Question 1 below) and Likert-type questions (Questions 2 and 3 below).

1. Describe the three important things that you learned from the physics labs.
2. Below is a list of possible goals that a college-level science lab course can have. On a scale of 1 to 5, rate how important you think each goal is for you. (1 means it is not important for you and 5 means it is very important.)
   Learn to design your own experiment
   Learn to interpret experimental data
   Prepare for your future professional career

Understand concepts better
Learn to work with other people
Learn to communicate ideas in different ways

3. Below is the same list of goals [not shown in this paper]. On a scale of 1-5, rate how successful the labs were in terms of achieving each goal. (1 means the labs were not at all successful and 5 means they were very successful.)

DATA ANALYSIS

In this study we report the analysis of survey responses of 187 students who took the survey.

After the first reading of the responses to question 1 (the open-response question), we noticed that the things students mention they learned in labs repeated often. Thus we could classify all of the students' responses into 11 categories that are shown in Table 2. We then found the percentage of students who said that they learned a particular thing.

TABLE 2. Analysis of question 1 in survey.

What students said they learned	Percentage who said it
Physics content (understand concepts better)	33%
Work in groups with other people	28%
Apply physics to real world	26%
Design experiment	24%
Evaluate effect of assumptions and uncertainties on the outcome of an experiment	20%
Solve problems experimentally	16%
Communicate in writing	14%
Operate equipment	13%
Interpret data	11%
Figure out things independently	10%
Test a prediction based on a concept	6%

To analyze students' responses to questions 2 and 3 in the survey, we grouped students who rated a particular goal as 4 or 5 as "high", those who rated it as 3 as "medium", and those who rated it as 1 or 2 as "low". The results are shown in Fig. 2. As all of the goals listed in question 2 were considered "high" by us, it is possible to say that the majority of the students have expectations of the labs that are in agreement with our goals. Also, a majority of the students agreed that most of the goals were achieved by the labs. The only exception was the goal of preparing for future careers. Students' responses to questions 2 and 3 were significantly correlated with each other.

We also compared students' responses to question 1, which was open-ended, with their ratings to question 3. For example, 45 out of 187 students (24%) said in words they learned how to design experiments. Out of these 45, 28 students (62%) gave a "high" score for "learn to design own experiments" as an achieved goal of the labs in question 3 of the survey. On the other hand, out of 142 students who did not explicitly say that they learned how to design experiments as a response to question 1, 72 students rated this goal as highly achieved. Thus 50% of the students who did not mention that they learned how to design an experiment in an open-response question agreed that the lab achieved this goal.

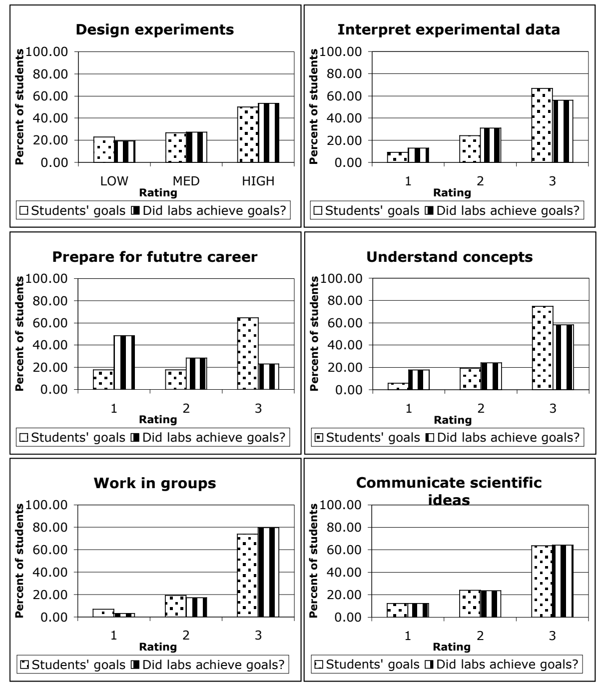

FIGURE 2. The figure shows the percentage of students (N=187) that rated different goals in the survey as being important to them (grey dots) and as being achieved by *ISLE* labs (dark vertical lines).

INTERPRETATION OF RESULTS

The response from students that the labs helped them to improve the understanding of physics is consistent with the findings of Lippmann (her study had 125 students). A possible explanation might be that to design an experiment, one has to analyze, synthesize, reexamine and apply the existing knowledge, leading to a better conceptual understanding. This explanation is consistent with the video data that we have. What is different from Lippmann's findings is that many *ISLE* students said without prompting that they learned how to design an experiment (24% versus 14% in Lippmann's study). In addition, comparing responses to questions 1 and 3 in the survey, we can say that even if a student did not mention that she learned to design an experiment in question 1 (open-response), there is a 50% chance that this particular student considers this goal to be achieved by the ISLE labs. Another important finding is that 50% of the students agreed that the labs achieved the goals of helping them learn to interpret experimental data and 11% mentioned it in their open responses (8% mentioned it in Lippmann's study). One explanation might lie in the structure of the *ISLE* lab write-ups and assessment tools. Our students had rubrics that focused their attention on design, data analysis, and the effect of assumptions and experimental uncertainties on the outcome of the experiment. In fact, one-fifth of the students responded that one of the important things they learned from the labs was how to evaluate if the outcome of an experiment makes sense, in terms of the assumptions and uncertainties. Since this was stressed in the labs by the teachers, we find this to be an encouraging result. However, another explanation is also possible. Students might have looked at their choice of possible goals in question 2 and based their responses to question 1 on the choices given.

The only goal that the majority of the students thought should be achieved and perceived as not being accomplished was that of preparing them for future careers. One can interpret this finding in different ways. Possibly, students do not know how much they will need the scientific abilities that they acquired in the labs. Another explanation is that they thought the content of the labs should be more connected to their future professions. In any case we found a deep mismatch, which is a disappointing result.

IMPLICATIONS FOR INSTRUCTION

Students come to our courses with certain expectations. Even if we structure our instruction with the best possible goals in mind, they do not necessarily match our students' goals. Or if they do, students might not understand that goals match. As a person's goals affect how she approaches learning, we need to make sure that we not only communicate the goals of instruction to the students but also help them understand why these particular goals were chosen and how the instruction achieves them.

As achieving a good grade is an important goal of most students, we need to make sure we reward them for achieving the goals that we find important. This means we need to assess our students on exams not only on the knowledge of concepts and problem solving abilities but also on the ability to design experiments, interpret data, and so forth.

We need to make an explicit connection between the content of the labs and students' future professions. For example each lab write-up can contain a specific example of how a particular ability addressed in the lab is used in students' future work.

As a result of this research project, our students will have a course packet with written goals of the course and a description of learning strategies that might help them achieve those goals. Some exam questions will require students to describe an experiment that they would design to solve a problem. Lab write-ups will contain examples from popular science periodicals that show how certain skills that students learn in the lab are used by scientists.

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