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ABSTRACT

A dissertation study is described which employed action research methods and was conducted over four semesters of practice in a large first year undergraduate physics laboratory making extensive use of microcomputer-based laboratory (MBL) technology. Three cycles of action research are recounted, along with the resultant changes in goals, methodologies, and curricular practices. The study included the pursuit of 10 students through the course by open-ended interviews, commentary, user observation protocols, and artifact analysis. The various curricular and instructional changes resulting from the study findings are reviewed. Findings include: (1) Study participants claim that they acquired previously unfamiliar technical skills, there was inadequate curricular feedback, and their laboratory experiences helped illustr.te their lecture material; (2) Participants felt that the study itself was a valuable experience for them and led to an improvement in their physics learning; (3) Participants indicated that they felt that the preparation of joint lab reports made the reporting activity more worthwhile; (4) Participants appreciated the mental challenge of conceptual problems as opposed to the more typical algorithmic problems; and (5) Action research is not an appropriate method for pursuing student alternative conceptions research. Emergent knowledge claims, implications, and recommendations are also discussed. (Author/JRH)

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CURRICULAR REFORMATION IN UNDERGRADUATE PHYSICS LABORATORIES VIA ACTION RESEARCH

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ABSTRACT

A dissertation study employing action research [AR] methods and conducted over four semesters of practice in a large scale (2000+ students/year) first year undergraduate physics laboratory making extensive use of MBL (Microcomputer Based Laboratory) technology will be described. Three cycles of AR will be recounted, along with the resultant changes in goals, methodologies and curricular practices. The data collection and analysis techniques and emergent knowledge claims of the fourth cycle of AR will be described in detail. This cycle included the pursuit of ten students through the course by open-ended interviews, commentary, user observation protocols and artifact analysis. The various curricular and instructional changes resulting from study findings will be enumerated and briefly reviewed.

Purpose of the Study

This study attempts to improve the quality of the educational experience of the many participants in Physics 152 Laboratory (PHYS 152L) through reflections upon personal actions. Students, instructors and curricular designers of PHYS 152L attempt to improve the rationality and justice of their own practices, their understandings of these practices and the situations in which these practices are carried out.

Guiding Questions:

1. About what do participants construct meaning during their Physics 152 Laboratory experiences?

2. How can we improve the quality, worth and justice of the Physics 152 Laboratory experience perceived by participants by modifying the curriculum and practice of that course?

In brief, the questions try to determine what the enacted PHYS 152L curriculum was during this study (what student participants involved in this study actually did and learned about), and how these activities can be made more appropriate for perceived student needs. During this study, student participants typically defined worth in terms of their own scholastic and professional training needs (these students are mainly engineers and want to develop engineering skills like data collection, analysis, reporting and computer tool use. Instructors had slightly different goals, like improving the conceptual richness of student [illegible] about different mechanical phenomena).

A BRIEF REVIEW OF MBL AND MBL CURRICULAR REFORMATION

MBL: Microcomputer-Based Laboratories

MBL effects upon student learning and conceptual development in undergraduate physics have been studied by Thornton, Laws and their associates at Tufts University and Dickinson College (Laws, 1991; Thornton, 1989; Thornton and Sokoloff, 1990). These researchers and instructors have developed quantitative instruments designed to measure changes in the physics-related graph interpretation skills and kinematics conceptual understanding of undergraduate students. Their research attempts to contrast such skills and knowledge acquisition of students using their own locally-developed MBL materials working in small groups with typical undergraduate students in traditional physics laboratory curricula. Their large scale testing at various sites indicate that their own laboratory curricula incorporating MBL and the instructional strategies proposed by Arons and McDermott are considerably more effective in teaching basic kinematics (mechanics) concepts than standard lectures (Thornton, 1990).

Another group of science education researchers at the University of California at Berkeley have also examined the role played by MBL-based activities in science education, but at the middle-school level. Linn, Nachmias, Songer and associates (Leiberman & Linn, 1991; Linn, 1988; Linn & Songer, 1989; Nachmias and Linn, 1987; Stein, 1987; Brasell, 1987) have examined the roles of changing curricular expectations and MBL based activities on middle school student conceptual development and graphical skills acquisition. Their research has indicated that curricular activities and expectations play a pre-eminent role in student science laboratories where MBL technology is used. Linn, et al., also claim that curricular evolution taking advantage of several characteristics of MBL technology can achieve profound conceptual changes amongst students.

Other researchers (Amend et. al., 1989; Nahkleh & Krajcik, 1991; Lehman & Campbell, 1991; Heck, 1990) have all examined various aspects of MBL implementation in educational laboratory settings. Prevalent findings include significantly higher levels of both student and instructor motivation, and increased level of curricular control by both students and instructors. Yet others (Beichner, 1990; Stuessy & Rowland, 1989) have tried to examine the effects of delayed MBL information presentation practice in greater depth.

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These studies examine groups of students who perform laboratory activities in carefully controlled environments with considerable access to MBL apparatus. Such research has not concentrated upon large-enrollment university mechanics laboratories using locally-developed materials, which is the case with this study. Several of these studies have suggested that the maximum quality of student experience and greatest conceptual change can be achieved through careful incremental modification of curricular expectations, exploitation of technology during instructional activities, and improved pedagogical materials (Linn & Songer, 1989). However, this study is one of very few to explicitly document such practice as carried out by a group of participants (including students) actively involved in curricular reformation incorporating MBL.

Curricular Reformation and Technology

The "crisis" of ineffectiveness in U.S. science education is recognized as a major concern and technological innovation is being heralded as at least a partial solution. Prescriptive plans to integrate technology into the science curriculum have mentioned possible improvements as due to the following facts:

1. Scientists are using these tools - students might also be helped by them.
2. Technology has already invaded schools - over 1.4 million computers at schools [in the US].
3. The information explosion has changed student needs and access to information handling skills should be made available in schools.
4. Technology has transformed the workplace and students will require more extensive learning skills (they will change jobs and retrain more often), and technological skills.
5. Educators make use of technological tools for managerial tasks such as secretarial tasks and record-keeping.
6. The experience of scientists using technology to solve complex problems can be used to instruct technological problem-solving skills to students. (Linn, 1988)

Linn goes on to suggest that the implementation of technology for instructional purposes moves through three major stages of acceptance (Linn, 1988):

1. Technology in the service of established goals; followed by
2. Adapting science education to technological innovation; and finally
3. The integration of technology and learning.

This would suggest that MBL adoption will catalyze significant changes in science curricula by making apparent present procedural shortcomings in instructional delivery, then by changing the curriculum content to surmount these limitations and finally by supporting reforms in the curricular paradigms of science pedagogy. Such reforms are already apparent

in the constructivist movement in science pedagogy, which embraces many of the characteristics of free investigation and student empowerment ascribed to technological innovation .

Technological Innovation in Laboratory Science Education

Typical high-school science laboratories attempt to approximate research methodologies. In the research lab, the researcher chooses an experimental problem and designs the experiment; in the school lab these activities are usually prescribed by the curriculum or text due to time constraints. Students usually do not participate in experimental design.

Students follow the given directions in the lab procedure, acquire data, perform calculations to treat the raw data appropriately and then complete some form of analysis, usually including graphical procedures. Then a generalization of some form is extracted (usually including an explanatory theory in active research) and results are documented for a report.

MBL procedures most notably affect those steps in the laboratory experiment sequence involved in data acquisition and analysis. MBL procedures are an adaptation from research use of the same technology (MacKenzie, 1988). MBL laboratories typically involve the use of sensors or probes to directly collect data in an electrical form and to display it in both numerical and graphical form as it is collected. This real-time display greatly abbreviates analysis and allows for immediate observation and control of experimental variables (Amend et al., 1989).

Students set up their apparatus and sensors, set scaling and display options on the microcomputer and then calibrate their sensors using known standards. Data are then collected using a series of real-time "runs", with continuous observation of the computer screen and the physical process. After a run is complete, data are saved to disk and/or printed, results are discussed and compared with others and decisions regarding experimental repetition or variable control are made. Usually, some variable is modified and the experiment repeated, with results juxtaposed and examined. When complete, the experiment is written up into a report (Amend et al., 1989).

Laboratory Advantages to MBL Procedures

The advantages for science students inherent in the use of MBL technology in the laboratory are twofold: (Amend et al., 1989)

1. MBLs allow students to do the steps in the experimental process faster, more thoroughly and more accurately, and
2. MBLs involve the student in more of the scientific process.

The computer becomes a tool which allows repeatability -- the reliable and untiringly accurate collection of data -- in volumes not otherwise possible due to time and attention constraints. Events become more easily quantified, and those events which happen too quickly to examine otherwise may be analyzed. Additionally, experiments involving a number of simultaneous measurements may be easily performed.

The data collected can be displayed instantaneously, and in any numerically processed form desired. This rapid processing and analysis allow the testing of user suggestions and conjectures not otherwise possible due to time constraints. The amount of data throughput is greatly increased. The data can be meaningfully examined while being collected, encouraging investigation by discovery. More time than before can be spent examining relationships, postulating relationships, controlling experimental variables and redesigning the experiment. MBL technology has the ability to free the user from the drudgery of quantification and graphical analysis and allow active investigation (Amend et al., 1989).

MBL technology also introduces students to scientific measurement. This includes errors of measurement, graphical interpretation, instrumental effects (calibration, accuracy, repeatability, error of quantification, resolution, scaling) and control of extraneous variables. These topics are not typically treated in the school laboratory because of the nature of "precooked" experiments, the lack of available precision and time. They are nonetheless valuable laboratory science skills (Linn, 1989).

Instrumental effects refer to the inherent distortions in data due to the collection process. When using MBL, data can be made unreliable by five major instrumental causes: inappropriate graph scaling (in software), inappropriate setup, poor probe calibration (and resulting inaccuracy), inadequate probe resolution (where the equipment cannot discriminate fine enough gradations in the phenomena) and experimental variation (due to random error or invalid procedures). Students can be trained to recognize and correct these problems

(Nachmias & Linn, 1987). Such training should be an integral part of MBL laboratory instruction.

Changes in Science Pedagogy

Recently science education has been turning from the content-based curriculum established by the revolutions of the 1950s and 1960s (Duschl, 1985) with voluminous transmission of information and attendant laboratory exercises stressing the replication of proven concepts to a more process-oriented curriculum stressing skills of analysis, questioning, synthesis and problem solution via laboratory experience.

As an example, the National Science Teachers Association (NSTA, 1983) has identified the following concerns regarding science education:

1. The textbook is the curriculum.
2. The goals of individual classes are not related to previous or subsequent classes.
3. The lecture is the main form of instruction with laboratories used for verification.
4. Science is evaluated in the traditional method.
5. Science is removed from the world outside of the classroom.

Several investigators suggest that the adoption of MBL techniques provides a response to several of these concerns by making students active participants in science (Woerner, 1987), or in the words of Tinker:

> "..give students these tools and you will see a (pardon the expression) revolution in science education -- a true embodiment of Piagets' notion that children learn best by discovering and creating the world for themselves. (Tinker, 1984a, p. 26)

The pedagogical basis upon which science is taught is currently changing from a teacher-oriented presentational style to a participatory style involving the negotiation of meaning (constructivism) wherein teachers must surrender a large degree of situational control. MBL technology and methods can provide a route to this style of interaction by encouraging student control centered upon the experimental relationships under study rather than instructor and textbook direction (Linn, 1988).

Additionally, MBL technology has been seen to enhance the qualities of on-task inter-student communications:

> Students' propensity to monitor and compare their results to others, which was made possible by the fact tha results were displayed graphically on the computer screen. Students compared results with one another constantly and thus were alerted to disparities. The sharing of data also encouraged cooperative remediation of problems, with students forming into consulting groups of increasing size according to the difficulty of the problem at hand. (Stein, 1987, p. 233)

Methodology and Preparatory Research

In summary, the methodology used in this study is that of Action Research grounded in Habermas' critical theory. Extensive discussion of these paradigms and methodologies are given elsewhere (Bodner, 1992; Bodner & MacIsaac, 1995; Lowery & MacIsaac, 1995). Norman's model (1988) of task analysis and his user observation protocols was investigated and modified for use collecting data when laboratory proocedures were videotaped.

The Reconnaissance: A Review of the Author's Previous Research

This study represents the extensive documentation of observations and reflections upon a single, one semester long cycle of action research extracted from a series of related investigations spanning several years. All of these investigations took place within the context of the reformation of science laboratory curriculum through the incorporation of computer technology. The methodology used (action research) emerged from this set of experiences. Those experiences preliminary to this study are known as the reconnaissance in action research methodology.

First, this dissertation was a direct outgrowth of research originally performed for my own Master's thesis (MacIsaac, 1991). My choice of a site for this dissertation was due to the opportunity to continue examining curricular reformation -- the topic of my MA research. Second, my research into science learning with technological curricula continued through another complete documented cycle of action research inquiry conducted here at Purdue. These data were analyzed during a course in qualitative research methods. And third, I piloted the data collection techniques for two months during the summer before the semester of dissertation data collection. All of these efforts and findings set the stage for this specific study. The previous research provides context and grounding to this study.

M. A. Thesis Overview

My M.A. thesis research was concerned with the development and implementation of computer hardware and software for a high-school chemistry laboratory curriculum using action research. These efforts were entirely focused upon the iterative design and development of the apparatus in question; the initial aim of the study was to 'computerize' existing practice without modifying the curriculum at all. This approach was set by two high school chemistry teachers and myself. The goal was an alternative set of apparatus for the standard curricular activities (MacIsaac, 1991).

M.A dissertation data were collected in the form of artifacts (student laboratory reports and surveys), report grades, observers' notes and open-ended student and teacher interviews from a total of seven classes of approximately 25 students each and three chemistry teachers. Analysis primarily consisted of characterizations of student laboratory behaviors, attitudes and responses towards the use of MBL technology in the standard curriculum. Teacher attitudes and behaviors were also characterized.

The M.A. study served as my introduction to action research. The data collection and analysis occurred over several cycles of action research, where one cycle consisted of equipment development for one of the chosen experiments, an evaluation of the apparatus during student use in the classroom, data collection and analysis. Insights gained from preceding cycles guided and informed the development of apparatus for following cycles. Four laboratory experiments were examined for a total of four cycles of research in all.

There were four major findings from the M.A. research, of which three are applicable to succeeding research: 1) the technology was found to be intrinsically motivating and appropriate; 2) the inclusion of technology in the standard curriculum was found to inherently redefine the curriculum (creating tensions in regard to the expectations of participants towards both the curricular activities and student-teacher relationships), and 3) action research was found to be an appropriate means to further refine and develop technology-based instructional materials (MacIsaac, 1991). These findings are summarized in Table 1.

Table 1
Summary of the Author's M.A. Research

Master's Thesis Research **1989-1990 School Year** **Analysis 1990-1991** THE DESIGN AND IMPLEMENTATION OF MICROCOMPUTER-BASED INSTRUMENTATION IN THE BRITISH COLUMBIA HIGH SCHOOL CHEMISTRY CURRICULUM	- reviewed MBL literature - reviewed action research (AR) methodology - used 4 cycles of AR - research and development of MBL HW and SW for 4 separate experiments in grade 11 and 12 HS Chemistry - data collection by grades, participant interviews and feedback - found that AR is useful approach: curricular issues predominate instructional applications of technology - made extensive suggestions regarding the implementation of MBL activities into the H.S. Chemistry Curriculum in BC

Qualitative Research Methods at Purdue

I have been associated with the Physics 152L curriculum continuously since January 1991, and during this time I have had the opportunity of performing several investigations of the curriculum and participants as part of graduate coursework. For a course in qualitative research methods I conducted an exploratory assessment of the impact of the Physics 152L curriculum, which had been entirely rewritten in January of 1991 to incorporate MBL technology. The purpose of the study was to characterize participant perceptions of their Physics 152L experiences and identify for further research those experiences which have profound impacts upon student motivation, attitude and conceptual development.

The methodology used in the qualitative research methods was a single cycle of action research. I assumed the stance that Physics 152L had both curricular strengths and weaknesses which could be addressed through rational inquiry and set out to identify these with the knowing assistance of both student and instructor participants. I collected ethnographic field notes from four different sections of students completing the last course activity -- Experiment E4. I conducted and transcribed open-ended interviews following this activity with four students and one graduate instructor, then Icollected and thematically analyzed student laboratory reports from two sections of students (about 35 reports in all). I wrote the final report using data extracts to illustrate and document themes from which knowledge claims were extracted. In the end, I generated a series of recommendations from these knowledge claims, and curricular changes addressing these recommendations were implemented (MacIsaac, 1992).

From the analysis of these qualitative methods data, several major themes emerged. From the field notes emerged insights concerning timeliness, student interrelationships and instructor practice in the laboratory. These indicated that MBL practice considerably changed student and instructor roles in the learning environment, and provided data immediately and in an appropriate form for student learning. From the interview notes came comments regarding participant appreciation of the quality of the laboratory experience, and the value of the use of specific curricular adjuncts such as MBL technology, measurement analysis, prelaboratory questions, conceptual questions, and group reporting. Participants also discussed issues of curricular content, pacing, goals and improvements, concentrating on technical improvements. Artifact analysis of the report data determined that the curriculum was both underspecified in design and insufficiently articulated in practice, and that students required interrelational support to foster group work (MacIsaac, 1991).

augment current audio recording practice; cabling for video-audio recorder interconnection and a transcription machine were all obtained. The actual trial and evaluation of the video and audiotape data acquisition occurred during the summer 1993 term of Physics 152L, and formed the pilot data collection for this dissertation. Findings from this research are summarized in Table 2 and Figure 1.

Table 2
Summary of the Qualitative Research Methods Study

Qual Rsch Methods Spring Semester 1992 PHYSICS 152L: A MICROCOMPUTER-BASED INTRODUCTORY MECHANICS LABORATORY	- one cycle of AR examined the last PHYS 152L curricular activity and course summary comments - aimed to characterize overall student perceptions of whole-course curricular experiences, and identify experiences with most profound impact on motivation, attitude and conceptual development for further research - data collection by ethnographic field notes, artifact (report) analysis, participant interviews - found insufficient attention to technical detail in curricular practice and materials; inadequate support for motivation and interrelations; divergent instructor-student practices and expectations - recommended greater curricular articulation via communication of goals and theoretical underpinnings, technical improvement through collaborator interviews, videotapes protocols, encouragement, of means for student interrelations - presented portions of findings to professional physics teachers' organization at national conference

Pilot Data Collection for this Study

At the start of the summer 1993 semester, the Physics 152L staff acquired videotaping apparatus and a summer student employee who was asked to participate in the pilot data collection for this study. This participant completed all activities forming the version of the PHYS 152L curriculum to date -- the four experiments and two measurement analysis worksheets. She completed most of the activities in front of the video camera, and completed open-ended audiotaped interviews before and after each activity. After considerable technical difficulties, many insights were made into taped data collection, transcription and reduction during PHYS 152L activities.

5. REFLECTION

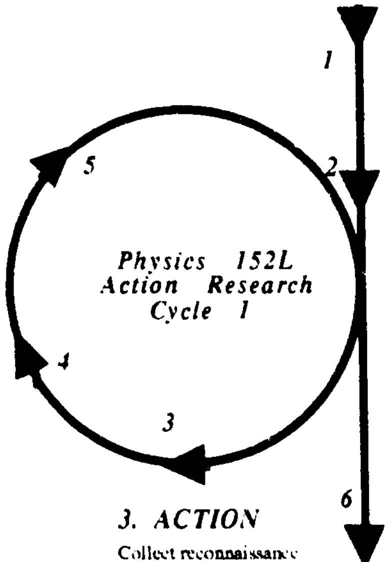
There is insufficient attention paid to technical detail in the curriculum articulation.

There is insufficient support given to student motivation and interrelations. More guidance relating goals to curricular activities is also required.

Instructor teaching practises, styles and philosophies are divergent and in some cases conflict with implicit curricular assumptions. Basic curricular assumptions must be better made overt and shared amongst all of the course participants.

1. RECONNAISSANCE

Researcher's background, describe previous research, briefly describe PHYS 152L curriculum.



2. PLAN

How do Physics 152 participants describe their laboratory experiences?

Which specific Physics 152L activities do students believe help them develop new insights into mechanics? What do students believe helps them learn in the laboratory?

4. OBSERVE

Collect ethnographic field notes during a variety of different laboratory sections taught by different Graduate Teaching Assistants. Supplement with some videotape.

Conduct open ended course closing interviews with students to collect their general impressions regarding the course and their specific impressions on a number of preselected issues.

Descriptive statistics of participants and general course population.

Collect ancilliary data (email, lab reports, other comments from students, instructors).

3. ACTION

Collect reconnaissance information with the intent of identifying areas for curricular and course practise improvement.

Assess field notes, vide tape collection, open-ended interviews and artifact analysis as possible data collection methods.

Assess ancillary data collection methods.

6. REVISED PLAN

Pursue individual students through the entire course, collecting data for technical refinement via user observation protocols as well as interviews for each individual activity.

Use audio- and video-taped user observations supplemented by interviews as primary data sources.

Incorporate discussions of course and individual activity goals,and better exemplars into the laboratory manual. Define worthwhile practise for all course participants, and refine this definition during regular instructor meetings.

Improve course participant interrelations by conducting some open hours, offering additional access to laboratory facilities and discussing computer data reduction with course participants.

Knowledge Claims

Students were very enthusiastic with the use of computer data collection apparatus and enthusiastic about the curriculum, which they found worthwhile, demanding and challenging. Laboratory reporting and numeric uncertaintly analysis were particularly demanding and often new to the students. Students expressed concerns with the laboratory pacing and syncronisation with the lecture course. Instructors felt group reporting was particularly valuable.

Technical improvement must continue, and should be systematized. Models of user observation prevalent in computer software design may be appropriate for guiding technical assessment.

Guidance (roles) in personal conduct and interrelations amongst lab participants must be formulated and promulgated in the curriculum.

Goals and values implicit within the curriculum must be made overt for the entire curriculum and for each and every activity. The qualitites that constitute worthwhile practise in the laboratory must be regularly discussed and refined by all laboratory participants. Atheoretical curricular development must cease

Figure 1. A summary of the qualitative research methods study

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Experience gained during the pilot study revealed that the collection of data presented great demands on the student-participant. When asked to 'think aloud' and explain her actions as she was completing them, her performance digressed considerably from activities carried out without the requirement to justify aloud what was happening. When the observer asked the participant to 'think aloud,' the participant was more reflective and deliberate in her actions. As the participant gained experience with the think-aloud protocol, she became much more at ease with the procedure and required far less prompting to provide audible comments. At the same time however, she began to treat the observers' requests for additional information as stimulus for engagement in Socratic dialogue (MacIsaac, 1992).

This situation was very unlike typical student experiences in terms of the focus and depth of thought accompanying laboratory activity. This was the case even though the participant performed the experiments at roughly the same pace as regular students in group settings required. The participant was very aware of the attention of the researcher; requests for additional verbiage or clarifying comments on critical points provided considerable guidance and almost certainly stimulated learning. Both the timing of the questions and their paucity -- when questions were asked and when they were not -- cued learning. However, data collection from participants working in groups (with partners) were surmized to be considerably more akin to regular class practice than one participant and the observer. This was because the partnered participants' audible and visual interactions (supplemented with a requests to talk aloud to one another with feedback) provided more natural observations. However, these group trials were never conducted during the study ilot work. The findings from the dissertation pilot work are summarized in Table 3.

Table 3
Summary of the Dissertation Pilot Work

Summer Pilot Work **Summer 93**	- no design structure; development of more appropriate means of data acquisition and analysis - hired a part-time student employee (recent HS grad) intending to major in physics; had her work through curriculum and interview on all activities - practiced task analysis, user observation and think-aloud protocols on audiotape during laboratory activities - developed videotape data collection and interview practices - gained insights into specific student difficulties and perceptions on an individual activity basis

As a result of student learning from the data collection and the probability that the curriculum enacted by study participants would cumulatively diverge from typical practice, I decided to stagger collection from any single student where possible. I decided that future participant observations should contain some form of a break as the curriculum progressed. By observing future participants on alternate experiments, and allowing them to return to the regular group environment for some activities, better baseline data were collected. Also, audio interviews of students who performed all of the curricular activities in their regular group environments would be collected to provide some baseline data reflecting student experience without observer Socratic questioning during the activities.

Background and Role of the Researcher

I am an ex-high school computer and science teacher and community college computer applications instructor, with five years experience using computerized data acquisition to instruct high school and university level science laboratories. As noted earlier, my M.A. thesis was devoted to the design, development and evaluation of such materials for high school chemistry over a two year period. This investigation used action research as a methodology, and involved several high school teachers and many students as active, knowing and critical participants.

I have worked on the design, writing and construction of materials for undergraduate mechanics instruction in the physics department (Physics 152L and Physics 163L) for the past three years. The physics faculty member responsible for Physics 152L and I have co-written several versions of the laboratory curriculum used to instruct Physics 152L, and formally published the first edition of a laboratory manual one term after my arrival (Shibata and MacIsaac, 1991). This dissertation in physics education is based upon the continued development of these instructional materials for undergraduate mechanics. (MacIsaac, 1992, 1993).

I was a non-participant observer while taking field notes during the laboratory session and from videotape. I was an active interviewer during semi-structured interviews and an active correspondent by e-mail with participants of this study. Student participants in this study seemed to typically treat me as a tutor or mentor in these activities. Participants behaved quite informally with me for the most part — much less formally than as a faculty member but not quite as a peer.

Context for the Study

The Physics 152L curriculum consisted of six activities: two Measurement Analysis assignments (MAs -- problem sets and graphs) and four Experiments (E1, E2, E3 and E4). Written descriptions of all activities were purchased by the students as a spiral bound lab manual (Shibata & MacIsaac, 1992) before commencing classes. The MAs were due at the start of experiments E1 and E3 and covered algebraic manipulation of measurement uncertainty, graph theory and uncertainty interpretation. Time was not provided during laboratory or lecture for the completion of these activities; students were expected to do them elsewhere. The material was reviewed in two voluntary evening lectures at the start of the term and near the term break, usually conducted by the author. Many students (approximately 30%) chose not to attend either MA lecture, as the exercises were straightforward and were intended to be easily completed using the handout alone. A detailed description of the measurement analysis curriculum is available (Shibata & MacIsaac, 1992).

Each experiment performed was typically broken into several parts (four to six) identified by Roman numerals, which each required specific data collection. Before commencing each laboratory activity, students were required to turn in a set of Prelaboratory Exercises or questions which contained practice calculations and precursor conceptual questions for the specific activities. One week after the laboratory, a laboratory report consisting of an Abstract, Data and Calculations, Analysis and Conclusions sections was due. The curriculum and report are described elsewhere (Shibata & MacIsaac, 1992).

Site for the Dissertation Study

All field notes and videotape were collected in the Physics 152 laboratory. This facility was the site of all Physics 152L laboratory experiments, and therefore the students were in their natural surroundings for this activity. Each laboratory session was conducted by an experienced Graduate Teaching Assistant (GTA) and one or two Undergraduate Teaching Assistants (UTAs). These instructors were familiar with the curriculum and with standard laboratory practice and procedures. They all were available to the students outside of regular laboratory times (during an office hour), and they also staffed a student help center open to provide students with assistance completing laboratory reports and prelabs. All protocols, interviews, audio/videotape analysis and so forth were conducted in rooms near the laboratory.

The Plan: The Problem and Guiding Questions

The plan for this dissertation study was to pursue a group of student-collaborators through the PHYS 152L curricular activities and to collect data from and with them in such a manner as to address the guiding questions (Figure 2).

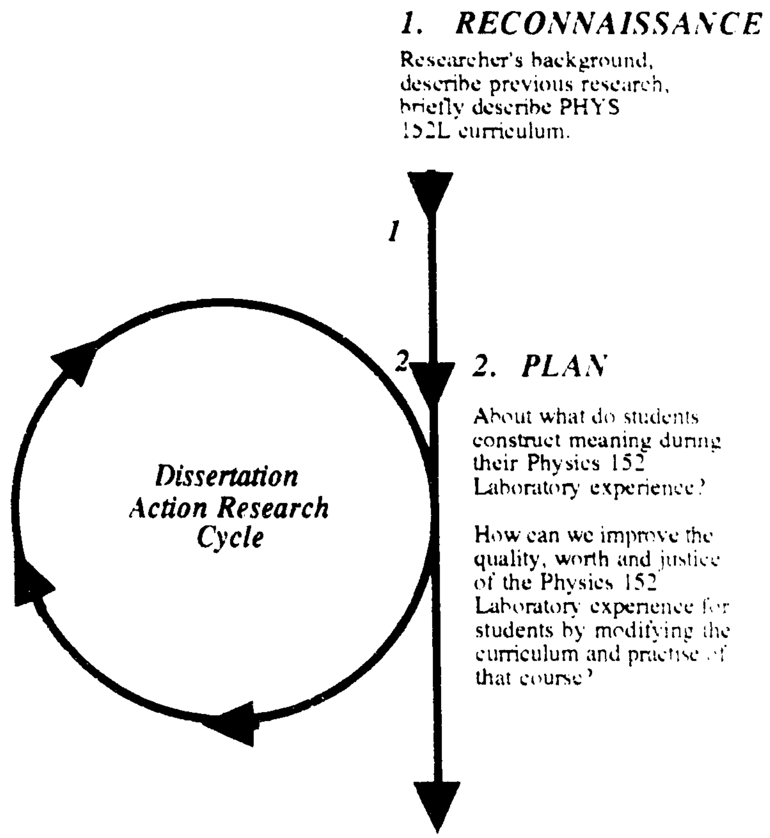


Figure 2. The Plan in the Methodological Design

Restatement of the Problem

This study attempted to improve the quality of the educational experience of the many student in Physics 152 Laboratory (PHYS 152L) through reflections upon personal actions. Students, instructors and curricular designers of PHYS 152L attempted to improve the rationality and justice of their own practices, their understandings of these practices and the situations in which these practices are carried out. Collected observations and their subsequent interpretations by both the author and the student-collaborators were used to address the guiding questions.

Guiding Questions

1. *About what do students construct meaning during their Physics 152 Laboratory experiences?*

2. *How can we improve the quality, worth and justice of the Physics 152 Laboratory experience for students by modifying the curriculum and practice of that course?*

The Action: Pursuing Student Participants through Physics 152L

All of the volunteer student participants in this study were freshman engineering majors, which reflects the majority of the enrollment (65% - 80% typically) in PHYS 152L. Freshman engineers are a highly select group of talented individuals. Freshman engineering applicants are selected for admission to the school of engineering primarily on two criteria: high school SAT scores (Math >600; Verbal >500) and standing in their high school class (typical rank was >90th percentile of an average graduating class size of 300 students). Greater descriptive detail regarding freshman and freshman engineers is available elsewhere (Cheng H.C., LeBold W.K., Ward S.K. and Pretorius, M.B., 1987; School of Science, 1992).

Despite this outstanding status, these students actually had enormously different levels of physics and mathematics preparation appropriate for Physics 152L. The student participants participating in this study were split almost evenly between rural and urban school backgrounds. Two had studied introductory differential calculus before their arrival (one at a nearby university), while the remainder had not. All had studied some trigonometry. Half of the American students had at least one full year of high school physics and one student had a previous semester of college level non calculus physics. No student had ever had a course in elementary statistics (during the first activity it emerged that only three understood the terms *mean value, standard deviation* and *variance*).

Two participants were international students for whom English was a second language, but not a communications barrier -- they were both fluent readers and slightly less fluent speakers of English. While these students had a much more extensive background in physics and mathematics (6 and 7 years respectively of grade school physics as a separate course) than their American peers, their reactions to the Physics 152L curriculum appeared to differ little from their American counterparts. Academically their performances fell within the mean expected of their peers, although they often required additional time to complete written reports.

Introductory Participant Interviews

Descriptive interviews were conducted with all participants at the outset of the study. Participants described their previous educational experiences, in particular their mathematics and science education prior to enrollment in Physics 152L. Student participants came from a wide variety of backgrounds and cultures, including large urban high schools offering extensive science and mathematics content and rural schools where science opportunities for high school students were quite restricted. During these interviews, each participant briefly recounted their personal histories. Two summaries of these histories for a few of those students provides a context for this study:

Bill. Freshman engineer from NY state. Is a philatelist who likes to play soccer. In high school, he took AP Calculus and AP Physics, 1 year Biology and 2 years of Chemistry. Bill spent last summer at the University of Delaware, taking Math and Chemistry. Now taking Calculus, English, Chemistry, Materials Science, Computer Science, Engineering seminar and Physics. Joined the study for the challenge -- he wanted to 'stretch [his] mind.' and 'make me think.'

Wei. International student from Indonesia, freshman engineer who transferred here after one year at the University of Indiana. At the University of Indiana she took first year Math and Chemistry, not Physics (other courses were religion, art, general pre-med. studies). Now taking 2nd year Calculus, Communications, Computer Science, Economics and Physics. Grade school in Jakarta covered six years of Physics. Has trouble with English (spoken and written). Sees this study as an opportunity for 'additional help with labs.'

Ian. Indiana native from a nearby small city. Freshman engineer, wants to major in materials (industrial) engineering. In high school Ian took introduction to Calculus, Algebra, Trigonometry, 2 years of Chemistry, 1 year of Physics, 2 years Biology, studied trombone and photography. He is now taking Calculus, Art and Design, Architecture, Communications and Engineering Seminar. Not a strong academic student, but very personable. He joined the study because he 'wanted to take advantage of [the author's] help, and get a better background to the lab.' and 'is interested in the study.'

Louie. Freshman term 1, Indiana native, wants to be an industrial engineer. Currently enrolled in Calculus, Communications, Physics, Engineering seminar and Engineering computing. In high school took AP calculus, AP Chemistry, AP Biology, one [illegible] high school [illegible], 5 years of trigonometry and precalculus, likes to write BASIC computer [illegible] Louie is a perfectionist.' chose opportunity to work with the study

because he 'always messed up in lab' and sees this as an opportunity for extra help.

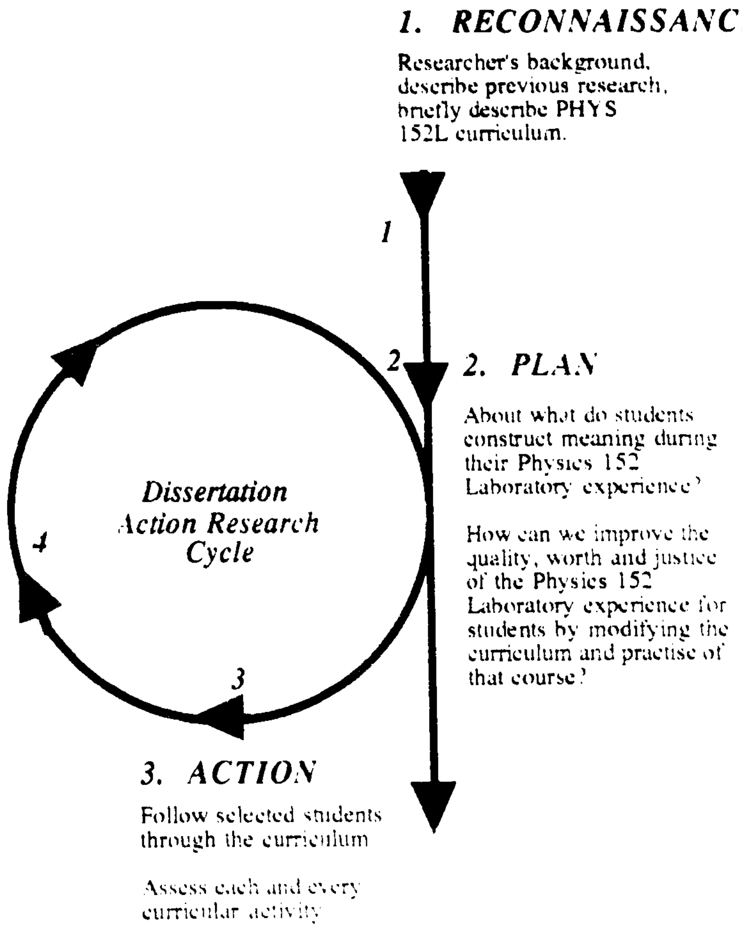
Michelle. From a nearby small town. In high school had one year Physics. one year AP Chemistry one year regular Chemistry, Algebra and Trigonometry. Freshman engineer (no specialty preferred yet) taking first year Calculus. Chemistry, Physics, Spanish and Engineering seminar. No computer background. Joined the study because she 'wants to meet people, get more meaning out of her lab. increase her understanding'. Michelle likes science and math, socializing and swimming.

Student Participant-Collaborator Selection and Roles

Action research is predicated upon the knowing and empowered involvement of all participants, and as a result students who eventually took part in the study were self-selected individuals with an interest in contributing to the reform of the first year physics laboratories. Students were recruited from the Fall 1993 Physics 152 registration list by posting calls for volunteers around the Physics Building, by advertising at the evening sessions of MA1 and by word of mouth. Of the approximately 600 students who enrolled in Physics 152L during this term, twelve students responded. Participant selection is summarized in Figure 3.

Most of the participants decided for themselves which of the two alternatives (10 or 20 hours total commitment) they were willing to participate in, but some whose spoken English was not clear were later asked to participate in the 10 rather than the 20 hour videotaped option. (These were international students for whom English was a second language.) Transcribing the speech of some of these individuals was quite difficult in places. In addition, some students were unable to meet the time commitment for the videotaped option and participated in the non-videotaped option.

Of the twelve initial student respondents, two were lost almost immediately from the study. One respondent (Andy) could not make the scheduled initial meeting time and performed all activities with his regularly scheduled classes. Although he was contacted by the researcher, he was unable to schedule and keep an appointment for an initial interview. The second (Bill) completed only a first interview with the researcher after he had completed the first two curricular activities -- MA1 and E1. As a result, his only interview addressed his own background information, MA1 and E1 in a single session. Bill was also unable to schedule and keep subsequent appointments.



STUDY PARTICIPANTS

Two student participants did all activities with their regular assigned section and were interviewed after each activity.

Eight student participants completed activities while videotaped with researcher and were interviewed before and after each activity. Of these, two went back to their assigned sections to complete one single activity, then completed the study with the researcher. Four of these participants worked alone, and four with partners in pairs of two during activities.

Two student participants dropped out of the study due to previous time committments and scheduling difficulties.

One student participant offered unsolicited general commentary on the lab experience; another student participant offered unsolicited commentary on the lecture course experience.

One Graduate Teaching Assistant and one Undergraduate Grader participated in itinerant interviews.

Figure 3. Action in the methodological design

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Student participants were all paid an hourly wage ($5.00/hour) for activities performed with the researcher -- mainly a series of initial audio interviews and videotaped laboratories. During recruiting, students were asked if they would be able to participate in a 10-hour or 20-hour study option. The 10-hour participants were interviewed on audio tape before and after each activity, and carried out all activities with their regular assigned lab divisions, which completed one experiment every three weeks. The 20-hour participants were also interviewed on audio tape before and after all activities, but did not complete the laboratory activities with their scheduled divisions. Instead they were videotaped while completing these activities in private with the researcher (sometimes with a partner as well). From this point on these different groups of students will be referred to as the videotaped and non-videotaped student participants.

Table 4
Data Collected With 10 Hour Participants (Audiotaped Interviews Only)

INTERVIEW	Andy	Bill	Wei	Danar	Esther	Frances	George
Preliminary Interview	nil	9/18/93	9/2/93	9/22/93	10/21/93	10/21/93	9/25/93
MA1 Assignment	nil	9/18/93	9/2/93	9/22/93	nil	nil	9/25/93
E1 PreLab Questions	nil	9/18/93	9/2/93	9/22/93	nil	nil	9/25/93
E1 Lab	w/class	w/class	w/class	w/class	w/class	w/class	9/25/93
E1 Report	nil	9/18/93	10/7/93	9/23/93	nil	nil	9/25/93
E2 PreLab Questions	nil	nil	10/7/93	10/8/93	nil	nil	9/25/93
E2 Lab	w/class	w/class	w/class	w/class	w/class	w/class	9/25/93
E2 Report	nil	nil	nil	11/4/93	nil	nil	9/25/93
MA2 Assignment	nil	nil	10/25/93	11/20/93	10/21/93	nil	nil
E3 PreLab Questions	nil	nil	10/25/93	11/22/93	nil	nil	nil
E3 Lab	w/class	w/class	w/class	w/class	w/class	w/class	nil
E3 Report	nil	nil	11/22/93	11/22/93	nil	nil	nil
E4 PreLab Questions	nil	nil	11/22/93	nil	nil	nil	nil
E4 Lab	w/class	w/class	w/class	nil	w/class	dropped	nil
E4 Report	nil	nil	12/9/93	nil	nil	crse	nil
Final Interview	nil	nil	12/16/93	nil	10/21/93	10/21/93	nil

After initial interviews were held, two student participants were asked to participate in the non-videotaped interview option. Both of these students (Wei and Danar) had reduced proficiency in spoken English, and one was unsuited for continuous videotape observation due to personal discomfort and nervousness. Much later in the study, two other female students voluntarily came forward (Esther and Frances) to be interviewed by the author, but in each case, their participation was limited to a single general joint interview. A schedule summarizing the data collected from and dates of audiotaped interviews held on the curricular activities with these six students and a participating Graduate Teaching Assistant

(George) is shown as Table 4. Transcripts of these (and all) interviews are available upon request from the author.

The remaining eight students chose to participate in the videotaped option, and were subsequently pursued through the curriculum by both audiotaped interviews and videotapes recorded when these students performed the curricular experiments with me. During these interviews, I questioned these students in an attempt to elicit their reasoning and activity. They were encouraged to think aloud (this practice was developed in and is described with the summer pilot study). A schedule summarizing the data collected from and dates of audiotaped and videotaped interviews held on the curricular activities with these students is shown as Tables 4 and 5.

All of the videotape option students performed E1 alone with the author in the laboratory, except Michelle and Norma, who completed E1 with their regular classes. When asked for their preferences for partners after E1 several students (Harry, Ian, Michelle, Norma and Oscar) expressed the desire to work with partners for future experiments. The remainder indicated that whether they worked with a partner or not was not important. Harry indicated he preferred working alone. Subsequently, half of the participants were paired off by schedule constraints and performed E2 in two pairs.

These pairs (Joan and Kevin, Norma and Oscar) subsequently had great difficulty scheduling time to work together both videotaping the lab with the author and preparing a group report, and as a result a considerable hiatus in their laboratory work ensued. After some time, one pair (Joan and Kevin) split up and completed the remaining two experiments alone, while the other pair (Norma and Oscar) completed the final two experiments together at a very late date in the semester. There were a total of three such situations where participants completed the final videotaped curricular activities in a very hasty fashion at the end of the term due to earlier delays associated with scheduling group reports.

While the majority of the videotaped students completed their experiments with the author, three students (Harry, Michelle and Norma) completed at least one activity with their originally scheduled laboratory division without videotape collection. Michelle completed two activities with her regularly assigned division. Of these four activities, two occurred due to scheduling difficulties, and two were primarily due to the author's request for participant comparison -- the author asked the participant to compare the individual experience to the typical lab section experience.

Table 5
Data Collected with 20 Hour Participants (Both Audio and Videotape Interviews)

INTERVIEW	Harry	Ian	Joan	Kevin	Louie	Michelle	Norma	Oscar
Preliminary Int	9/9/93	9/9/93	9/7/93	nil	9/10/93	9/16/93	9/14/93	9/2/93
MA1 Assignment	9/9/93	9/9/93	9/7/93	9/8/93	9/10/93	nil	9/14/93	9/2/93
E1 PreLab Questions	9/9/93	9/9/93	9/7/93	9/8/93	9/10/93	9/16/93	9/14/93	9/2/93
E1 Lab	9/14/93	9/16/93	9/17/93	9/13/93	9/17/93	w/class	w/class	9/11/93
E1 Report	9/23/93	9/23/93	9/29/93	9/23/93	10/1/93	no int	9/28/93	10/2/93
E2 PreLab Questions	9/23/93	9/23/93	9/29/93	9/23/93	10/1/93	9/23/93	9/28/93	10/2/93
E2 Lab	10/2/93	10/7/93	10/22/93	10/22/93	10/15/93	10/3/93	10/24/93	10/24/93
E2 Report	10/16/93	10/14/93	11/18/93	11/23/93	10/22/93	10/13/93	12/3/93	12/3/93
MA2 Assignment	10/16/93	11/4/93	11/18/93	11/23/93	10/22/93	10/13/93	12/3/93	12/3/93
E3 PreLab Questions	11/18/93	11/4/93	11/18/93	11/25/93	10/28/93	nil	12/3/93	12/3/93
E3 Lab	w/class	11/11/93	11/19/93	11/25/93	11/6/93	w/class	12/4/93	12/4/93
E3 Report	11/18/93	12/3/93	12/1/93	12/6/93	11/16/93	10/28/93	nil	nil
E4 PreLab Questions	11/21/93	12/2-3/93	12/1/93	12/6/93	11/19/93	11/18/93	12/5/93	12/5/93
E4 Lab	11/23/93	12/3/93	12/2/93	12/6/93	11/19/93	11/19/93	12/5/93	12/5/93
E4 Report	12/15/93	12/7/93	12/3/93	12/17/93	11/29/93	12/1/93	nil	nil
Final Interview	12/16/93	12/10/93	nil	nil	12/6/93	nil	nil	nil

Highlighted blocks indicate lab partners

The Observation: Data Collection for the Study

There were several sources of data for this study (Figure 4), but the primary source was field notes made by the author during open-ended audiotaped interviews of student-participants. These interviews were conducted before and after each activity in the Physics 152L curriculum completed by the participants, and elicited participant impressions of overall laboratory content and examined each activity for noteworthy aspects (confusing portions, easy or difficult portions, those parts which were rapidly completed, and those which were lengthy and so forth). Participants raised their own concerns and addressed those raised by the researcher and by other participants in the course of other interviews.

These interviews with participants were conducted in as open-ended a fashion as readily achievable. Interviews started with vague inquiries like "What did you think of..." or "Tell me about..." or similar cues designed to get participants talking about their major perceptions of the activities. Participant comments were first listed in the field notes until participants exhausted their memory on the topic. Next, the meanings of each comment listed in the fieldnotes were probed by requesting supplemental information, and the in-depth descriptions added to the notes. Then the [illegible] activity was reviewed, part by part and

question by question, and comments were elicited for each portion of the activity. Finally, summary comments on the activity and advice for improving the activity by enlarging activities and cutting others was solicited, along with advice to be given to hypothetical 'other students' who would be taking the course in future semesters.

I kept extensive field notes of the conversations. These field notes were the primary criteria used to decide which sections of the interview audiotape would be transcribed. All of the fieldnotes (over 500 pages) were closely examined and reflected upon, then critical segments of audiotape were closely examined and transcribed (about 10% of the total).

Videotaped Activity Interviews

Approximately 35 hours of videotape were collected (all of which were replicated by the audiotaped data) of participants completing the curricular experiments and attempting to 'think aloud' or describe aloud what they were doing and thinking about. These also were not transcribed in total; selected segments were transcribed and were used to annotate fieldnote transcriptions of appropriate data exemplars. For instance, if participants repeatedly described some portion of an activity as confusing during interviews, this was first noted in the fieldnotes, then transcribed from audiotape and finally annotated by partial videotape transcription describing the participant behavior and apparatus interaction in question.

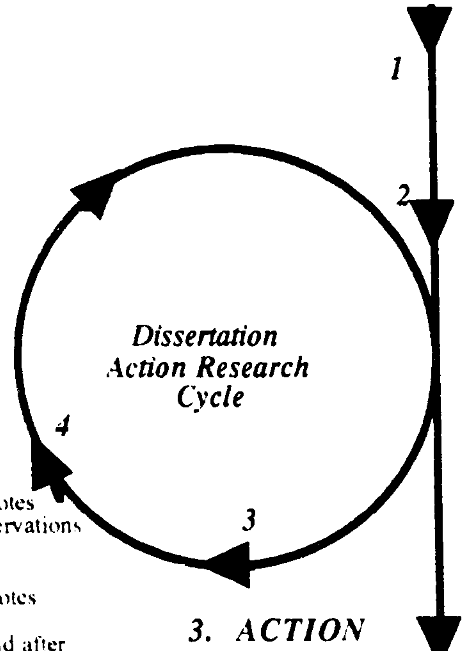
Other Artifacts

Other artifacts collected in this study included copies of all participants' lab reports from Physics 152L and some from similar courses, participant annotated laboratory manuals and other curricula materials and copies of e-mail correspondence between participants and the author.

These different data collection techniques repeated across a number of students complemented one another by examining laboratory practice from a wide variety of viewpoints and providing a means of triangulation to validate or disprove assertions drawn from the data. Two GTA interviews were conducted at the end of the semester and at the halfway point during the semester, and these were also used for the pruposes of triangulation. Field note data was treated as the primary source for student commentary, and the primary [illegible] on participant behavior in the laboratory.

1. RECONNAISSANCE

Researcher's background, describe previous research, briefly describe PHYS 152L curriculum.



2. PLAN

About what do students construct meaning during their Physics 152 Laboratory experience?

How can we improve the quality, worth and justice of the Physics 152 Laboratory experience for students by modifying the curriculum and practise of that course?

3. ACTION

Follow selected students through the curriculum.

Assess each and every curricular activity

4. OBSERVE

Videotape and field notes from participant observations of all activities.

Audiotape and field notes from interviews with participants before and after all activities.

Descriptive statistics of participants and general course population.

Ancilliary materials (email, lab reports, other comments from students, instructors).

STUDY PARTICIPANTS

Two student participants did all activities with their regular assigned section and were interviewed after each activity.

Eight student participants completed activities while videotaped with researcher and were interviewed before and after each activity. Of these, two went back to their assigned sections to complete one single activity, then completed the study with the researcher. Four of these participants worked alone, and four with partners in pairs of two during activities.

Two student participants dropped out of the study due to previous time commitments and scheduling difficulties

One student participant offered unsolicited general commentary on the lab experience; [illegible] participant offered unsolicited commentary on the lecture course experience

One Graduate Teaching Assistant and one Undergraduate Grader participated in [illegible]

Figure 4. Data collection in the methodological design

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Reflection: Analysis of the Data

After collection, the data were reduced by the author using inductive analysis (Goetz & LeCompte, 1984). In brief, I subjected the raw data to repeated examination and reflection over time. From the raw data selected transcriptions were made and re-examined until a series of meaningful categories were established. This thematic analyses of the different data sources provided triangulation upon convergent inferences which were eventually used to make knowledge claims and subsequently to generate suggested interventions (Figure 5).

I commenced the data analysis by fastening copies of all field notes and some transcripts and laboratory report extracts to the walls of a large room. Here approximately five hundred 8.5" x 11" sheets of data could be viewed with ea simultaneously across both different students and curricular activities. These data were posted for several weeks (some for months). I examined them repeatedly over time and reflected upon them at length. My analysis of these data started by examining, annotating and highlighting data patterns (perceived similarities) using different highlighter and marker color codes, colored post-it stickers and marker symbols. My analysis proceeded by preparing summaries and concept maps from these data patterns.

Next, I returned to secondary data sources (videotapes, additional transcriptions, participant commentary on the summaries) for re-examination or additional transcription as seemed appropriate to clarify the patterns. From these originally quite vague data, I generated a number of specific categories by repeatedly coding and recoding, concept-mapping and summarizing the data. I further refined the categories by identifying characteristic properties and discriminating criteria for each and by choosing high-quality exemplars to illustrate each category. These categories emerged naturally from the interaction of the data, the researcher and the participants in the study.

I documented these categories, and used them to make highly situational and specific knowledge claims about various curricular activities. Next, I thematically grouped these categories and used th n to formulate general assertions or knowledge claims concerning the curriculum as a whole. These knowledge claims would be made in such a manner as to guide generalized curriculum development. I formulated these assertions upon their enactability -- the principle value of these assertions lay in their ability to guide curricular interventions -- to determine specific, active curricular reforms that could be used to modify and better inform curricular practice in the laboratory.

1. RECONNAISSANCE

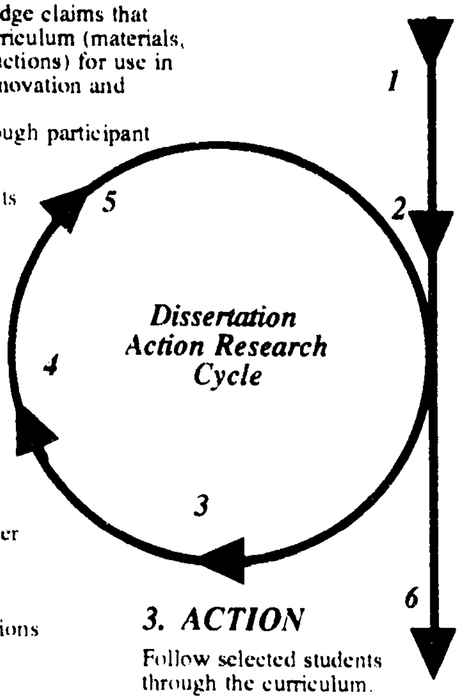
Researcher's background, describe previous research, briefly describe PHYS 152L curriculum.

5. REFLECTION

Formulate general knowledge claims that will guide revisions to curriculum (materials, goals, activities and instructions) for use in next cycle of curricular innovation and evaluation.
Validate these claims through participant review and commentary.

What meanings are students constructing from the curriculum and why?

How can we better match curricular goals and outcomes?



2. PLAN

How can we improve the quality, worth and justice of the Physics 152 Laboratory experience for students by modifying the curriculum and practise of that course?

About what do students construct meaning during their Physics 152 Laboratory experience?

4. OBSERVE

Audiotape and field notes from interviews with participants before and after all activities

Videotape and field notes from participant observations of all activities.

Descriptive statistics of participants and general course population.

Ancilliary materials (email, lab reports, other comments from students, instructors).

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Follow selected students through the curriculum.

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STUDY PARTICIPANTS

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Figure 5. Reflection in the methodological design

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Finally, these knowledge claims were documented with categorical evidence and were presented in writing to several the participants in the study. The participants read, reflected and commented upon the appropriateness of these claims, providing validations or alternate interpretations. The claims were then used along with exerpts from Physics education research to restate the major curricular goals for Physics 152L, which were also presented from commentary to the study participants.

Principal Categories Emergent from the Data

Characteristic 1: Participant Learning Claims

Study participants claim that they are acquiring a series of previously unfamiliar technical skills as a result of their PHYS 152L experiences. Skills reported by participants in interviews include proficiency in formal reporting, laboratory data acquisition, measurement analysis techniques, computer graph generation and interpretation and least squares fitting practice. Furthermore, participants described their acquisition of these skills with some considerable pride and indicated that they felt the development of these skills was appropriate and worthwhile practice for the PHYS 152 course, their other undergraduate studies, and probably in their coming professional engineering careers. These are the kinds of things that they felt engineers do and that they should be learning.

The perception of student proficiency is characteristic of every curricular activity summarized in the data set and became strongly stated by student participants as the study progressed, after student participants completed a number of activities, reflected upon their experiences, modified their practice, and obtained feedback from their instructors through graded reports and MAs. This claim to learned skills was most evident in the prevalence of the things participants claimed they learned in PHYS 152L during their final interviews. By order of prevalence, participants felt that the course had reinforced the lecture material; taught report writing skills; taught graphing, least squares fitting and computer plotting skills; taught statistical, measurement analysis and significant number skills; and promoted teamwork.

Particularly in E3, several participants commented on their LSQ fitting and plotting skills. Harry remarked that he was then discussing least squares fitting simultaneously in his honors Chemistry and Mathematics courses, as well as in PHYS 152L. Other participants commented they felt their lab work was improving -- that they were doing better on their [illegible] in the lab. Joan commented that she had located the sample writing in the

manual and that it, along with explanation from the author helped her improve her abstracts considerably. She felt that least squares fitting 'made more sense now,' and that 'she felt more confident, perhaps even a little bored with the apparatus.'

Also in E3, Norma showed particular skill and élan with the interface, clicking on various parts and managing to considerably reduce rescaling by planning and mastering some of the more esoteric scaling controls. Finally, during E4, participants claimed to be quite comfortable with least squares fitting procedures. Ian wrote a Lotus 1-2-3 spreadsheet to do all of his fits. Louie claimed to be able to do them 'in [his] sleep'.

Characteristic 2: Curricular Feedback and Pacing Inadequacies

Study participants believe there is inadequate curricular feedback to guide the progress of their learning in PHYS 152L. Student participants and instructors felt there are too few activities, that the three week cycle between their laboratory experiences and graded feedback is too lengthy, and that prelaboratory questions and instructor critiques are unavailable and possibly forgotten when they are required. For example, during E2 student participants forgot basic elements in the control of the software (how to scale, how to print) learned during E1, suggesting that greater access or more frequent access to the software might help.

Also during E2, Harry remarked that he 'wanted the E2 prelab questions [available] during the lab,' and suggested that rather than collect that document from students at the start of the data collection the instructors 'should just check off that it was done' and check a few numbers. Harry also wanted to have the E1 report in hand during E2 data collection (the author returned it to him after data collection for E2 was completed).

Participants during E1 claimed that data collection 'seemed easy,' and felt that the graphical displays were 'good for visualization' (referring back to E1 PLQs). However, when specifically requested to contrast and compare the PLQ predictions, graphs and descriptions to the laboratory data collected, seven of twelve participants were unable to do so -- they simply could not recall their PLQ answers. Two participants specifically requested that they have their PLQs graded and returned before completing the main report.

Characteristic 3: Curricular Content and Lab-Lecture Correlation

Student participants also believe that their laboratory experiences helped illustrate their lecture material. All felt that the lab experiences added considerable depth to their

understanding of equations discussed in class. Michelle stated of E4: "The lab makes you see it better -- it's in depth. In lecture you sleep through it.' and '[lab] looks more real. It gives it more meaning, instead of just the definition.' Louie felt that the rotational motion activity 'showed something from the book where you learned it, but it wasn't really an understanding of the principle.' Ian stated he 'never had labs like these [rotational motion' before, but has seen all of these definitions before.' Two participants even went to the length of claiming that they preferred to learn their physics through initial experience to phenomena in the laboratory followed by lecture, rather than the more typical inverse order.

While all study participants stated that the laboratory activities illustrated their lecture material well and that this was a worthwhile and appropriate role for laboratories, several noted that lecture and laboratory were not always synchronous. For example, student participants who performed E4 during the first scheduled week of the three week lab rotation complained that they had to learn material not yet covered in lecture to complete their PLQs. Those who completed the E4 activity with the author or with the final week of the rotation made no similar claim. This was most pronounced with E4 as E4 covers an enormous amount of lecture material (rotational motion and simple harmonic oscillation) in a very sketchy fashion. As well, the topic of rotational motion is traditionally one of the most difficult topics for student learning in elementary mechanics (Arons, 1990). Unsurprisingly, several participants requested additional laboratory activities on rotational motion.

Participants also perceived that inadequate variety in apparatus (the SONAR - Airtrack System) detracted from learning the different concepts examined in each activity. Participants appeared to have difficulty remaining focused on the changed conceptual content when they used the same apparatus from experiment to experiment. They appeared to relate concepts to concrete apparatus rather than to all of the different physical phenomena (the physical behavior of the apparatus under different constraints). The inclusion of additional experiments employing more varied apparatus would address such problems, and would also provide an opportunity to introduce more kinesthetic and conceptually well-founded activities (Arons, 1990: Laws et. al., 1992). As well, greater opportunity for lab-lecture linkage could be found, and the slow pace between labs could be addressed.

Some curricular topics assumed by the curriculum authors to be trivial background information were not seen as such by students. Most noteworthy was a dearth of student knowledge of introductory statistics (apparantly not part of the standard high school curriculum) and considerable [illegible] regarding significant numbers (which is part of most junior high school [illegible] participants claimed they had never before seen

summation notation, did not recall having ever calculated a variance or standard deviation, and could not interpret the term mean value (all twelve students had previously calculated arithmetic averages). These issues clearly require greater attention.

Characteristic 4: The Commitment to Reflective, Analytic, and Critical Practice

Participants feel that the study itself was a valuable experience for them and that the study itself led to an improvement in their physics learning. This characteristic was confirmed by the author and the instructors. Participant commitment to critical practice and reflective change is characteristic of the reasoning required within the laboratory investigations and (in particular) the measurement analysis curriculum as well as this study. Their participation in this study paralleled the laboratory commitment to the refinement of measurement practices through data collection, observation, reflection and modified practice.

Several student participants took their critical responsibilities for this study as seriously as those required in their laboratory report analyses. Each laboratory report analysis section required students to numerically assess sources of uncertainty in the experimental apparatus and procedure and both qualitatively suggest and quantitatively evaluate the results of using alternative apparatus and techniques. This study demonstrated a similar commitment to rational investigation and managed change in the curriculum.

For example, Louie initiated and carried out an extensive editorial review of the experiment instructions and described how he felt they could be more appropriately reorganized. He also identified less than optimal placement of lab manual figures as leading to student confusion, and later suggested mechanical improvements (removing extra stops and limit guides) to the torsion pendulum apparatus that made it easier to use. These changes were adopted and have become standard practice in PHYS 152L. Other participants reflected upon and described obstacles to their data collection (e.g., the use of an error beep to indicate apparatus calibration completion) and to their learning (e.g., the use of staggered tables when calculating average velocity and acceleration from instantaneous position measurements).

It should also be noted that this situation radically illustrates the incidence of an unusual learning phenomenon felt characteristic of the data collection methodology (by the author). Students were interviewed on their PLQs and lab reports, and answered questions designed to document their practice throughout data collection in the laboratory. All of these activities were in excess of ordinary student experience. The student participants in this study were all spending a great deal more time examining and reflecting upon the PHYS 152L than their peers. The curriculum they experienced was not the equivalent of their peers.

and they learned a great deal more as a result.

The results of this commitment to critical practice were also evident to course instructors from descriptions of previous editions of the PHYS 152L curriculum. GTAs participating in the study stated that they felt their experiences with critical analysis and successive refinement in teaching PHYS 152L worthwhile and appropriate. Ideally, we should change the curriculum to better reflect a committment to this kind of reflective activity by making the lab like this study: encouraging critical reflection in all participants and involving all participants (including the GTAs) in critically evaluating their activity in the lab as well as their measurements.

Characteristic 5: Cooperative Learning and Group Interactions

The majority of student participants indicate that they felt working with others on the preparation of joint lab reports made the reporting activity more worthwhile and much more pleasant. Even those participants who initially refused to work with partners (such as Harry) or who had unsatisfactory experiences with a partner (Joan) felt that they had missed out on a valuable experience and indicated they would prefer to work with others in future laboratory activities. Notably, Harry started PHYS 152L indicating that he had detested the thought of working with a partner. After E3, Harry stated that his partner 'learned more' from him than he did from his partner. In the end of course interview, he felt that the author should create a course policy making group reporting mandatory -- 'the course [PHYS 152L] is too passive about working with people.'

Those who had good experiences working with their partners (e.g. Rao) felt that this was amongst the most valuable experiences in the course. Rao said that 'E3 was easier because we did a joint report ...[this was] responsible for [all] the increased ease [performing the data collection and preparing the report].' His partner 'made the lab much more enjoyable,' and he was definitely going to do E4 with the partner and prepare a joint report.

Other students found that group reporting 'degenerated' into purely social conduct and was detrimental to completing the laboratory report writing tasks. Norma and Oscar were highly successful at relating to one another, but mentioned that their interactions were 'too social, indicating they often went off-topic. Norma and Oscar indicated that while they benefited from checking one another's work, they also encountered difficulty finding free time they could schedule to work together.

Characteristic 6: Conceptual vs. Numeric Analysis of Lab Phenomena

Participants appreciate the mental challenge of conceptual (non numeric) problems as opposed to the more typical algorithmic (plug and chug) problems found in their textbook. This was most particularly illustrated during experiments E2 and E4: E2 had a very open-ended conceptual activity while E4 had almost no conceptual activities. Other activities (e.g., E3) suffered from a lack of linking questions comparing similar theory and measurement. However, these activities can be perceived as too vague and open ended (e.g., by Joan in E2) if the goals are not clearly stated and promoted by instructors. Clearly these kinds of activities need to be better refined and made more pervasive in the curriculum.

Michelle stated (of E2): '[E2 PLQs] made me think about friction -- things that I never really thought of before. [There was] ...more thinking than the E1 PLQs -- the other was just math and graphs.' 'I enjoyed [the] mental challenges.' This perception of E2 was typical amongst the participants. They wanted more opportunity for 'thought' and 'fewer plots'. Student participants particularly enjoyed the last question where they were asked to design investigations examining various possible sources of uncertainty in the measurement apparatus. Oscar commented 'I like designing experiments. In high school we got to design one experiment for credit.' This same student wanted 'bigger questions' of this nature. Even Kevin stated that he thought designing these activities was 'fun' [!]

In contrast, participants described the E4 PLQs as 'just plug-and-chug,' you '...just look up the equation and put the numbers in to the problem,' 'just do what they tell you to,' and (most alarmingly to the author) 'just like in class.' Harry described a sense of finality about E4 -- 'this time in the semester I'm pretty burned out,' 'I didn't have to think so much -- the other prelabs made you think a lot more.' While participants were happy to go through the E4 calculations, they felt something was incomplete in their appreciation of rotational phenomena when they performed labs without conceptual (non-numeric) challenges.

Characteristic 7: General Technical Problems

The critical examination of the curricular activities exposed many shortcomings and technical difficulties. The uncovering and explaining of these problems was turned from an instructor's chore to a task appropriate for each and every person involved in the study by the critical theory/action research paradigm and methodology combination. Participants excelled at the task, uncovering and suggesting remedies and solution approaches for hundreds of individual minor difficulties as described in the preceding summary.

In the curriculum, confusing directions, faulty procedures and technical glitches abounded. The more striking examples included reversed air tracks, confidence-destroying beeps, poor manual layout (inappropriate siting of graphics, inappropriate sequencing of instructions for data collection), poor descriptions of reporting procedures and for determination of uncertainties on monitor screen measurements. Participants also spotted mis-labeled axes, disappearing labels, references to missing equipment, poorly worded instructions and questions (e.g., Rao noted that his grade suffered because he had solved all the equations at t=1.0s rather than leaving time as an explicit variable).

Other problems included graphics controls that destroyed all scaling, slow computers and sometimes erratic printers. Many participants suggested highly appropriate solutions, of which several have since been implemented and are now standard practice in PHYS 152L. For example, in E4, after encountering troubles trying to get the pendulum disk rotated a full 90^{o}, Louie suggested we change the way the safety stops were mounted on the torsion pendulums to allow a much greater rotation angle (while still preventing the disk from moving past 180^{o} for safety). Louie's improvement was subsequently implemented and is now standard practice in PHYS 152L.

Characteristic 8: Shortcomings of Action Research in this Setting

<u>8a. Action research is not an appropriate method for pursuing student alternative conceptions research</u>. During the E3 PLQ interviews, a series of gross difficulties were uncovered in student understandings of mechanical potential energy. Action research did not prove to be a fruitful way of pursing an investigation of the topic, as a thorough theoretical understanding of the taxonomy of alternative conceptions for mechanical potential energy is required before interventionary strategies can be developed.

The last three parts of the first question in the E3 PLQs asked about a situation involving the measurement of potential energy from two different reference points and then asked about the consistency of potential energy measure. The intent was to make clear that the potential energy definition included an arbitrary constant. These question invoked heated debate amongst two participants (partners who were interviewed together) and a great deal of confusion amongst all others. All participants felt they learned more from their questions and discussion with the interviewer than they would otherwise have learned from the question. The topic (potential energy definition) was clearly not appreciated or understood by most participants and was insufficiently addressed in the lecture. The lack of participant responses indicates that this particular subject is worthy of in-depth pursuit through modified Piagetian-

style interviews (there is a paucity of research addressing this particular topic).

Student participant interviews with the author all turned into detailed theoretical discussions of what the principal ideas in E3 were supposed to be, and then how they might be approached in the manual. Only one student felt the topic was trivial, and our discussion turned to state functions in physical systems. The remaining discussions resulted in participants listening to me during the interviews rather than the reverse, with little interpretable return data to the study. Participants did not have the basic context for a meaningful examination of the problem, resulting in probes becoming lectures.

8b. The learning of study participants in this study was atypical of the general; PHYS 152L student population. It should also be noted that this situation radically illustrates the incidence of an unusual learning phenomena I feel is characteristic of the data collection methodology. This was previously discussed in the summer pilot reconnaissance work for this study (Chapter 3). Students were interviewed on their PLQs and lab reports, and answered questions designed to document their practice throughout data collection in the laboratory. All of these activities were in excess of ordinary student experience. The student participants in this study were all spending a great deal more time examining and reflecting upon the PHYS 152L than their peers. The curriculum they experienced was not the equivalent of their peers, and they learned a great deal more as a result.

At first, I tried to minimize the impact of the interviews and data collection observations by attempting to keep the language and kinds of inquiries as neutral and random as possible. This helped, but the fact that students had more opportunity to reflect and felt that their role as participants in the study was to reflect meant that their insights into the material were greater than typical. Asking neutral questions during critical moments or situations or time during data collection carried significant import to the participants -- this focused their attention on important data and concepts. Asking questions randomly simply meant there were more occurrences of mental reflection and summary than was typical of student lab practice without the questions.

Hence, it needs to be clearly recognized that student participant experiences in this study should not be claimed generalizable to or representative of typical PHYS 152L students. Their experiences and insights gained were profoundly different. However, characterizing and examining their experiences throughout this study process did result in the construction of many insights and appreciation's of curricular shortcomings and strengths. This knowledge was of great worth informing curricular designers and instructors when

reformulating the curriculum and interpreting the experiences of PHYS 152L students in general. As well, the desirable critical elements of their experiences might be made part of the regular curriculum.

Emergent Knowledge Claims from this Study

Three knowledge claims emerged from this study, each representing a collection of related characteristics and leading directly to a series of curricular reforms.

Knowledge Claim #1: The Perceived Quality and Worth of PHYS 152L

Student participants and instructors felt strongly that PHYS 152L was a generally worthwhile experience. Student participants judged worth primarily in terms of the acquisition of the skills typically required of practicing engineers and scientists. They felt that PHYS 152L provided both appropriate challenges and valuable experience for their academic and post academic careers as engineers. They also felt particularly strongly that lab illustrated the lecture material and encouraged the construction of meaning through greater experience and physical context and that this was an appropriate goal for the lab. Instructors measured worth in both skills acquisition and in conceptual familiarity with the subject being studied (Newtonian mechanics).

Participants felt that developing and mastering several skills in particular was highly appropriate. The most desirable skills were the plotting skills and least squares fit; the elementary statistics instruction and significant figures review; the development of formal report writing skills; the group work practice; the development of laboratory measurement skills including the manipulation and analysis of measurement uncertainty, and the opportunities for critical and analytical thought (in contrast to traditional plug-and-chug equation memorization and problem solving, which was associated with the course lectures).

Knowledge Claim #2: The Need for Greater Access to Laboratory Experience

Along with a recognition of particularly appropriate facets of the PHYS 152L experience came participant demands for greater levels of access to those experiences. This claim is a synthesis of Characteristics #2 and #3 -- which address curricular pacing, feedback and lab-lecture synchronicity. Participants were quite concerned with their time pressure -- with having adequate time to collect all of their data and having adequate additional access to the laboratory. They felt that the evening and one day per week open access was worthwhile and requested that it continue. If TAs spoke excessively, this also cut into limited student

laboratory experience and was resented.

Participants also felt that while the prelaboratory questions and previous reports helped prepare and guide their laboratory practice, they did not have timely enough return of these materials and adequate access to appropriate grader commentary and feedback. This suggests a reformed, more timely system of grading PLQs and lab reports.

While most participants succeeded in making use of scientific plotting software after some initial difficulty, fewer succeeded in making use of spreadsheet software. All who did succeed at either computer software package felt these skills invaluable for their other coursework as well as for professional training as engineers. Greater access to these laboratory data reduction and presentation tools should be provided as well as formal training in their use. These would be additional appropriate activities to add to the curriculum.

Participants had some difficulty with the sparse schedule of the laboratory; one experiment every three weeks meant that participants had trouble recalling basic laboratory skills acquired during the last session. The sparseness of the experiments and frequency of the lectures -- two lectures each week -- led to difficulties synchronizing lab and lecture. As well, while participants found their lab experiences helpful illustrating theory described in the lecture (particularly with rotational motion), they specifically requested more experience with this very same topic.

Additional experiments would ameliorate these conditions, and allow the introduction of high quality, illustrative, kinesthetic experiments in rotational motion and momentum that would add variety to the laboratory experience and likely improve student learning. Suitable candidate activities are readily available (Arons, 1990; Laws et al., 1992).

Knowledge Claim #3: The Role of Critical Theory in Analytic Thinking, Curriculum Development and the Laboratory Learning Environment

This study made use of a number of nontraditional approaches to educational curriculum development and to research in the working classroom. For the purposes of in-depth curricular development, I feel that action research methods have no equal. Students and instructors enjoyed contributing to the study and provided meaningful insights, extensive interpretive guidance and concrete suggestions for improvement. Many of these suggestions were directly and immediately implemented in the curriculum. Of particular worth were the videotaped user observations. These observations revealed many shortcomings in the [illegible] materials, methodology and apparatus. Traditional educational research methods

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could not have readily provided the rich in-depth insight and guidance for curricular implementation.

However, there were clearly shortcomings in regards to the kind of insights acquired during this study (see Characteristic #8). Particularly evident was the confusion associated with the role of mechanical potential energy in E3. The design of this portion of the curriculum is particularly weak, and suffers from a lack of formal guidance (of the nature provided by learning theory and student conceptual research). This problem is not restricted to PHYS 152L -- there is a dearth of research into student learning of mechanics potential energy theory in the literature, and further investigation is warranted. Such student learning research is non interventional, it is essentially probing and descriptive in nature, and action research methodology is inappropriate. More appropriate methods such as modified Piagetian-style inquiry like that typified by the research of McDermott et al (McDermott, 1984; Trowbridge & McDermott, 1980; 1981) needs to be conducted. The curricular implementation of the theoretical fruits of this kind of research would be appropriate for action research development.

While the data collected from these participants were insightful, they should not be considered characteristic of the general student population of Physics 152L. Study participants had relatively greater opportunities to learn -- they were paid to spend about twice as much time with the curriculum than their peers. They also had greater opportunity to reflect upon and review their own learning with an expert present to guide their reflective process. And finally, the nature of the research called upon participants to repeatedly analyze and communicate their curricular experiences -- another opportunity to learn generally denied their peers. While it is unlikely the curriculum can be made as effective as one-on-one learning with twice as much curricular experience, insights gained from the research can be used to improve the curriculum experience for all of the students enrolled in PHYS 152L. As well, some of the characteristics from the research that aided student learning may be incorporated into the curriculum itself.

For instance, there were many instances of technical shortcomings in the curriculum and the materials and these are probably best identified by continued cycles of Action Research inquiry. A notable example occurred in the discovery of inappropriate reified practice in the MA1 curriculum: incorrectly assuming no need for elementary statistics instruction. Such instruction is required, including introducing Gaussian statistics and the provision of high quality examples of measurement analysis calculations and report writing. Better examples and more guidance for different portions of report writing and determining

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uncertainty on computer generated plots are required. Participants were particularly distressed when the manual was vague or did not fully correlate with either the apparatus or the software, and more attention needs to be paid to this problem. A host of other technical shortcomings in the curriculum materials (the manual, apparatus and computer software) have been described at length in the previous chapter and require attendance.

Emergent Recommendations for PHYS 152L Curricular Reform

As a result of this study, the PHYS 152L curriculum is being significantly reformed and the new curriculum (now in preparation) should be in place for student enrollment in Summer of 1995. This reformed curriculum will feature a number of changes as follows:

1. The reformed curriculum will be rewritten to portray the importance of report writing, measurement analysis and cooperative learning and reporting. These will be made overt goals of the activities. Initially, one assignment will become a mandatory (not optional) group activity, and more may be similarly designated after trial. The enaction of these changes to the curriculum will have to be assessed through additional critical examination via action research.

2. To aid assessment and to continue technical refinement, curricular evaluation through student observation and student and instructor feedback will be entrenched into regular practice. This will be attempted by creating a support framework so that each instructional staff member carries out some limited form of critical inquiry during the semester. PHYS 152L routinely has between twenty and forty instructional staff members. Many of these have been informally evaluating and reporting curricular shortcomings to be addressed by the author for several semesters. This process will be formalized by requiring it in all instructional job descriptions, and by offering informal encouragement, extra credit or additional employment opportunities for those interested in in-depth curricular reform and development. The formal separation now extant between curricular development personnel (the development crew) and instructional personnel (the teaching staff) will be reduced or eliminated by allowing course staff to freely move between both kinds of activity. This will also create an atmosphere of critical evaluation which models the rational investigation conducted by laboratory scientists and professionals for the benefit of the students in the course.

3. Formal instruction in the use of computer data analysis and presentation software will be incorporated into the new curriculum and use of these tools will become integral to all activities. They will become required, not optional [illegible] will likely be part of the

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very first activity students complete in their lab.

4. The reformed curriculum will be more closely integrated with the lecture through topical matching and assessment. More experiments will be added to the curriculum and these activities will contain appropriate illustrative activities upon the topics of momentum conservation and a much more general and kinesthetic activity on rotational motion. Apparatus will be more varied than in the previous curriculum. PHYS 152L will become a six experiment course (one every two weeks), instead of the current four (one every three weeks), allowing tighter synchronization. This will fully utilize all space and instructional resources available to the course for the foreseeable future. Questions typical of laboratory practice will be included in the pool of items from which midterm and final exam questions are drawn for the whole PHYS 152 course.

5. Laboratory assessment will occur in a more timely fashion. Prelaboratory questions in the reformed curriculum will be graded during the first thirty minutes of class data collection and will then be immediately returned to all students. This will require that the PLQs be reduced in length, and will likely mean that the PLQs will not be fully graded -- collected PLQ sets will be spot checked (closely graded on a chosen subset of specific questions) and the remainder simply scanned for completeness. Students thus will have their PLQs when collecting, interpreting and reporting their laboratory data.

6. The amount of equation verification during activities in the reformed curriculum will be reduced, and more interpretive, non-numeric activities will be assigned.

Participant Reactions to the Proposed Reforms

These proposed reforms were shown to four study participants and comments elicited. All of the (admittedly few) comments received were favorable, including those of Joan and of Harry. Regarding greater skills emphasis, Joan said: '...these are skills very much need and will be re-emphasized in classes such as [Mechanical Engineering].' Harry was a bit more conservative stating 'good idea, but how do you plan to do this?'

Regarding greater lecture integration and the placing of lab questions on exams, Joan suggested that this would lead to more responsibility being paid to learning in the lab: "good! I think students will take the lab more seriously and learn it better, not just copy files.' Regarding the more timely return of graded work, she similarly was positive: 'great improvement! If other students felt like I did, questions on the PLQs were similar to those on the lab report. I would have grasped the material better and spent less time if I could look

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over my own previous work rather than re-reading the manual.' Joan also noted: 'Nothing is more frustrating than losing points for the same error on more than one assignment -- due to the current return procedure this happens often.'

Harry's response to an accelerated means of evaluation was one of concern -- he was afraid that the quality of evaluation would drop and he might lack feedback on problems he answered incorrectly but that might not be checked over carefully in the pursuit of faster grading. He noted: 'I'm not at all partial to this kind of grading... I question our ability to grade [in such a short period of time].'

Implications Beyond PHYS 152L

The categories, knowledge claims and recommendations of this study have been primarily generated to address the specific needs of Physics 152 Laboratory curricular reform. This is an appropriate and sufficient task in its own right, given that some ten thousand students have participated in these activities in the last five years and a similar number will directly benefit from this study in the next five years. However, there are a number of implications from this research that hold significant bearing and possible impact upon the Physics Education and Science Education communities in general, particularly upon introductory university instructional laboratories.

1. Laboratory course goals should include the deliberate, explicit student acquisition of skills and techniques required by working engineers and scientists. These include reporting skills; modern (e.g., computer aided) data acquisition; computer data presentation, reduction and analysis; the use of measurement analysis and statistical and graphical analysis; and critical, reflective analysis methods. These activities should be practiced for mastery (e.g., by completing several similar format laboratory reports) in the contexts provided by a variety of appropriate illustrative phenomena for the laboratory subject being taught (e.g. mechanics, biology, chemistry). Student attention should be explicitly focused upon the acquisition of these skills to promote their own mastery learning and develop student motivation through awareness of and confidence in their own newly acquired abilities. As well, the activities should be chosen to well-illustrate the lecture material.

2. Action research and critical theory provide appropriate paradigms to guide reflective practice and the involvement of all participants in the learning science laboratory. The tenets of such critical curricular development appropriately reflect and guide the spirit of analytic and critical examination of both laboratory phenomena and day to day instructional practice. Action research provides a means for all participants to contribute in a rational

manner to learning practice, and takes a profoundly nontraditional attitude towards the role of Instructors, Teaching Assistants and Graders -- encouraging these people to become curricular assessors and by extension, curriculum developers. This means that all participants in the laboratory have a responsibility towards worthwhile and just practice, not only the Professor and course developers. It also suggests that a primary responsibility of all Teaching Assistants is course assessment and development.

Action research encourages appropriate TA preparation as professional educators in their respective fields by requiring them to become active in interpreting their fields of study and in examining the learning of their students. This refutes the widely held notion that TAs and even science faculty must await professional education researchers to provide such initiatives in educational settings. Some elementary training in action research methodology and critical theory should be included in the background of all professional educators, particularly those in the sciences.

3. Action research provides an ideal means of sustaining a commitment to curricular change and refinement, by allowing many participants in the educational setting to contribute. The sum total of these contributions is far greater than any single curriculum developer's efforts are likely to be by simple additive power, and greatly supplement the motivation and drive required to sustain a commitment to improvement. While educational research and trained educational researchers can provide profound insights and interpretive ability to curriculum development, without this essential spirit of rational inquiry in many participants in each educational setting such efforts are unlikely to be understood, productive or continued.

Suggested Further Research

Several profound opportunities for further research arising from this study. First is the need for an appreciation and taxonomy of student alternative conceptions upon the subject of mechanical potential energy The topic of mechanical potential energy is probably best approached via modified Piagetian interview as espoused by Trowbridge & McDermott (1980, 1981). To address this problem a much more thorough theoretical description of student thought is necessary than have been typical of this study.

A second avenue for further study is research into those characteristics of user observations protocols which helped students learn. Many of the characteristics of the user observation protocols (thinking aloud, repeated rationalizing and expressing one's own reasoning) appear to be similar to the unique Socratic Dialog Inducing (SDI) curricula

activities of Hake (1987, 1992). Hake has not fully characterized his own curriculum, and it may be that action research conducted upon that highly unusual curriculum might characterize those portions of that curriculum of greatest value and worth to those participants. Along the way, something could be revealed of the SDI protocols that could be included in the much more traditional laboratory environment such as PHYS 152L.

A third opportunity would be an examination of the incidence of tinkering and physical explorations with the apparatus beyond the curricular requirements in group settings and when working alone. During this study there appeared to be a complex relationship amongst student comfort, tinkering and the presence of a partner. There may be further reasons to indulge in cooperative learning in the laboratory if groups encourage additional experimentation.

Finally, I would like to reiterate in closing that the findings of this study will be summarized and promulgated amongst the instructors and participants in PHYS 152L. The recommendations will be implemented into a new curriculum to be piloted in the summer of 1995 and will guide the implementation and development of that new curriculum. Further action research will be conducted to assess the impact, worth and appropriateness of those reformations.

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