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ABSTRACT

The last decade has seen the development of a number of computer-based interactive physics programs at the university level. Set in a cognitive apprenticeship framework, such programs view the instructor as a mentor, and the essential learning constructed in a collaborative process. It is expected that such programs, grounded as they are in educational research, will help students develop a more robust and accessible knowledge of fundamental concepts as well as a more positive attitude toward the subject matter in general and their own abilities. This paper considers the cognitive and affective outcomes of the initial implementation of one such program, the Comprehensive Unified Physics Learning Environment (C.U.P.L.E.) Studio Physics Program. Though results were encouraging, initially strong positive results, gathered informally during an earlier pilot implementation, were less so during the full and more formal evaluation. Early analysis indicates several possible reasons, including a gradual increase in the amount of time devoted to lecture and the elimination of whole-class discussion of laboratory activities and problem solutions. Contains 34 references. (Author)

Innovation and Persistence: The Evaluation of the C.U.P.L.E. Studio Physics Course

by

Marie A. Cooper
Angela M. O'Donnell

INNOVATION AND PERSISTENCE: THE EVALUATION OF THE C.U.P.L.E. STUDIO PHYSICS COURSE

S. MARIE A. COOPER, *Immaculata College, Immaculata, PA*

ANGELA M. O'DONNELL, *Rutgers University, New Brunswick, NJ*

The last decade has seen the development of a number of computer-based interactive physics programs at the university level. Set in a cognitive apprenticeship framework, such programs view the instructor as a mentor, and the essential learning constructed in a collaborative process. It is expected that such programs, grounded as they are in educational research, will help students develop a more robust and accessible knowledge of fundamental concepts as well as a more positive attitude toward the subject matter in general and their own abilities. This paper considers the cognitive and affective outcomes of the initial implementation of one such program, the C.U.P.L.E. Studio Physics Program. Though results are encouraging, initially strong positive results, gathered informally during an earlier pilot implementation, are less so during the full and more formal evaluation. Early analysis indicates several possible reasons, including a gradual increase in the amount of time devoted to lecture and the elimination of whole-class discussion of laboratory activities and problem solutions.

The physics education community has long been concerned about the nature and effectiveness of physics education for those students seeking to become professional physicists as well as for those whose physics background should enable them to live responsibly in a technological society. Research through the years has shown the traditional lecture-recitation-lab format of the introductory university physics sequence to be ineffective in helping the great majority of students either to take a firm grasp of the principles of Newtonian mechanics, or to build a strong foundation for subsequent learning. Conferences and innumerable papers throughout the years from 1956 have documented, and sought solutions to, the problems of extensiveness of material presented in introductory physics, lack of coherent framework, the existing strong concentration on problem-solving rather than on conceptual structure, and the intimidation of many students by the large lecture format (Arons, 1993; Tobias, 1990; Tobias & Hake, 1988).

One possible remedy for the difficulties suggested by cognitive scientists is the introduction of the cognitive apprenticeship process to the introductory physics program. In cognitive apprenticeship model of constructivist educational practice, instructional events are designed with a view to embedding the acquisition of concepts within realistic and meaningful tasks. Student involvement in these tasks, within a structured social setting and under the guidance of an expert, is intended to give students a more realistic picture of the components of expertise in a given domain, practice in higher order thinking skills, and the ability to apply new knowledge in a variety of problem-solving contexts, and in the manner of experts (Brown, Collins, & Duguid, 1989).

A number of innovative programs in introductory college physics have arisen during the last two decades, employing the cognitive apprenticeship model and boasting varying degrees of success and exportability. At the University of Washington, Lillian McDermott and her colleagues are currently developing a set of tutorials, based on Socratic dialogue and structured-group learning activities, as a supplement to the introductory program. Ron Thornton and colleagues at Tufts University have developed Tools for Scientific Thinking and their accompanying microcomputer-based laboratory materials to answer the need for laboratory experiences that are both efficient and profitable to the student, devoid of computational drudgery, but not of active participation or meaningful content (Thornton & Sokoloff, 1990). Priscilla Laws and colleagues at Dickinson College contributed workshop Physics, a hands-on, minds-on, activity based introductory course (Laws, 1991, 1993). Eric Mazur at Harvard University converted a standard lecture format to a qualitatively based collaborative format, coupled with the use of short ConcepTests and an electronic response system for immediate response/feedback to his presentations (Mazur, 1993). Across the country and around the world, innovations are multiplying at an amazing rate. Testing of the programs has found most to have achieved some measure of cognitive success. Drawbacks, where they exist, tend to be in the expense of implementation, size constraints, or lack of faculty support.

OVERVIEW

The study described in the paper sought to document the first full implementation of the C.U.P.L.E. Physics Studio Course, an integrated, collaborative, multimedia-based introductory university physics course. The course takes its name from the cognitively and technologically supportive environment within which it is framed, the Comprehensive Unified Physics Learning Environment. The current study examined cognitive and affective outcomes for participating students, difficulties of implemenation, and outcomes for faculty and teaching assistants. The researcher employed both quantitative and qualitative analysis tools in an effort to understand the effects of such a program, problems encountered in implementation and implications for more widespread adoption or adaptation of the C.U.P.L.E. program in particular.

The C.U.P.L.E. Studio Course

The C.U.P.L.E. Studio Physics Course is an effort to implement the most promising appplications of the cognitive apprenticeship model of constructivist educational theory in an integrated learning environment. Its architect takes as a guiding framework the application of the findings of cognitive science within a realistic community of practice. Communication and collaboration are essential, as are the anchoring of concepts in experience and in the contemporary applications of physics principles, and the integration of computers (Wilson, 1993, 1994).

The Comprehensive Unified Physics Learning Environment (C.U.P.L.E.), which forms the framework for the C.U.P.L.E. Studio Physics I course, is a computer-based multi-tasking, windowing graphic environment operating on IBM 486 computers. The C.U.P.L.E. environment, the product of designers from a consortium of universities led by Rensselaer Polytechnic Institute and the University of Maryland, and funded by the Annenberg/CPB Project at the Corporation for Public Broadcasting and IBM, incorporates hypertext and computational and modeling tools, as well as a variety of physics research and laboratory tools, material from the publications of the American Association of Physics Teachers, bibliographies, and glossaries. All materials are interconnected and accessible from buttons within each topical module. A dynamic interface acquires data from real-time experiments in the classroom, or from video stored on disc or tape or stored digitally within the computer network. Data thus obtained is sent directly to a spreadsheet for analysis, interpretation, and graphical display. When appropriate, several measures, such as force and position, can be made simultaneously, and graphs of force, position, velocity, and acceleration developed and displayed simultaneously (Redish, Wilson, & McDaniel, 1992; Wilson & Redish, 1992).

The C.U.P.L.E. Studio sets this tool in a classroom environment designed for communication between students in a cooperative learning structure, and between students and instructors in collaboration or Socratic dialogue. In its entirety, the studio is built according to the situated cognition format of constructivist view of education, and responds to the understanding that immediate application of concepts in a variety of concepts helps make students' scientific knowledge more coherent and more accessible in a variety of situations (Reif & Allen, 1992).

The Studio Physics classroom at present accommodates no more than 48 students, arranged in cooperative dyads, each dyad having access to a computer and its accompanying laboratory tools. Dyads are arranged within the room in such a way as to facilitate the formation of groups of four when larger discussion groups seem advisable. Each studio is under the direction of a professor, with the assistance of a graduate teaching assistant, and an upper level undergraduate teaching assistant. At present, during the beginning semesters, each professor also has the assistance of a second professor, a co-lecturer in the course (Wilson, 1994). This arrangement serves both to facilitate the initial implementation and to introduce professors unfamiliar with the studio format to its use in the introductory physics classroom.

The C.U.P.L.E. Studio Physics class is scheduled to meet for two sessions (one hour and 50 minutes each) each week. Each class uses a number of approaches in dealing with a single physics concept. While multifaceted and interactive, the studio is highly structured. Students are free, within their dyads, to work at activities at their own pace within certain limitations. The activities are carefully chosen and are used by all students simultaneously. Work is to be completed and submitted within a certain portion of the class The ordering of activities is predetermined and carefully planned.

The class is intended to begin with a brief summary of the previous session's work, followed by, and linked to, a discussion of the homework assignment that is due. Effective and confident communication is a valued ideal, and students are expected to present and explain homework solutions, and to participate in any discussion of those solutions, any suggestions for their improvement. All students within the class are expected to participate actively and respectfully. The instructor participates, but is expected to serve as a guide and mentor, rather than a leader at the head of the class. Since students are expected to complete homework assignments in preparation for new material, rather than as follow up of previous instruction, discussions can be quite active.

Following the summary and review, the professor sets up a readiness for the next activity, usually a computer-interfaced or video-based laboratory investigation. In the space of a few minutes, he or she introduces the students to the theoretical basis for the investigation, and any special items to note. Since the pre-lab is generally stored within the C.U.P.L.E. computer structure, the introduction can be brief. Student dyads or, when needed, groups of four, work through the lab, and collaborate on the brief report, which can be recorded directly in the computer, but usually carries some type of pencil-and-paper summary to be collected, graded, and returned for later availability to the students. The program calls for a general class discussion of the outcomes of these investigations, highlighting the conceptual framework and connecting it to the earlier work in the class.

A second activity, a lab or a collaborative problem-solving session, follows, reinforcing the same concept within another type of application. Introduction of this activity is intended to interconnect all of the applications of the concept encountered thus far, and this interconnection is strengthened in the discussion that follows the activity.

Finally, in a mini-lecture after the discussion, the concepts of the class are gathered and summarized, and carried forward into the next ideas to be encountered. Preparation is made for the students homework. It will be their responsibility to read all new material, and to work on problem solutions for the new material in preparation for the next class.

Need for Evaluation

While the C.U.P.L.E. Studio Physics Course is a strong effort to respond to the recommendations of cognitive studies, and while it combines proven elements from earlier programs, it is a unique entity, new to physics education and in need of closer examination. Can it effectively help students to form a stronger, more cohesive knowledge base? Can it model expert problem-solving and explanation techniques, and guide students into more expert modes of thinking and acting? Can it be used with equal effectiveness by any instructor?

The current study was initiated to document the cognitive and affective outcomes of the first full implementation of the C.U.P.L.E. Studio Physics I Course. The investigator sought to understand the extent to which the integrated structure of the C.U.P.L.E. Studio enables students to more fully incorporate the essential concepts of the traditional introductory mechanics curriculum into their own cognitive frameworks, whether the integration of spreadsheet physics, analysis of real-time video data, and graphical simulations promotes a stronger understanding of graphical representation and interpretation, the level of development from novice to expert approaches to problem solving, revision of inadequate solutions and construction of explanations and, finally, any evidence of teacher-dependence in the extent of students' conceptual development. In addition, the researcher sought to document some of the affective outcomes of such a program for students and instructors.

With the power of the components built in to the C.U.P.L.E. Studio course, it was expected that, despite the decrease in contact hours from six to four, that students would show more robust understanding of the essential concepts of introductory physics than is generally true in a more traditional program, that their skills in problem solving and graphical interpretation would display evidence of advancement to a more expert level, and that satisfaction would be greater for both instructors and students than in a more traditional course.

EVALUATIVE STUDY

Participants

The population of the C.U.P.L.E. Studio Physics Course during this study consisted of 251 students. One hundred fifty of these students were men. One of the six sections was composed of engineering students who, because of previous failure or insufficient background, found it necessary to enroll in their first physics course out of the usual sequence. Students from a variety of major programs made up all other sections. The students came from at least nineteen majors in the non-physics sciences and in non-science programs. Ninety two percent of these students were freshmen, and all except the engineering students were rostered into their sections randomly in the computer registration process. All pertinent testing and observation of these students, and examination of their in-class test and attendance records, was in the course of normal class practice and no compensation was provided.

Testing was completed on all classes, but time constraints and the volume of material to be considered demanded that only two sections be included in the most intensive investigation. The choice of classes to study more closely was made because the two classes are held in sequential time periods, and were taught by different professors. No consideration was made of the characteristics of the groups, and the randomness remained uncompromised. Section three had a total of 44 students, 25 men and 19 women. Thirty- eight of the students were freshmen. Section four was comprised of 37 students, of whom 22 were men and 15 are women. Thirty of these students were freshmen, 91% of the total who responded to the survey question of their year within their respective programs.

Eighteen students, taken from the two target classes and the engineering class, were chosen for collection of class materials and possible interviews, six each from the lower range, mid-range, and upper range of scores on the Force Concept Inventory. They were selected simply by number and no student was known to the evaluator at the time of choice. Nine of these 18, the first three positive respondents each from the lower range, mid-range, and upper range of scores on the Force Concept Inventory, were interviewed at regular intervals through the semester.

Materials

The C.U.P.L.E. Studio Physics Course is a carefully orchestrated, multi-faceted program with several strong hopes for students' cognitive gains. The use of a single evaluative instrument or analysis technique cannot be expected to give a full picture of the effects of such a complex program. Each of the instruments and procedures listed here was chosen for its applicability to a specific outcome of the program. The researcher hypothesized that the aggregate of instruments and techniques would provide a broad view of cognitive and affective outcomes of the implementation of the studio program.

Quantitative Measures

The Force Concept Inventory. Developed by Hestenes, Wells, and Swackhamer, the Force Concept Inventory (FCI) measures the students' use of Newtonian mechanics, as opposed to naive understandings, applied to real situations (Hestenes, Wells, & Swackhamer, 1992). The test, a multiple choice instrument consisting of 29 items which deal with the full range of concepts encountered in an introductory course in Newtonian mechanics, was chosen for use for two reasons. Since 1989, it has undergone extensive testing and is recognized within the physics community as one of the best instruments currently available. For each of the 29 questions, answers correspond to the correct understanding of a given topic, as well as the most common naive or incorrect understandings. Each concept and each naive understanding is represented several times within the test, so that, while putting undo faith in the results of a single question may be foolish, the aggregate of similar questions gives the examiner a clear perception of the conceptual state of the students. An extensive body of data has been gathered in recent years on the results FCI as taken by students in a variety of traditional and non-traditional introductory courses throughout the United States, giving a large comparison group in the absence of a local control. Ibraham Halloun continues the building of the database at the University of Arizona, and Richard Hake of Indiana University has made an ongoing comparison of a variety of University programs by mean scores on the instrument.

The Motion and Force Conceptual Evaluation. This test, developed by Ron Thornton, measures similar skills over the same area of physics, and is likewise keyed to correct and naive understandings, but was expected to provide additional insight because of its strong emphasis on the use and interpretation of graphical representations of physical situations. Such representation is common language for practicing physicists, but is a weakness in many students of the traditional course. (Thornton & Sokoloff, 1990; Thornton, 1989).

Problem Solutions and Explanations. Each week, each student was asked to solve and explain a single problem for evaluation by the researcher. These problems were based on problems from the students' own textbook and from an auxiliary text (Resnick, Halliday, & Krane, 1992; Jones & Childers, 1990), and structured on the pattern of information-rich problems developed by Heller, Keith, and Anderson at the University of Minnesota (Heller, Keith, & Anderson, 1992b). Such problems, containing extraneous information or leaving the determination of some unstated, but easily obtainable, information to the student, provide a good measure of transfer from textbook and class to the extended context of the real world. Early problems, in the area of kinematics, were quite limited in the richness of their information, but the richness of context increased to some degree as students began their study of dynamics, which provides more opportunities for such extension. Because the problems represented an additional weekly task for the student outside class, none of these problems reached level of sophistication of those in the Heller project. To increase the insight available from the problem-solving exercises, students were asked to explain their solution, on the reverse side of the paper, as though explaining to another student who was encountering difficulty in the class (Larkin , McDermott, Simon, & Simon., 1980).

Class Records. In order to obtain information on the attendance and attrition of class members, as well an understanding of the comparative academic achievement of the class under study and the corresponding, but traditional, class conducted during the fall semester of 1993, the investigator requested, and was granted access to general class testing records as well as the daily grade books for the two target classes. Since this access involved the disclosure of their academic records to a person beyond their instruction team, students were asked to read and sign a release form. Signed forms were retained.

Qualitative Measures

Observation of Classes. The two target classes, taught by two different professors, were observed throughout at least two classes every two weeks and examined for degree and nature of interaction among members of cooperative groups, student involvement in the class, use of multimedia and interactive materials, mathematical representation by students, interpretation and presentation by the students, as well as the degree of adherence of the class to the C.U.P.L.E. original framework.

Interviews. Designed to study the students' growth in both problem-solving skills and meta-cognitive habits, each interview consisted of student planning of an evaluator-prepared problem, solution of the problem, and subsequent explanation of the solution with any revision of the original plan that the student had made. Questions concerning the progress of the course, study patterns, difficulties, and successes were included in the interview protocols as sources of additional affective and procedural information (Ericcson & Simon, 1984).

Data Gathering Procedure

Both the Force Concept Inventory and the Motion and Force Conceptual Evaluation were administered as diagnostics at the outset of the course, and again as measures of change at the end of the course. Student scores for both tests, as well as each item response were recorded in a database for consideration of preconceptions supplanted, and those unchanged by instruction. Comparison of mean scores was made to existing databases, and appropriate correlations computed.

At the second class meeting of each of nine weeks, all students received a problem to be solved for the next meeting, the first class of the following week. Those problems submitted by students in the target classes (N = 81) were evaluated either by the principle investigator or by one other graduate student. Intergrader reliability was established using problem sets of a non-target class, after which each of the graders assumed sole responsibility for the grading and charting of the problems of one target class. Both the problem and the accompanying explanation were evaluated with respect to a fixed taxonomy developed after the models of Heller and colleagues, Chi and colleagues, and Touger and colleagues (Heller , Keith, & Anderson 1992a;

Chi , Feltovich, & Glaser., 1981; Touger, Dusfresne, Gerace, & Mestre, 1987). A profile sheet was constructed for each of the students as a means of measuring individual progress through the semester.

Observation of target classes was carried out twice within every two-week period. As a follow-up to both evaluation of problem solving and observation of classes, six students were chosen from each of the target classes, two each from the lower, middle, and upper level of achievement in the Force Concept Inventory pre-test. All collected in-class assignments and homework from these students were copied and collected for later analysis. Nine of these students had periodic interviews with the evaluator, eight of them having five, and one having four, problem-solving interviews during the course of the semester.

In order to assess the instructors' view of the C.U.P.L.E. Studio program, the investigator conducted audiotaped interviews with both instructors of the Physics I Studio course, and also with the instructor in the Physics Studio II course during the first week in December. These were transcribed for consideration. A number of less formal conversations were conducted with associate professors and teaching assistants in the Studio I course during the course of the semester.

In addition to the instructor interviews, and during the same week, the investigator conducted 16 telephone interviews with Physics II students. Of these 16, six had participated in both Studio Physics I and Studio Physics II; five had participated in the more traditional Physics I course, and then enrolled in Studio Physics II, though, of these, one had to leave the class because of a scheduling difficulty in his major program; five students had been part of Studio Physics I, but had then enrolled in the more traditional Physics II course. These interviews were brief and were not taped, but were recorded in paraphrase for the principally affective information they could yield.

RESULTS

Limitations of the Study

In response to the strong positive results of an initial pilot program conducted in the spring semester before the current study as well as to economic constraints, the physics department of Rensselaer Polytechnic Institute chose to implement the C.U.P.L.E. Studio Physics Course with all enrolled first semester physics students during the fall semester of 1994. This decision eliminated any concurrent local control group. The researcher offset this difficulty, to the extent possible, by use of national databases of results for the objective testing instruments, the availability of local comparison groups from earlier years for study of class materials, and the use of a broad spectrum of objective and subjective instruments.

In evaluating the data obtained, the researcher found that cognitive outcomes for students participating in the four-hour studio were equivalent to those of students in a six hour traditional course. Affective response was mixed, but predominantly positive. While not negative, the outcome was disappointing for the designers.

Summary of Outcomes

Use of the Force Concept Inventory as a pre-instructional and post-instructional measure of students' beliefs about the concepts of classical mechanics showed that, in general, the gains of the students in the current course were equivalent to gains made by students in a good traditional course. Students showed improvement over the semester, but not so great an improvement as designers and instructors sought. While allowance can be made for the fact that students in the studio course had only four contact hours per week in contrast to the average six hours in traditional courses, the outcome is still less than its designers hoped for. Student achievement in the post-instructional administration of the Motion and Force Conceptual Evaluation showed that, while students did make gains, especially in understanding kinematics concepts and Newton's First and Second Laws, these gains were less than those recorded by the students using the microcomputer-based laboratories at Tufts University.

Students showed little gain either in problem-solving skills, or in the quality of their explanations. The lack of improvement in explanation skills may explain much about students' achievement in the two objective instruments, since there is little evidence that their cognitive processing of the concepts has changed significantly beyond that of more traditional programs.

Quantitative Instruments

The investigator administered the Force Concept Inventory before instruction began in the C.U.P.L.E. Studio Physics I course, and again after students had met all mechanics topics. The results of that testing, and a comparison of outcomes to those of other programs follows. Results for all students who completed both pre-instructional and post-instructional testing were examined on two levels: first, overall score on the test was considered and compared to other institutions.

Before instruction, students in the C.U.P.L.E. Studio Physics I answered a mean of 51.6% of the Inventory items correctly, with a standard deviation of 18.9%. It is interesting to note that 97% of the students included in tabulations had studied physics in high school, so that what was considered a pre-test for the purposes of this course followed at least one full year of physics instruction. The mean post-instruction score was 62.2% with a standard deviation of 19.2%.

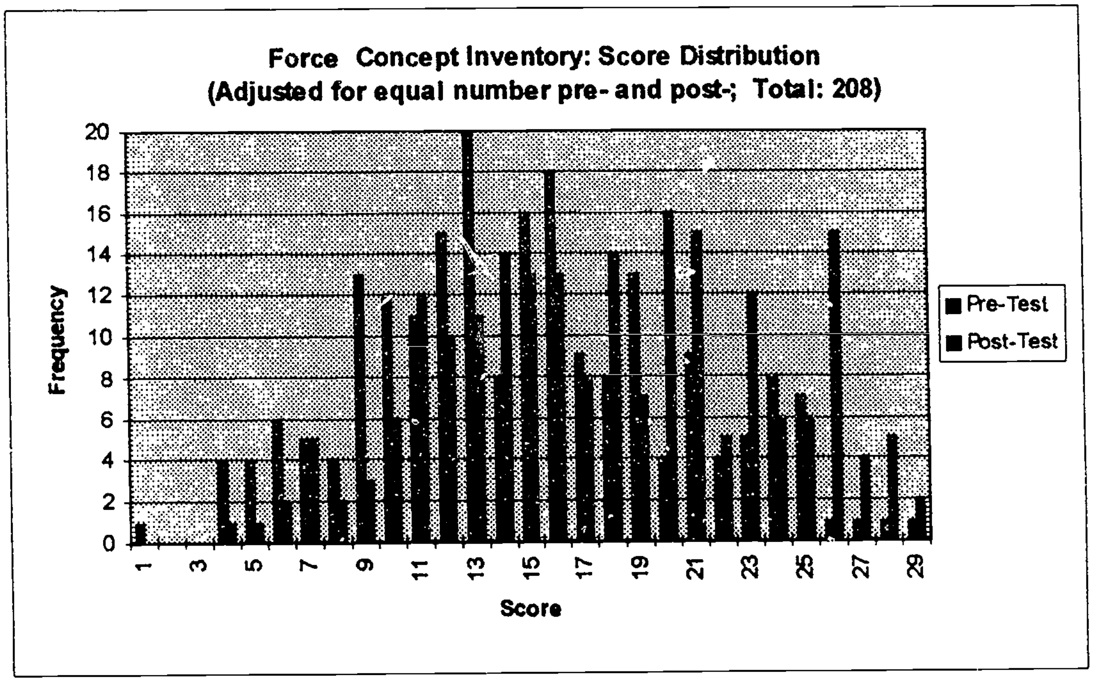

Figure 3: Students' Pre-Instructional and Post-Instructional Score Distribution in the Force Concept Inventory
The graph above demonstrates a shift to the higher end of the score range, and a drop in the number of students scoring below 50%. While the absence of a local control group would seem to limit the usefulness of such data, an available database does help give some insight into the meaning of the outcomes.

Richard Hake (1994) of Indiana University has compiled FCI results from both high school and college programs across the country. As one way of comparing the relative effectiveness of instructional programs, Hake graphs the percentage gain (percentage post-score - percentage pre-score) for a great number of introductory physics programs. The results for the C.U.P.L.E. Studio Physics course for fall, 1994, with a mean gain per student 10.6% and a pre-instruction score of 51.6%, fall in the same area several longer traditional, Calculus-based courses, above the threshold of Newtonian thinking, but below what Hake and his colleagues consider true interactivity.

Students demonstrated strongest gains in their discrimination among position, velocity, and acceleration, and in their understanding of Newton's First Law. Strong misconceptions remained relative to Newton's Third Law, a difficult concept for physics students generally. Fewer than 60% of the students correctly responded to three of the four questions in the category. This continuing difficulty with Newton's Third Law was evident in the outcomes of the Motion and Force Conceptual Evaluation as well.

Motion and Force Conceptual Evaluation. Microcomputer-based laboratory investigations are an essential element of the C.U.P.L.E. learning environment and, subsequently, of the C.U.P.L.E. Studio Physics Course. The computer interfaces, digital video, and spreadsheet tools that are part of this program make it possible for students to analyze and display data using differentiation and integration as needed. It was expected that the proximity in both time and space between real phenomena and their graphical representations would help students to form a stronger conceptual understanding of those phenomena.

The Motion and Force Conceptual Evaluation (Thornton, 1989; Thornton & Sokoloff, 1990) is an instrument designed to measure growth in competence in the interpretation of graphical representation of the concepts found in the introductory mechanics course. This test was administered to all the students enrolled in the C.U.P.L.E. Studio Physics I course on the first day of class, and again after all mechanics topics had been completed. It was hoped that the administration of this instrument would add to the Force Concept Inventory's documentation of students' understandings of physics concepts, as well as give some view of students' growth in the interpretation and construction of graphical representations of these concepts.

Data on both pre-test and post-test administration of the Motion and Force Conceptual Evaluation (Thornton, 1989; Thornton & Sokoloff, 1990) was recorded for all students who were able to take both tests, though only data for non-engineering students was fully analyzed as part of the study. As is true with the Force Concept Inventory, the Motion and Force Conceptual Evaluation, at least to some extent, measures the students' belief systems. Analysis of test scores showed advances in belief systems, but a number of students retained naive understandings.

While students improved on their own scores, they did not show the dramatic improvement recorded by some programs, most notably the full use of Tools for Scientific Thinking at Tufts University by Thornton in the late 1980's.

The microcomputer-based labs are a single component of the C.U.P.L.E. Studio Physics course, and the course does not use all of the same instructional materials as the Tufts group, but the labs are used consistently in a collaborative environment, with the presence of professors and teaching assistants as consultants and as mentors engaging students in Socratic dialogue. The key difference between instructional patterns of two groups is that whole-group discussion as a follow-up to activity diminished, and then was almost entirely eliminated from the studio group as the pressures of extensive content within a shorter time frame becaame more urgent. That decrease in discussion, and its possible impact on learning outcomes, will be discussed in the final section of this paper.

Problem Sets. In the effort to understand the day-to-day cognitive effects of the C U.P.L.E. Studio Physics Course, and to document student progress along the continuum from novice to expert, the investigator examined students' problem-solving and explanation skills at regular intervals throughout the semester. Students were asked to solve and explain a single problem at each instance for evaluation by the researcher. They complied with this request in each of eight consecutive weeks, beginning with the second week. An additional episode occurred after a lapse of 3 weeks necessitated by holidays and the pressure of students' schedules. Problems were based on those from the students' own textbook, or from an auxiliary text (Jones & Childers, 1990; Resnick, Halliday, & Krane, 1992), and were structured, to a limited degree, on the pattern of information-rich problems developed by Heller, Keith, and Anderson (1992a) at the University of Minnesota.

Each of the weekly problems distributed to the students resulted in the collection of three types of information:

1) Students' written solutions of problems enabled the investigator to document any change in six aspects of problem-solving skill, considered characteristic of expert solvers: effectiveness of diagram, representation of information, logical flow, match of equations to situation, appropriateness of mathematics, and consistency of units. Evaluative characteristics were compiled after consideration of the work of Chi, Feltovich, and Glaser (1981), Chi, Glaser,

and Rees (1983), and Heller, Keith, and Anderson (1992). Additional guidance for this process, and for the development of an evaluative scale for student explanations, came from the SOLO taxonomy (Biggs & Collis, 1982).

2) Student explanations of each problem were expected to lend further insight into the cognitive advancement of the students, since explanation skills typically lag solution skills (Vygotsky, 1962).

3) Finally, with each of the first eight problems, students were asked to note any aspect of the Studio class which they had found particularly helpful, or particularly difficult during the previous week. With the ninth problem, they were asked several additional questions concerning their preference for a studio course or a more traditional course, and the strengths and weaknesses that they felt were characteristic of the studio course as they had experienced it.

Heller, Keith, and Anderson (1992a) documented that group solutionswithin a structured environment, and with explicit instruction in solution technique, are consistently more advanced than those of the best individual problem solver within the group, and that the gain in skill transferred well to individually solved test problems. Group work within the C.U.P.L.E. Physics Studio course is less formal and not so highly structured as that in the Heller investigation, but collaborative problem solving is, nonetheless, a major component of the program. It was expected that this component, reinforced by the ongoing availability of instructors and teaching assistants for consultation within problem-solving sessions, would promote a growth in problem-solving and explanation skills. Students did demsonstrate an increase in the effectiveness of their diagrams and in the mathematical representation of physical situations, but other characteristics remained essentially unchanged. Overall, a substantial subset of students retained ineffective problem-solving strategies throughout the semester, drawing incomplete or ineffective diagrams, and attempting to match textbook equations to all the information given in the problems. This last point will be revisited in the discussion of student interviews.

Explanations. A typical problem solution is limited to its mathematical expression, so that it is difficult to gain genuine insight into students' cognitive processes from solutions alone. With each problem-solving exercise, therefore, students were asked to explain their solutions as though explaining them to a student having difficulty in the class. Since explanation skills typically lag solution skills, it was hoped that student responses would extend and deepen insight into the transition from novice to expert.

The criteria for grading explanations was developed in agreement with characteristics of experts as indicated in Chi et al. (1981), Chi, Glaser, and Rees (1983), and in the description of the SOLO Taxonomy given in Biggs and Collis (1982). As with the problem solutions, graders gave students no feedback so that no additional intervention would be implemented.

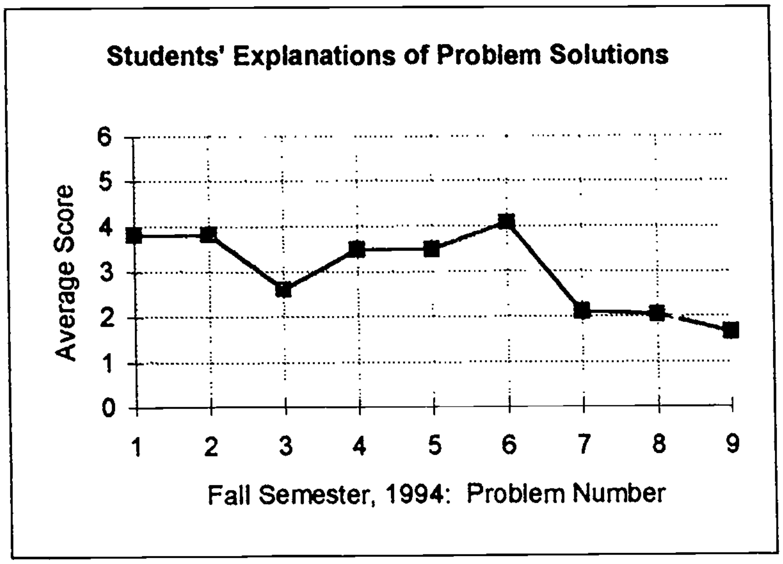

Figure 18: Quality of Explanations in Problem-solving Exercises.

Although student explanations of problem solutions and whole class discussions of laboratory investigations and group problem solving, originally part of the design of the studio course, were essentially absent from this semester's implementation, it was hoped that the dyadic collaboration and small group discussions which remained would provide an improvement in explanation skills. The data shows little evidence of this. Students who scored well in solution frequently gave minimal or no explanation. Statements of procedural steps in calculation were frequently used instead of true explanation of reasoning. Students tended to describe the geometry of a given problem as a justification for a choice of equations. The development, and even the writing, of a good explanation is more time-consuming than a straightforward problem solution, and explanations submitted by students may have been casualties of time constraints. This data, then, is open to question, but its consistency with other outcomes lends it support.

Student Interviews. As an additional source of data on students' cognitive growth and affective perceptions throughout the semester, the investigator selected nine students, three each from the lower level, middle level, and upper score level of the pre-instructional administration of the Force Concept Inventory (Hestenes et al., 1992), to participate in problem solving interviews. The students were chosen by score alone, and they were unknown to the investigator before the choice was made. All but one of the students had studied at least one year of physics in high school.

Each interview consisted of a problem-solving session in which the students was requested to read a problem and predict how he or she would solve the problem. The student was then given time to solve the problem, and was asked to explain the solution, how it differed from their original plan, and why they had made the changes. This allowed for the observation of metacognitive skills as well as explanation and solution skills. In addition, a series of questions was asked in an effort to record affective data concerning student background, the progress of the class, attitudes toward physics, and perceptions of physics as a science. Interviews were audiotaped and later transcribed.

In general, the interviewed students seemed to progress within their skill groups. The three less skilled students continued to work from surface features of the problems, and to seek formulas that would process all the information given. Though all of these less skilled students used diagrams as the semester continued, the diagrams were not necessarily complete or very helpful. Only one of the three developed better self-monitoring skills. She became more aware of her mistakes while her work was in progress, but was not more able to correct them. All three continued to use description of procedure as a substitute for true explanation. Each of the three said that they used the example problems in the book for study at least some of the time, but for all three, this use was a matter of reading and rereading rather than of solving independently or employing self-explanation, both expert characteristics. Though each of the students in this group ultimately earned either a B or a C in the course, the post-instruction administration of the Force Concept Inventory indicated that they remained pre-Newtonian in their thinking, each scoring below 50% on the instrument. Explanation of this may lie in the failure to develop metacognitive and self-direction techniques. Without dissatisfaction with a current state of thinking, no real change can occur.

Those students whose pre-instruction test scores were in the middle range were generally more successful problem solvers. Though they still tended to work backwards from desired solution to necessary equations, they also worked increasingly from basic principles and showed the ability to derive equations when needed. Explanations were a mixture of basic concepts and procedural descriptions, leaning more toward the fundamental underlying concepts in later interviews. All three knew when they were working in an unprofitable direction, and they were able to change strategies more easily. All three expressed the belief that the logical structure and essential interconnectedness of mechanics concepts makes derivation of forgotten equations possible.

There is a point that must be considered here. While these students showed an improvement in their explanations, they also had the opportunity to explain at least five times during the progress of the course. Except for clarifications between partners in dyads, the opportunity to construct and present full explanations did not exist within the whole class. Even without feedback, the expectation of giving an explanation in the problem sessions could have led students to a different mode of thinking.

Those students whose pre-instructional scores in the Force Concept Inventory were in the top third of possible scores solved problems effectively from the beginning. Their metacognitive skills were good, and they had a consistently good perception of the plausibility of results. All three derived equations as needed and tended to work from basic principles. Two of the three consistently used diagrams, and occasionally re-drew those diagrams as they shifted direction during the process. Both of these students regularly worked through examples in the text as a study aid. All three students generally based their explanations on fundamental concepts, though they occasionally reverted to procedural descriptions.

Observations

Two major considerations of the current study were the conformity of the studio course as implemented to the original plan for implementation and the sensitivity of the course to differences in teaching style. Classroom observations afforded some insight into these considerations. Since each part of the studio, as well as the coordination of the whole, was planned in conjunction with research in cognitive science, it could be expected that serious alteration of the format would adversely influence outcomes. While the program must be flexible and open to emerging needs if it is to meet its goal of responding to the varied backgrounds and learning styles of the students, the essential framework must be stable.

The investigator observed one target class for each of the 2 professors twice in every two-week period. Observations were not video- or audio-taped, but a written record was maintained of the time distribution of instructional components, the type and level of interactivity, and the apparent response of students to the process. It was expected that these observations, coupled with instructor interviews and a study of students' cognitive products, would give insight into the sensitivity of the program to individual teacher's styles and philosophies of learning. This section provides a summary of the observations.

Implementation of the C.U.P.L.E. Studio Physics Course requires a willingness to shift the focus of both responsibility and attention from the instructor to the students. This does not diminish the role of the instructor in any way. Rather he or she has greater responsibility for an awareness of the progress of the students than is possible in most lecture formats. The careful coordination of topics and activities for optimum benefit and smooth transitions demands both skill and effort. The two primary professors during the semester of the study had very different teaching styles, but coordinated their activities very carefully, so that the structural differences between the sections was minimal.

Among the various elements of the studio course as planned, two which never really emerged in practice were the student presentation of materials, and the whole group discussion. Homework solutions were presented, from the beginning and in both classes, by a professor or teaching assistant. While responses were elicited from the students, the students themselves never presented, and discussion was generally limited to responses by students and summaries or corrections by instructors. Two instructors made the point of asking for justifications of responses, and the reasoning which provided the structure for solutions. 'What if?' questions were not unusual. Students were reminded to check for the reasonableness of their answers. This pattern was not universal, however, and in some cases, a simple statement of final answer was accepted as sufficient. All instructors made connections among the homework, previous concepts, and upcoming material. In all cases, the instructor was increasingly the center of the activity, and most students worked at correcting their own work from his presentations. This part of the class, originally designed for a 20-minute segment, lengthened as the semester continued, occupying from 25 to 45 minutes in an average class period. Introduction of new material and review of major concepts also approached the traditional more closely after the opening weeks.

As students encountered more difficulty with the material, professors employed more familiar lecture-based teaching patterns.

As the homework review gradually increased in length through the semester, so to did the principal activity, whether it was a lab investigation or a collaborative problem-solving session. With time constraints caused by this shift, follow-up discussion decreased, and frequently existed only as a summary of results or did not occur at all. Discussion of procedures, outcomes, and interpretations was a continuing part of the interaction between instructors and smaller groups, but the benefits of these discussions were seldom available to the full class, nor were insights of other members of the class available to individuals.

Within the activity periods themselves, students tended to be strongly task oriented. The collection and grading of results may have provided some incentive for this, but discussion within and between dyads frequently evidenced a level of involvement that seemed to stem from genuine interest. The dyads within the classes were not assigned, but voluntary formations.

Questions addressed by student dyads to instructors and teaching assistants ranged from procedural details within the computer environment to clarification of concepts and theoretical questions about conclusions. Most instructors probed student understanding during the activities through the use of a modified Socratic dialogue.

Perceptions of the C.U.P.L.E. Studio Physics Course

Instructors' Perceptions. While observations of their classes led to some understanding of the instructors' approaches to implementing the C.U.P.L.E. Studio physics course, the investigator sought a more specific and detailed picture of their view of the program, with its strengths and weaknesses for both students and instructors, as essential to a clear understanding of the program itself. Of special concern was the effect that instructor's views on the outcomes of the implementation. Throughout the study there was an effort to understand the sensitivity that the program might show in response to implementation by persons of different teaching styles and philosophies of learning and teaching.

When asked to describe the C.U.P.L.E. Studio Physics course, both principle professors responded by describing the integrated and varied nature of a class. They mentioned the inclusion of computer tools and the daily use of labs. One of the two stressed the interactive nature of the course. Both found the interactivity and the integration good, and important to students' learning. Co-lecturers in the class had noted that the opportunity for instructors to deal with students as individuals, to have a truer picture of students' understanding, and to be able to help students change that understanding made the class a much more positive experience for teachers than the standard lectures. The principle professors also found the direct interaction with students a satisfying part of the program for instructors, and the immediate feedback that results from it, a real benefit for the students.

Both professors acknowledged, without solicitation, that the program was not really implemented as fully as intended. Recitation, the solution of homework problems, occupied more of the class time than was expected or desired, and both instructors would decrease the time for that segment of the class. Both indicated that they became gradually more convinced of the need for longer lectures, some time for presenting and stressing the important concepts. This represents a shift in focus from the planned format for the program. One of the professors felt that the format left him feeling less in control and led to a gradual decrease in his energy and enthusiasm. Above all, both professors expressed concern over the lack of time for discussion of the outcomes of activities. The lack of these follow-up discussions deprives the students of an opportunity for really seeing the concepts underlying these activities. Even among the smaller groups of students within the class there is a need for more discussion.

Student Perceptions . Though classroom observations gave some sense of responses to the C.U.P.L.E. Studio Physics Course, a more complete and detailed documentation was sought. To aid in the process, students received two additional questions with each weekly problem-solving exercise: "Was there anything that you found particularly helpful to your understanding in physics class during the past week?" and "Was there anything that you found especially difficult in physics class during the past week?"

Students considered discussion of material very important and helpful throughout the semester. While homework review increased in its share of class time used, its importance diminished in the view of the students. Demonstrations, on the other hand became increasingly important as concepts became more complex. The collaborative nature of group work seemed to be invisible to the students, simply a part of the normal ambiance of the room, though interviewees frequently noted its helpfulness. The same can be said of access to professors and teaching assistants for help when needed. Interviewees valued this aspect of the course highly, but it was seldom mentioned on weekly problem exercises. Students' perceptions of difficult aspects of the class also shifted over time. A number of students said that they found no difficulties. Among those who did say that they found some aspects of the class difficult, the early candidate for most difficult was the solution of homework problems. By the eighth week, this had decreased in importance, and individual concepts or problem solutions were seen as presenting the greatest difficulty. The use of computer tools never presented a major difficulty, and, despite the full coverage of a single topic at each meeting, students did not generally consider the pace of the class a problem.

An exit survey, attached to the final problem-solving exercise, asked students several questions regarding demographic and affective characteristics. The survey asked students whether, given the option, they would choose a studio physics course or a more traditional one, 60% said they would choose studio, while 37% would choose traditional and 3% remained undecided. Students had the opportunity to give free responses to their reasons for choice and these reasons gave more insight than the simple choice itself.

Among those who said they would prefer the studio course, the most common reasons supporting their choices were that:

- the studio format provides the opportunity for more direct interaction of students with instructors, teaching assistants, and other students;
- questions can be asked as they arise, and answered immediately, with the possibility for demonstrations, simulations, or lab investigations readily available as needed;
- integration of activities provides the opportunity to apply concepts immediately and in a variety of contexts;
- the variety of modes of interaction provides for students' different learning styles;
- responsibility for learning is shifted from the instructor to the student; it is impossible to remain passive.

Several of the students' comments are worth quoting: "You know if you can actually do it when you leave the class. Lectures don't help - we already know the professor can do it." "Studio format makes time valuable, so I'm less likely to skip it. Professor actually knows us and our work, and recognizes us out of class, which is a nice change." This comment was from a sophomore, with experience in two years of large lecture courses. Attendance averaged above

90% overall, but work is collected and graded. This is not true of the less well-attended lectures. "In the studio setting it is easier to ask questions and get help." "The class is interesting, interactive, and contains time to learn the lesson, and then participate in lab while it's still fresh in our minds."

Not all students responded so positively. The aspects that some students saw as positive reasons for choosing studio were perceived by other students as reasons for choosing traditional format. Some students felt that classes were too 'jumbled' with the variety of activities.

Student reactions seemed to be colored, at least to some degree, by their own learning styles and study habits. One student who said that instructors "don't run through problems slowly step by step" also said that he spent about 1/2 hour per week studying physics. Another who felt the class was "too long and boring" also spent 1/2 hour per week studying. Some students would wish a greater variety of labs, with less dependence on the digitized video clips, and others would like more work room.

Affective Responses of the Interview Group. Several characteristics were almost universal among the interviewees. Nearly all stated in some way that physics was a way of looking at the world and seeing how things worked. They may have given more thought to their perceptions of physics, and of the class, because of the ongoing interview process, and their responses were always well-thought-out. Though two students felt that the general applicability of physics depended upon what one chose as a career, all saw practical ties between the theory and the everyday world.

Perhaps because the interview process encouraged them to think about the experience, the interviewees did see some aspects of the course that tended to be invisible to the others. All the interviewees found the interaction with peers and instructors in the studio to be profitable. They found that working with partners helped clarify ideas, and that contact with teaching assistants and professors gave an immediate feedback that helped them understand concepts more clearly and deeply. The availability of several points of view helped them, they said, to see ideas more completely and from new directions.

Of the nine students interviewed, seven would choose studio over traditional format. Immediacy and variety of application and interaction with others were the chief reasons given. The one student who had never studied physics before believed that studio format was the reason for her success. The constant accessibility of the views of others convinced her that physics presented difficulties to everyone, but that it was possible to learn the concepts. The availability of teaching assistants in the classroom, and their eagerness to help, encouraged her to seek help outside the class as well, and made her feel comfortable with the process. The variety of demonstrations and activities and applications of each concept within a short time helped her to make the connections she needed in order to understand and remember.

Two of the students would not choose studio. One of them, from the middle range of pre-instructional scores felt uncomfortable with so many authority figures moving around the room while he was working. He had a very good working relationship with his partner, he said, but he felt constantly observed. He found that feeling somewhat unnerving and very distracting. The second of those who would choose studio, one of the students from the lower range of scores, said that she was 'basically a little bit lazy', and would prefer that the professor present all the material in lecture and demonstrations so that she did not have to work so hard to understand the material in the book. Even these two found the collaborative group work and the variety of activities helpful.

DISCUSSION

Reform of undergraduate physics education, and indeed of science education in general, demands the implementation of the principles of cognitive science in the educational environment. The growing response to that demand is resulting in classrooms and laboratories designed and conducted within the cognitive apprenticeship model of constructivist theory. Such learning environments are guided by educators who view themselves as mentors, designing and guiding the experiences of the students to optimize their cognitive impact. New designs employ the ancient tools of Socratic dialogue, often framing these tools within a contemporary computer environment. Laboratory experiences range from those that students can easily manipulate and measure to those that become part of the classroom by way of videos and network links. Collaborative construction of learning with peers helps students to confront and restructure naive beliefs, and explanation and discussion enhances the rehearsal and refinement of new knowledge. All of these elements are linked in a highly structured learning environment. In the current study the researcher documented the implementation of a single prototype of the format, the C.U.P.L.E. Studio Physics Program.

The various data resulting from each method of measurement employed in the study repeated and extended the same outcome: students showed neither loss nor gain cognitively over comparable groups after participating in the course, though affective gains were evident for both teachers and students. Outcomes for the course proved less positive, especially cognitively, for the C.U.P.L.E. Studio than for the individual instructional elements of which it is an integrated whole. Several factors may contribute to this conclusion. These factors will be discussed in this section. The conclusions of the study give rise to a number of implications for further implementation of such a program, and for science programs in general. In this section the implications are discussed and extended into recommendations both for further study and for possible actions.

Each element of the C.U.P.L.E. Studio Physics program has been carefully chosen to respond to recommendations of researchers in cognitive science and its applications to physics education. All of the elements have been thoroughly researched and proven successful in individual settings. Collaborative problem solving and student explanation of homework solutions are designed to deepen students' understanding of both physics concepts and effective problem-solving strategies. Microcomputer-based laboratory investigations (MBL's) and their accompanying spreadsheet analysis tools have been shown to aid students in making the connection between physical phenomena and their graphical representations. Firmly establishing the MBL's within a collaborative context, and in conjunction with Socratic dialogue with instructors and assistants, makes possible the engagement and adaptation of students' misconceptions or naive conceptions. The whole is carefully integrated so that each concept is encountered in a variety of contexts and approached with a variety of tools, thus allowing for different student preparations and learning styles. All of this leads one to question why the outcomes should be as they are, what the outcomes imply about the program, and what they have to say about the design of innovative programs.

Some Possible Reasons for Outcomes

Time Constraints. In instituting the C.U.P.L.E. Studio Physics program, with its variety of integrated instructional tools, the physics department of Rensselaer Polytechnic Institute, in collaboration with the program's designers, consulted the cognitive literature which endorsed the elements and concluded that the program should support a reduction in contact hours without a corresponding loss of cognitive outcome. The Physics I course at RPI is a four-credit-hour course, but the true classroom time had increased over the years to nearly six hours as it has almost universally. It was hoped that effectiveness of the new program would allow for the reduction of time to the credit listing. This would enable savings in two areas. It would represent an increase in cost effectiveness, a serious concern in a time of strong economic constraints, and it would free two additional hours in the pressured schedule of introductory students at the university.

The time constraint thus created may be too strong a limitation. The density of material dictates that each class session consider a new topic. The pressure of completing work in the allotted time may result in the abandonment of the cognitive tools that allow for the most efficient and effective use of time.

Cognitive Issues. Two casualties of the time constraint are believed to have had the greatest influence on student outcomes: whole group discussion of laboratory activities and student presentation of problem solutions and explanations. Whole group discussions were a vital component in the initial implementations of microcomputer based laboratories (Thornton, 1989; Thornton & Sokoloff, 1990). The discussions were intended to follow the lab experience, giving the students the opportunity to exchange their understandings of the investigations and to reflect on, and integrate, those understandings. Early response to the labs by both teachers and students was strongly positive. A number of teachers, observing students' complete involvement in the labs, and their apparent understanding of the principles underlying them, eliminated the discussions as unnecessary when time was needed for other activities. Without exception, classes that neglected follow-up discussions demonstrated markedly lower results on the corresponding parts of the Motion and Force Conceptual Evaluation than those groups that retained them, despite the appearance of understanding during the activities. Vygotsky (1962) told of the primacy of social interaction in the development of knowledge, and ongoing research has confirmed that importance. Without discussion there may be no challenge to naive beliefs.

Student presentation and explanation of the solutions of homework problem is the second element of the original structure of the C.U.P.L.E. Studio Physics Program that was not a part of the studied implementation. Teachers or teaching assistants presented problem solutions, soliciting contributions from students, and elaborating both on the solution structures and on the student responses. Questions asked of the students varied from simple numerical answers to how and why questions. Instructors presenting the solutions explained clearly and sought to understand and respond to student difficulties. They consistently followed expert problem-solving procedures.

A number of studies have shown, however, that it is student explanations which have the greatest influence in promoting cognitive change. Noreen Webb (1989), in her study of cooperative group learning, demonstrated that giving elaborations is of much greater value to students' learning than is receiving elaborations, no matter how clear the received elaborations may be. This suggests that the clarity and expertise of explanations given by instructors cannot have the same impact on a student's thinking as an explanation that he or she constructs and presents.

When students are asked to explain their problem-solving processes, several things happen. They are forced to stop and think about the significant features of the problem (Berardi-Coletta, Dominowski, Buyer, & Rellinger, 1995; Berry & Broadbent, 1984). This awareness of the salient features of the problem is essential to the transfer of problem-solving skill from a single problem to others of its type (Stein, Way, Benningfield, & Hedgecough, 1986). In the effort to explain the procedure that he or she has followed, and the reason for the various steps of that procedure, there is a triggering of metacognitive awareness: the student must think about his or her own thinking (Berardi-Coletta et al., 1995). Berardi-Coletta et al. have presented strong evidence that it is this metacognitive triggering that results in enhanced skill and increased efficiency (Berardi-Coletta et al., 1995); Dominowski, 1990). The explanation of reasoning is essential to the process. A simple description of procedural steps, without the demand for an explanation of reasoning, fails to produce lasting change, because it involves only that information currently in working memory (Ericcson & Simon, 1984).

Berardi-Coletta and colleagues demonstrated that self-explanation of reasoning for procedure is not a spontaneous process, but that, when it does occur, it prompts a shift in focus and a rehearsal of learning that facilitates enhanced knowledge, increased procedural skill, and greater transfer. The process also encourages development in self-monitoring skills, helping students to become more aware of their errors in thinking as they occur. Yet the process of explanation, demanding focus, as it does, on the problem and procedure, it may block negative self-criticism. This may help minimize the frustration experienced by many introductory physics students.

What implications does this hold for the C.U.P.L.E. Studio Physics Course? Sheila Tobias (1992) reminds the physics education community that the support of peers is as important to the success of an innovation as is the design of the innovation itself. If such elements as whole group discussion of laboratory investigations and student presentation and criticism of problem solutions are essential elements to successful outcomes for the students, the faculty implementing the course must be convinced of the value of these elements.

Earlier in the present paper, the program under study was described as embracing the cognitive apprenticeship model of situated cognition. Faithfulness to this model suggests the need for instructors to initiate students to the presentation and criticism skills that are so much a part of their work as practicing physicists and as educators. Berardi-Coletta and colleagues (1995) documented the fact that students do not explain spontaneously, nor do they employ good metacognitive skills without guidance. The explicit modeling of explanation and criticism skills and the opportunity to rehearse those skills seem indispensable to such an endeavor. Effective problem-solving and explanation skills modeled by instructors do not become part of the students' cognitive structure until they do have the opportunity to use and refine those skills.

Implications for Science Education

All of this indicates that something very simple underlies the most elaborate innovations. Students need guidance and rehearsal in explanation and discussion. In using these two skills students confront naive or incorrect understandings, adjust their cognitive frameworks for the assimilation of truer and more robust knowledge, and develop self-monitoring and metacognitive skills. Without these elements the benefits of the most advanced equipment and environments can be greatly diminished.

The success of any innovation demands the support of teaching faculty. Teaching faculty, in turn needs the support of cognitive science. The preservice preparation of science teachers needs to be directed as much to how students learn as it is to what they learn. The implementation of such innovative programs as the C.U.P.L.E. Studio Physics course represents a radical departure from traditional formats, demanding of the teacher a fundamental shift in his/her understanding of his/her role in the teaching-learning process. Such a shift cannot be automatic or instantaneous. Some arrangement must be made for the introduction of faculty to the essential design of the course and the cognitive science which underlies that design before teaching duties within the environment are undertaken. The course represents a carefully reasoned departure from the traditional format, each element of which responds to extensive studies in the science of human learning. Physics faculty members who are outstanding both in their professional research and in their reputations as traditional instructors have generally reached their level of expertise by strongly disciplined and highly focused attention to their fields. This, coupled with the continuing demands of research, leaves little time available for study in the cognitive sciences. Without a strong reason for embracing new forms of instruction, instructors will tend to revert to more comfortable and familiar patterns, especially when students seem to be encountering difficulty. Cuban noted this as a recurring pattern in classrooms at all levels (Cuban, 1987).

Modifications made during the implementation of the C.U.P.L.E. Studio Physics Course changed the course fundamentally from its original design. The researcher cautions, therefore, that the present study not be considered as a full criticism of the C.U.P.L.E. Studio. The researcher strongly recommends that a similar study be conducted during a full implementation of the course as designed for a truer understanding of the effects of the course.

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