A Review of Introductory Physics Laboratories and Hybrid Lab Classrooms Including Difficulties, Goals, and Assessments

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This paper reviews introductory physics labs and is intended as a broad introduction to laboratory possibilities and considerations. The focus is on laboratory curriculum developed since the advent of computers, in part because this coincides well with the timing of early papers in Physics Education Research. The discussion of labs is broadened to include activity-based learning environments that use physical equipment. A discussion of difficulties associated with labs (both administering them and student learning) is given as well as a discussion of typical goals physical activity-based learning environments address. Finally a discussion of assessments is provided.

I. INTRODUCTION

When we hear the words "physics laboratory" we are likely to have an immediate picture in our minds of a physics lab we have experienced. Chances are, our pictures are not dissimilar. This is partly due to the fact that certain equipment and furniture is very common and useful in a lab setting, but unfortunately also partly due to the fact that novel lab environments are not very common. For the purpose of this study we adopt a broad definition of the physics laboratory, since novel techniques will be a primary focus, rather than the physical setting. We will define a physics laboratory to be: the direct use of equipment by the students as part of a structured learning process.

This definition incorporates a wide range of classrooms. Some physics labs are completely separate from lecture instruction while others are fully integrated into the course in such a way that essentially all lecture is replaced by labs. Some labs are totally self-guided in that students can pick their experiments and perform them with no supervision while others involve constant interaction with peers and instructors. Some involve a multitude of small experiments throughout the quarter, while others involve long-term projects. Some involve students focusing on data and error analysis while others have students focus on qualitative written explanations. Some involve use of advanced technology while others rely on simple inexpensive equipment.

Many interesting lab courses have been developed, each with its own set of goals, difficulties, and student achievements. This paper will give many examples of labs that have been developed predominantly for introductory college physics courses. The focus will be on difficulties encountered with different lab types, the developments made to correct these problems, and whether the novel lab types were successful towards meeting their goals. A secondary focus will be on general methods of lab assessment, from both the standpoint of how the lab assesses student understanding for the purpose of grading, and how the lab as a course is assessed.

II. SURVEY OF LABORATORY CURRICULA AND ENVIRONMENTS

A. Computer-based Labs

The most striking changes in introductory physics lab instruction began with the introduction of the microcomputer. Prior to this, some universities were able to purchase a central computing device for students to use in the lab courses, but this was not affordable for most institutions. When computers became more portable and inexpensive, their use in instruction took hold in many forms. Early classes focused on teaching programming skills (Geller, 1972), and took advantage of the computers' computational power for statistical data analysis. When used as a calculator, the computer saves time for the students to do other activities. In computer simulations, variables can be quickly changed, allowing students an easy way to study multiple aspects of a phenomenon (Wilson, 1980; Lough, 1986; Guglielmino, 1989). While doing student interviews to assess conceptual understanding, it was found that students were more likely to repeat a computer simulation than a physical demonstration before coming to a conclusion about what they observed (Grayson, 1996). Most authors of early computer-based labs are of the opinion that combining computer simulations with physical experiments optimizes the student learning experience.

With advances in technology, the use of computers in labs expanded to include data collection. Motion detectors and interfaces allowed for motion to be studied much easier than with simple graph paper or more cumbersome measurement techniques. Furthermore, motion could be graphed in real time, aiding students understanding of velocity and acceleration (Thornton, 1990; Feulner, 1991). Another method that makes use of computers (and other technology) to gather data is digitized video images (Graney, 1995)[1]. Students can carefully analyze motion while it is slowed down drastically, or made completely still using a set of images. Not only does this help students analyze motion more precisely, but it also allows for quantitative lab-type experiments to be done remotely.

There are studies where computers are used in place of physical lab activities. One study found that students actually did better on assessments after performing a simulated lab experiment than their peers who did a traditional physical lab experiment involving circuits (Finkelstein, 2004). Students who did the simulated lab not only did better on related exam questions, but when each group was given a new circuit they could construct the circuit and answer the questions pertaining to it faster than the students who had originally done a physical experiment. Well-written simulations have the possibility of showing physical phenomenon more clearly than 'real-life', or showing things that are otherwise virtually impossible to observe. For example, in the simulation mentioned above, the current in the circuit was visible and students could see that it was not 'used-up' by the circuit elements.

Research studies indicate that the addition of computers is not sufficient to improve student conceptual understanding; careful attention must be paid to how activities are presented to students. One study had students use computer-based lab exercises with half of the class following cookbook style instructions and the other half using active-engagement based instructions (Royuk, 2003). The lab experiment was otherwise identical. The students who had cookbook instructions did not learn as much as the active-engagement students as measured by the Force Concept Inventory (the results were not quite statistically significant, though there were only 52 students among the experimental groups). Another study found an impact on overall student achievement with only one active-engagement computer-based lab activity added to the traditional course (Abbott, 2000). It is a tribute to well-written experiments that 2 hours of activity can have a measurable effect on student understanding over the course of an entire semester.

Other labs use computers either as introductory tutorials (Zacharia, 2003; Sung 1998) or to provide follow-up exercises (VanDomelen, 2002). These aid the student by providing them consistent multiple exposures to the material. Tutorials have also been used outside the lab setting and have shown a positive impact on student understanding (Hicks, 1989; Jones, 1994; Reif, 1999). In addition to the educational uses of computers mentioned above, computers "empower students, ... develop skills (both physical and cognitive), ... and develop attitudes (Zacharia, 2003)." Student attitudes are positively impacted, as students typically enjoy using new technology. Often the interfaces are attractive to the students and they want to use the programs. Virtual-reality based lab experiments were developed and tested at The Ohio State University. These include a joystick allowing the students to manipulate the object in the simulation directly and receive instantaneous feedback. These simulations resemble games; students enjoy using them and they gain a physical understanding of force and motion (Demaree, 2004).

(Sokoloff, 1999) was written specifically for the purpose of placing a value on computer exercises. A drawback found was that students tend to find the computer output authoritative. They are likely to think that something is true because the computer 'told them it was so,' rather than because of the physical principles behind the simulation (this is a strong reason behind taking the time to have students program their own simulations (Lough, 1986)[2]). It was also shown that well written active-engagement exercises whether using a computer or not can have the same educational benefit for the students. Combined with the results mentioned above, this supports the generally accepted idea that active-engagement is a necessary condition for improving student learning experiences. In conclusion, computer-based labs, when used in a research-based lab implementation, can produce many worthwhile benefits for students.

B. Research-based Physics Labs

Since the growth of research devoted specifically to physics education, new standards have been set for the development of curricula. The labs described in the literature are typically defined with a set of goals in mind, and are tested using standard assessments. A popular lab manual that makes use of active-engagement computer-based labs is RealTime Physics (Sokoloff, 1999). Background research related to the development of this text can be found in (Tinker, 1996). This manual makes use of the same type of information discussed in the computer section of this report, particularly using computers to collect data. Since the RealTime Physics lab manual is a published text, it is used at many schools. With dissemination there is often adaptation of a curriculum, with the possibility that the quality of instruction and the educational benefit to the student might decrease. A three-year study made use of standard diagnostic tests and an attitude survey (including the Maryland Physics Expectations Survey, the Force and Motion Concept Evaluation, and the Electric Circuits Concept Evaluation) to determine if this dilution effect is occurring. It was found that at most schools, the students showed considerable improvement on the diagnostic tests achieving gains comparable to that achieved by the original curricular developers. However, no positive change in student attitudes was found from the Maryland Physics Expectations Survey. It was found that the schools that did not show educational improvements with this text were not implementing the curricula as intended (Wittmann, 2000).

The Ohio State University (OSU) Physics Department has used a set of introductory labs called Constructing and Applying the Concepts of Physics (CACP) (VanDomelen, 2002). These labs attempt to create an explicit linkage between real phenomena and their representations, elicit student conceptions, and require students to make their reasoning explicit. They were created using PER-based knowledge about student conceptual difficulties. These labs were assessed using the Force Concept Inventory (FCI) (Hestenes, 1992), and when combined with traditional lecture instruction, students typically obtain normalized gain scores better than traditional courses, but not as good as many active-engagement courses (Hake, 1998). These labs also make use of motion detectors and computer tutorials similar to those mentioned above. A unique feature in these labs is 'experiment problems,' in which "students use the concepts of physics to make predictions about the behavior of more complex physical processes that involve experimental apparatus (VanDomelen, 2002)." Many of these activities grew out of the ALPS kit (Active Learning Problem Sheets) and are now incorporated in the published Active learning Guide (ALG) (VanHeuvelen, 2005).

Labs developed at Rutgers University (Etkina, 2002) called Investigative Science Learning Environment (ISLE) involve three different types of experiments: observational, testing, and application. The goals and expectations of these labs are precisely defined through a set of 'Scientific Ability Rubrics[3].' A detailed discussion of the use and benefits of rubrics can be found in[4]. The labs have an emphasis on writing; students turn in lab reports at the end of each class in which they must explain the goals, assumptions, errors and conclusions clearly (along with providing a description of the experiment, data, and other necessary details). In the first implementation of ISLE (at OSU), students achieved 5% higher (changing from an already high post-test average of 69% to 74%, effect size 0.5) on the Conceptual Survey of Electricity and Magnetism. Since that time, the rubrics and course structure have been refined, and further studies have shown significant increases in student learning, including transferable scientific skills.

The labs at the University of Minnesota (Heller, 1992)[5] are meant to complement an overall course structure aimed at teaching problem solving skills. Students are expected to provide detailed problem solutions, and students can typically solve problems much more complex than those found in typical textbooks. The labs provide experimental problems where the students can apply their problem solving techniques. The work is graded more on the quality of the solution than the final answer. The key to the success of this course design is structured group work (Heller, 1992). Students are assigned roles within their groups and are paired based on ability. It is found that the problem solving ability of the group exceeds that of any individual, and the students also do better on individual problem solving after completing their group work.

Other labs are designed to re-focus the students from finding an expected answer to testing a theory given in a false scientific paper (Erickson, 2005), or by asking students to settle a realistic debate about a scientific issue (Allie, 1997). These labs can be used throughout the course, as progress checks, or an assessment to see if students are developing critical lab skills (Demaree, 2005). These labs explicitly shift the student into the role of the authority in answering a scientific question. They require students to use hypothetico-deductive reasoning, measurement intervals for deciding if data agrees or not, and are more writing intensive than a standard cookbook lab.

A few other labs are included here based on their exemplary nature, though they have not been assessed as carefully as the ones mentioned above.

Labs developed at Piedmont Virginia Community College are very similar in philosophy to the ISLE labs (Lough, 1986). Students are given a variety of tools and must design their own experiment for examining a physics concept. However, in this lab, students are not only given physical equipment, but also computers with which they can choose to write simulations. The instructor stresses his role as a guide, and pushes his students to take ownership of their experiments. Students are also encouraged to go around the lab and see how other groups are approaching the topic in question. The author states that "as a result, [the students] seem to be much more involved with their learning, and seek personal understanding of the physics concepts."

At University of California, Berkeley a lab was designed primarily with the goal of improving students' attitudes and teaching skills which would transcend the lab setting (St. John, 1980). The lab developer focused on teaching the ability to make estimations, understand elementary statistics, and the ability to explain what is observed in lab. He makes use of games and everyday phenomena to get students interested in learning these skills. A useful exercise he suggests is having students evaluate descriptions of an experiment and compare their scores with those given by an 'expert.' This helps students learn to judge the quality of their own work.

Labs at Brigham Young University follow an open-format[6]. They have been run for over twenty years, and it is felt that they are quite successful. Students do the lab whenever the building is open and turn in their report to a mail slot when they are finished. Each student has an assigned day, but can do the lab anytime up to the end of that day. There has been no formal assessment of these labs, but their approach is unique enough to mention. With research showing the positive effects of active-engagement exercises, many curriculum methods have moved towards eliminating traditional lecture altogether. With an activity-based course, there is no clear distinction between lab and the 'rest' of the course. Reference (Beichner, 2008) points out one benefit of an integrated classroom that pertains to all courses mentioned in this section: any problems of coordinating lab and lecture are eliminated. For instructors who are not yet ready to fully loose the structure of a lecture course they can consider using minilabs. A minilab (Etkina, 2000) is a short qualitative experiment which is designed to be injected into a course with little effort. There are many aims associated with the minilabs, most of which overlap with typical lab goals, although a single minilab would only attempt to accomplish one or a few learning outcomes.

C. Integrated Active-learning Classrooms

Physics By Inquiry (McDermott, 1996) eliminates all form of lecture completely, and the entire course takes place in a lab setting. The text is made up of modules on different subjects, each containing very little explanatory text. Instead, "the modules formalize the process of Socratic dialogue by incorporating essential questions into the written materials

(Lea, 1993)." The aim of the course is to "provide a coherent set of activities leading to sustained development of concepts within a given area of physics." The students develop basic concepts from simple observations, building on what they have discovered until satisfactory understanding of a physics phenomenon is achieved. This course has been shown to be quite successful in teaching conceptual understanding to non-science students. This course has been used in a variety of different settings (Lea, 1993). However, implementation that achieves the results obtained at the developing institution requires a very low student to instructor ratio and small classrooms.

There are several course types that attempt to minimize lecture and instead focus on problem solving, computer-based activities, group work, and other activities which work together to enforce learning outcomes. These developed somewhat independently and with slightly different goals. They include Workshop Physics[7] (Laws, 1996), Studio Physics (Cummings, 1999), and Modeling Physics (Laws, 1991; Wells, 1995). The instruction room designed at Dickinson College for Workshop Physics is unique, with modular tables than can be rearranged for different activity-types, and a low-friction slab on the floor in the center of the room for doing large-scale experiments. Activities are also creative; in one, students observe the 'transformation of a dialectic into dielectric' by making a capacitor out of sheets of foil and their textbook (Laws, 1996). Studio Physics is conducted in a more traditional setting, but includes a similar variety of activities. The modeling physics curriculum has an underlying theme of creating 'models': "conceptual representations of physical systems and processes (Wells, 1995)" and has typically been used in high school physics, though Florida International University has implemented it in their university courses (Brewe, 2008).

In these courses students typically receive high gains on diagnostic tests; however, Studio Physics was initially no more successful than a standard lecture-based course. It was not until PER-designed activities were added that educational improvements were shown. It was not enough to minimize lecture, maximize student activity, and increase the interaction time with instructors (Cummings, 1999). Just as with computer enhancements to labs, without properly designed activities the educational benefits will be minimal. One difficulty associated with these courses is the high operating costs to the university. These courses require a small number of students per instructor and typically require a specialized classroom.

The SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs) (Beichner, 2008) curriculum aims to keep the benefits of courses similar to the ones mentioned above yet allow the course to function with large student enrollment. While the other courses typically cannot handle more than forty students with at least two instructors (one is typically a teaching assistant), the SCALE-UP design has been successful with class sizes up to 120 students and three instructors (one professor and two teaching assistants). This is accomplished primarily by the classroom structure. Students are put in groups of three, and three groups sit together at a round table. There is a laptop computer for each group to use during activities. This setup allows nine students per table, which can function fairly well without immediate access to an instructor since the groups can help each other. Accountability at the individual and group level is built into the course to help keep the groups productive. This format has been particularly successful at retaining at-risk students.

III. DIFFICULTIES ASSOCIATED WITH INTRODUCTORY LABS

There are many difficulties associated with traditional lab courses. Depending on the setup, instructor and other factors, some of these problems may be minimized. One practically unavoidable problem is expense. A typical lab requires multiple copies of each equipment setup, several computers and appropriate lab furniture. Student expectations are high; they typically believe that inexpensive equipment correlates with unreliable results and a lack of interest from the university. To manage a low-budget lab course, the instructors must overcome student attitudes and engage them without the aid of a flashy computer or piece of high-tech equipment. Some lab designs mentioned above aim to reduce the expense by minimizing the number of copies required for each piece of equipment, as with the open labs. Others add expense by providing more computers per student, believing that the educational benefit outweighs the cost.

Another expense is the cost of the instructional team. Lab courses require an instructor (often more than one) and a staff member to manage the equipment. At universities with high enrollment, it is cost effective to employ graduate students to teach lab sections. This creates the additional problem of teacher training. Comments in the publications regarding the issue of maintaining quality instruction using teaching assistants can be found throughout the history of physics labs.

Another instructional issue is coordination of the lab activities with the lecture topics. At many universities the lab is an associated part of the course, but meets separately and under separate instruction. At some universities the lab is a separate course altogether, which only some students take at the same time as the lecture course. This creates difficulty for the students: if lab falls before lecture, the concepts related to the experiment may be completely unfamiliar (Jacobson, 1986). In the opposite case, they may find the experiment un-stimulating because the material has already been covered in detail elsewhere.

Other problems with labs involve student attitudes. When students are intimidated by the course work, they are often more comfortable in a passive lecture situation where they can wait to struggle with the knowledge later in a place that feels more safe. The lab forces the students to be active, and may be very difficult for struggling students to adjust to without good instructor support (Brahmia, 2001; Dickinson, 1995). Some students struggle with group work, and find the additional stress of working with lab partners a barrier.

When group work is well-managed, however, it is shown to provide a significant educational benefit to the students[5]. This struggle may also be worthwhile for the future of the student; engineering majors are expected to develop group work skills during their undergraduate courses (Jacobson, 1986). When this issue is carefully addressed, at-risk students (including women and minorities) show increased success and a significantly reduced drop-out rate (Brahmia, 2001) in active-learning environments.

An interesting case study of open-ended experimental labs can be found in (Kay, 1981). The authors combined a variety of goals to create a lab environment that includes individual work, group work, writing, presentations, and projects. The emphasis was on providing 'real experimental situations', and having all activities be part of an overall plan. Although the authors set a clear list of aims for the course, they found that students often were not seeing any benefit in the course format. Concerned that the course was not working as desired, they invited an outside party to evaluate the situation. It was found that students felt open-ended experiments which did not lead to a specific answer were 'like nursery playtime', and had no educational value. When the list of aims was reviewed with the students, they were actually surprised to realize that they indeed had acquired many of the skills the course intended to teach. In future semesters, the authors went over the aims of the course at the beginning as well as mentioning them several times thereafter, decreasing student resistance to the lab course.

The interactive nature of lab can be very challenging for a student whose native language is not English (Kaunda, 1998). Teaching assistants are often non-native speakers, causing an increase in the classroom language barrier. Oral corrections or additions to the lab manual instructions are often lost for the non-native speaking student, and can lead to difficulties with the experiments which the instructor may mistake for conceptual problems (Jacobson, 1986). Language use in physics is so precise that even native speakers often have conceptual difficulties related to their understanding of the physics terms (Harrington, 1999; Itza-Ortiz, 2003). Students who have difficulty expressing themselves through English may not be learning as much from the physics experiments. Language and interaction skills required in a lab environment are considered quite advanced and complex by many people who study applications of language (Jones, 1994; Ford, 1999). As (Ford, 1999) points out, instructors must be quite astute, as another difficulty when helping students is that they can often mimic the language expected without actually understanding the material.

Another difficulty with lab courses is accessibility for disability students. It has been shown (Baughman, 1977; O'Brien, 1980; Frinks, 1983) that many lab activities can easily and inexpensively be adapted for students with a range of disabilities. An example is putting various sized pins into a ruler so a blind student can measure distances by feel (Baughman, 1977). For students in a wheelchair, the activities are often at eye-level; this adds additional safety concerns (Frinks, 1983).

IV. COMMON GOALS FOR A LAB COURSE

Before a new lab course is developed, it is necessary to prioritize the learning outcomes. A coherent course structure increases student learning and can be established through a set of clearly defined goals. When establishing the course goals it is necessary to consider the student population: for whom is the course aimed? what are their goals? what do their future employers expect them to learn from your course? For example, while tradition may state that students should learn error analysis in a lab course, is it really worth taking time away from another focus to develop this if the students will likely never use these skills again? It is also wise to consider what the research has to say about student retention. Skills are retained better than facts for most students, but more advanced courses require that a minimal amount of material is covered in the introductory course so content goals cannot be overlooked.

There are many goals for lab courses which appear in the literature. They include: conceptual understanding, problem-solving skills, 'Scientific Literacy,' 'Scientific Abilities,' critical and abstract thinking, specific measurement and statistics skills, building student confidence, increasing student appreciation for science and the world around them, increasing group work skills, and building project management skills. Scientific Literacy includes "an understanding and knowledge of: the content of science, the processes and methods of science, the ethics underlying science, and the interrelationship of science and other aspects of society (Spears, 1975)." Scientific Abilities (specified by the rubrics that underlie the ISLE labs) include representing information, conducting experiments, thinking divergently, collecting and analyzing data, constructing, modifying and applying relationships and explanations, and being able to coordinate these abilities (Etkina, 2006).

The American Association of Physics Teachers' (AAPT) Committee on Laboratories, the Apparatus Committee, the Two-Year College Committee, and the Committee on Physics in Undergraduate Education prepared a list of goals for the introductory physics laboratory in 1997 (AAPT, 1997). These goals are to teach the art of experimentation, experimental and analytical skills, conceptual learning, understanding the basis of knowledge in physics and developing collaborative learning skills. It is stated that "many of the goals are not explicit in traditional laboratory programs. However, the AAPT believes that laboratory programs should be designed with these five fundamental goals in mind (AAPT, 1997)." The AAPT report also cautions that it is uncertain if there is a best way to achieve these goals. It seems clear, however, that the approaches will depend on the student population in the course. There are groupings for student populations such as pre-health students and engineering students; however consideration should also be taken for groups of students from different socio-economic backgrounds, different universities, different countries, and so forth.

It is very useful to read the literature before embarking on the challenge of re-designing a lab course. For example, it might seem necessary to teach proper measurement skills in a lab setting. However, if measurement skills are to be emphasized, it makes sense to discuss statistics and data analysis. For a scientist this feels like a reasonable goal but studies show that for the average student, even the most basic of these skills is very difficult to acquire and apply (Sere, 1993; Allie, 1998). Both of these studies found that students persist with the notion that the first measurement is the most important, and all subsequent measurements are for the sole purpose of checking the first and are thus not really necessary. Courses which have been successful in teaching measurement skills have devoted a considerable amount of time to them at the expense of other types of exercises[6]. Labs were developed at the University of Maryland to explicitly scaffold the measurement goals each week so students built to more sophisticated reasoning about measurement by the end of the semester (Kung, 2005). This sort of look at which tools are needed for more sophisticated reasoning would be instructive when building a lab curriculum.

It is a worthwhile goal to attempt to improve student attitudes towards science in an introductory class. For many students, this will be their only formal exposure to physics, and previous science courses may not have left a positive impression. Some teachers have developed creative lab experiments with the intention of teaching physics concept using familiar and interesting objects like bicycles and motorcycles (Engel, 1983; Hunt, 1989). Many of the mini-labs mentioned above have a similar goal but use smaller objects. These experiments can engage the students' curiosity.

V. ASSESSMENT TECHNIQUES

Having a specific set of learning outcomes can guide what type of assessment is most appropriate when considering the effectiveness of a lab course. For example, when implementing PBI, it is suggested that one consider if students are actively involved, if they work well in groups, if they can express understanding in their own words, and if they are receiving prompt feedback (Lea, 1993). There are often external parties who can observe a classroom and/or interview students to help assess if these goals are met (as in (Kay, 1981)). Student interviews and feedback questionnaires can also be helpful tools when assessing if course goals are met. The Physics Education Research community has also developed several diagnostic tests and attitude surveys which can be used to assess a course.

The Force Concept Inventory (FCI) is perhaps the most widely used diagnostic tests in physics education (Hestenes, 1992; Savinainen, 2002). This test when combined with the Mechanics Baseline (MB) test provides a fairly complete view of student understanding in mechanics (Hestenes, 1992). The MB tests skills which should be learned in the course, and involves problem solving. The FCI can be taken by someone who has not yet learned physics; it is written such that the problems can be answered using real-life experiences and observations giving it validity as a pre-test. Student scores on the FCI and MB correlate well, showing that conceptual understanding is critical for problem solving (Hestenes, 1992).

(O'Brien, 1980) presents nation-wide FCI data and gives suggestions for developing further assessment tests. The suggestions include implementing standardized test-administering practices, using survey questionnaires, having widespread use of the standardized tests, keeping the diagnostic tests strictly confidential, using attitude surveys, and designing the tests to minimize the possibility of teachers 'teaching-to-the-test'. The survey of the literature also led to the following list of items which will help obtain maximal educational impact of a course: tightly integrating all active-engagement methods, carefully motivating student participation, probing conceptual understanding on exams, inexpensively improving student to teacher ratio by hiring undergraduates, being attentive to at-risk student needs, explicitly focusing on goals, effectively using computer tools, and being mindful of advances in physics education research and cognitive science.

Attitude surveys have been used for a long time; one of the earliest is the Schwirian Science Support Scale from 1967 (Sokoloff, 1999). This test was designed to probe student attitudes regarding five values: rationality, utilitarianism, universalism, individualism, and progress and meliorism. Three main themes were determined from studying the differences: "should scientific work be directed primarily toward national needs, what impact has science had upon religion and what impact has science and its resulting technology had upon people and their well-being?" A more recent survey is the Maryland Physics Expectations Survey (MPEX) which focuses on six main themes: independence, coherence, concepts, reality link, math link, and effort (Redish,1998). The questions relate less to societal issues and more to how students expect to approach science. A surprising result was found after testing this survey: student expectations actually became more different from instructor expectations after traditional physics instruction. For example, students initially might think that physics involves understanding real-world phenomenon, but after the course they may abandon this idea. Another attitude survey developed at the University of Colorado is designed to probe a variety of student beliefs that shape and are shaped by student classroom experiences (Adams, 2006).

A different type of survey technique uses the q-sort methodology to have students sort qualitative statements about lab activities based on their perceived relevance to the course (Lin, 2005; Aubrecht, 2005). This method shows clear distinctions between different lab types, and can be used to understand differences in teacher and student attitudes, help assess teacher training, and determine if course goals are met. In this assessment, students are asked to rank statements about lab into a quasi-normal distribution allowing for researchers to see how students prioritize the statements; which statements students think most describe their lab setting and which least describe it. It has been found that teaching assistants who are more familiar with PER or who have undergone more training sort the statements more like the faculty who developed the labs, and have students who rank statements, for example, about explaining reasoning higher than statements about following instructions.

Another concern is assessing student understanding for the purposes of assigning grades. Traditional courses typically rely on homework, quizzes, and exams. This method has many problems. First, it undermines the educational effectiveness of the lab portion of the course, because the learning that takes place in labs is not clearly related to the students' final course grades. Furthermore, students can often solve enough of these problems (to pass the course) by the plug-and-chug method without having an underlying conceptual understanding. It has been found that traditional exams are biased against at-risk students, and contribute to women and minority drop-out rates (Brahmia, 2001).

Alternative assessment types in lab include lab practicals, group projects, and lab skills tests. The AAPT list of lab goals included recommendations towards using assessments based on communication skills, presentations, and lab reports (AAPT, 1997). Lab reports or in-class write-ups are common components of the lab grade. In addition to grading these reports, students can do self-assessments to test their ability to judge the quality of their work. Another variation is to provide a sample report and have students critique it and compare their comments with those of an expert (St. John, 1980). These exercises may also help develop cognitive skills (Etkina, 2002).

VI. CONCLUDING REMARKS

Introductory Physics Laboratories can provide a rich environment with high educational potential. Strong evidence of this is the number of PER-based courses that are eliminating lecture in favor of a course environment which strongly resembles a lab setting. However, there are many problems associated with labs, and overcoming them require research-based considerations and a well defined set of prioritized course goals to guide assessment. These goals must be suitable for the population, be fully integrated into all activities, and be embraced by the students. The activities must engage the students, and also combine and build on each other to achieve learning outcomes. The course should be structured in a way that promotes students effectively using group work and overcoming personal barriers such as insecurities or language difficulties. New lab curriculum such as ISLE and Modeling Physics build on cognitive and education research and increase student learning of both content and skills. Reliable diagnostic tests and surveys aid in determining the effectiveness of these curricula, and their success can be measured.

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