Michigan State University

National Superconducting Cyclotron Laboratory

CONCEPTUAL QUESTIONS IN COMPUTER-ASSISTED ASSIGNMENTS

E. KASHY

MSUCL-947

AUGUST 1994

Submitted for publication to the American Journal of Physics, 8/25/94, Revised 12/22/94 MSUCL-947

Conceptual Questions in Computer-Assisted Assignments[1]

E. Kashy, S.J. Gaff, N.H. Pawley, W.L. Stretch and S.L. Wolfe
Department of Physics and Astronomy, and
National Superconducting Cyclotron Laboratory

D. J. Morrissey,
Department of Chemistry, and
National Superconducting Cyclotron Laboratory

Y. Tsai
Department of Computer Science
Michigan State University, East Lansing, MI 48824

ABSTRACT

The Computer-Assisted Personalized Assignment system, CAPA, has been used to prepare and present conceptual, qualitative questions to students in large introductory classes. The questions appear to be effective in helping students to grasp concepts, as they stimulate dialogue and discussion among the students while they are seeking correct solutions, and provide the instructor with feedback on difficulties students encounter with certain concepts. No formal evaluation of the effectiveness of these questions has been made. Many conceptual, qualitative questions for introductory physics have been written with this system and used in assignments. Several examples are given and briefly discussed.

I. INTRODUCTION

The importance of understanding scientific concepts is well recognized by teachers as well as authors of introductory science texts. Essentially all such texts now include qualitative questions to stimulate discussion and address misconceptions. A goal of such questions is to help students appreciate the concepts underlying mathematical solutions. Qualitative questions complement quantitative problems, and encountering both in a course is essential to learn physics. In classes with large numbers of students, detailed discussions of physical concepts can occur in small recitation sections. However many students come to these smaller sections unprepared and mostly ask for the solutions to assigned numerical problems, thereby taking up most of the time available.

[1]Supported in part by the National Science Foundation

It is generally recognized that teachers should build on information which students bring to the classroom. [1, 2, 3, 4, 5, 6] This prior information includes a broad spectrum of facts and observations, as well as many misconceptions about their origins or explanations. Identifying, addressing and providing appropriate scientific explanations of misconceptions is part of the instructor's task. Lecture demonstrations of phenomena are useful, but when used alone, have been shown to be generally ineffective.[1, 2, 4, 5, 7] Questions which attempt to qualitatively (or sometimes quantitatively) address misconceptions can be used to complement lecture demonstrations. These questions may require students to identify multiple factors which characterize particular physical situations and can also be based directly upon the students' understanding of the demonstrations they have observed. By confronting them with contradictions, the questions can lead students to resolve their misconceptions on their own. [1, 2, 3, 5, 8]

The computer-assisted personalized assignment system, *CAPA*, recently developed at Michigan State University (MSU) is the tool used for coding and distributing the questions to students, and for providing instructors with on-line student performance data.[9] *CAPA* has been used in many classes of physics, chemistry, calculus and biochemistry. [9, 10, 11, 12] To insure that students carefully read and consider their particular questions, to encourage discussion of the concepts in a problem rather than the answers, and to minimize direct copying, the order of statements within a problem is randomized and the wording of each statement can be varied. Each question has addressed the same concepts for all students in a class.

The task of preparing such questions is facilitated by pre-coded examples in which the instructor substitutes the science content. However, problem development time can be considerable, and several revisions are usually required to meet the critical comments of colleagues as they consider their answer to a problem. Their comments provide feedback to identify ambiguities and insure the correctness of the science involved. It is hoped that instructors will be willing to share their teaching experiences by contributing to a library of coded problems, and that communication among instructors within and across disciplines will occur more frequently.[6]

II. Description, Sample Questions and Discussion

A typical weekly assignment has included twelve to sixteen numerical problems and one or two conceptual or qualitative questions of the type presented below. The questions selected for discussion here are representative of those which have been used. The answers are given after the references. However, readers are encouraged to pretend they are students and to try the problems before referring to the keys (Suggestions for modifications from readers are welcome).

Pre-coded examples are available for the following problem types:

1. Select all the correct statements from a list.
2. Indicate the appropriate choices for a set of statements: T-True, F-False, G-Greater than, L-Less than, E-Equal to.
3. Enter the appropriate information for each statement. It may be either selected from a list or may have to be generated by students.

The system requires the appropriate choice or selection for every statement before a 'Correct' is acknowledged and credit recorded. This forces a detailed review of all statements in a problem when the computer response was 'Incorrect'. In the latter case, and at the discretion of the instructor, a hint appropriate to the course level is provided to help with anticipated difficulties in the problem. Many students have commented on the usefulness of the hints. Hints are not coded to respond to the specific error made by a student; students must discover their own errors. The questions aim to move students away from step-by-step calculational details towards conceptual strategies which can then be used when solving quantitative problems.[2, 4, 5]

No penalty is assessed for numerous attempts, and full credit is given for correct answers entered before the assignment deadline. This avoids the frustration and stress that could be generated if a penalty were assessed due to an error in typing even though the correct solution had been obtained or due to the fact that with so many choices it is easy to get an incorrect answer. Combined with on-line feedback and hints, it also permits more challenging questions. In addition, it provides less well-prepared students with the opportunity to succeed through focused and repeated effort.

The examples chosen below are in the format we have been using to present the personalized assignments to students, and illustrate some of the capabilities of the tool. The qualitative or conceptual physics aspects involved in each problem should become apparent from reading the statements and will be briefly discussed in a few cases. The hint associated with each problem is shown. It can be easily modified or expanded by the instructor when the degree of difficulty students are encountering with the problem is found, on-line, to be too large.

Problem 1 addresses the important concepts of vectors and scalars, emphasizing the importance of language in science, i.e., speed vs velocity. Variations are small but add some interest: sphere/cube, pint/quart/gallon. Also, the rocket, train, and runner are each used alternately with speed, velocity and acceleration.

---

1. Identify as vector (V) or scalar (S) each of the following (Example: If 'A' is a vector and 'BCDEF' are scalars, then enter VSSSSS as the answer).

A) Mass of a quart of milk.
B) Force of gravity.
C) Velocity of a rocket.
D) Volume of a cube.
E) Acceleration of a train.
F) Speed of a runner.

Problem 1.

The hint a student may call for on his/her computer terminal is:

```
A vector represents a quantity characterized by both a direction and
a magnitude. 'Speed' is conventionally used to describe the magnitude
of the velocity.
```

In problem 2, the topic is the dimensionality of physical quantities.

---

2. X and Y are physical quantities which have different dimensions. Select ALL the operations below which might be physically meaningful. (e.g. A, BC, ABDF, ...)

A) $X + Y$ or $X - Y$
B) $X^2 + Y^2$
C) $e^{X/Y}$ or e^{X+Y}
D) $\frac{X}{Y}$ or $X \cdot Y$
E) $X^{1/3}$ or $Y^{1/3}$
F) X^2 or Y^2

Problem 2.

Note that some operations share the same statement: Addition and subtraction, multiplication and division. The intent was to emphasize that they are essentially the same operations or have something in common. The hint is:

```
The exponent of 'e', the base of the natural log, should be dimensionless.
```

Problem 3 was written after viewing the film "Private Universe". [13] That film is often shown in educational circles to indicate the broad level of scientific misconceptions among both students and highly educated segments of the population about very basic scientific knowledge. In the case of the four seasons we experience each year, the primary misconception is that they are the result of the variation of distance from the earth to the sun.

---

3. Seasons on Earth: Identify all the correct statements (i.e., A, CD, ADFG,..).

A) The longer path of sunlight through air explains why winters are colder than summers.
B) The variation of the earth's distance from the sun causes the seasons in the northern hemisphere.
C) More than 99 percent of the energy heating the earth surface comes from the sun.
D) The tilt of the axis of rotation with respect to the earth's orbital plane causes the seasons.
E) Clouds in the sky make winters colder than summers.
F) When it is summer in Argentina, it is also summer in England.
G) The earth is nearer the sun in December than in June.

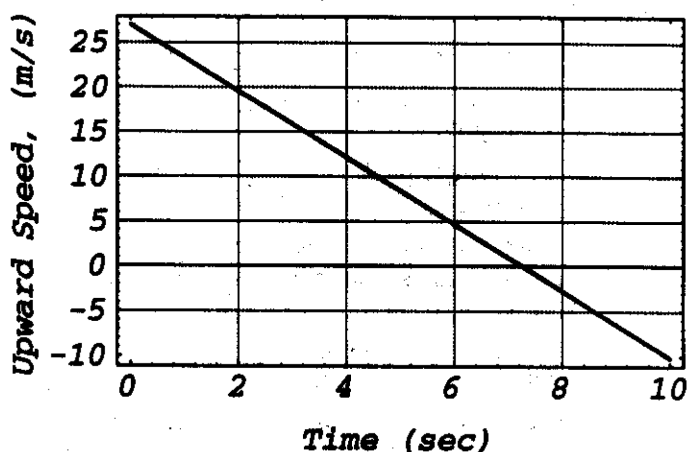
Problem 3.

The statements in problem 3 were chosen to address misconceptions and bring up well known facts that contradict the misconceptions.[2, 3] It is not easy to identify physical situations that are essentially understood, but for the wrong reasons. A question dealing with facts is relatively simple, but including reasons for the facts in the question is more challenging. The wording is critical, and it may take some effort to minimize ambiguities.

Problem 4 requires reading and interpreting a simple graph, and includes some basic qualitative questions about kinematics.

---

4. The figure shows the upward speed of a ball thrown upwards with an initial velocity of 27.0 m/s from the surface of Mars. Select ALL the correct answers (A, BD, ABDE, etc.).



A) Maximum height is reached at about t=7.3s.
B) The acceleration is constant.
C) The ball's KE increases during the first second.
D) The ball's PE is a constant.
E) v and g are in the same direction after t= 7.3s.
F) The acceleration is 0 near t= 7.3s.

Problem 4.

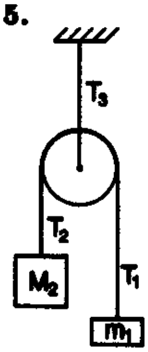
The two statements concerning the acceleration, i.e., statements B and F in the version shown in problem 4, are especially difficult for some students. The hint just states that:

`'The acceleration due to gravity is the rate of change of velocity.'`

The graph shown in problem 4 is one of seven used for this problem. The other versions have graphs appropriate to other planets. The assignment in which problem 4 was used included a related question in which the acceleration due to gravity was evaluated based on the graph.

Understanding how Newton's second law of motion can be applied in a qualitative way is the goal of problem 5. It deals with forces and motion in an Atwood machine with a massless pulley and no friction.

5.



A frictionless pulley with zero mass is attached to the ceiling, in a gravity field of 9.8 m/s^2. Mass M_2 is greater than mass m_1. The quantities T_n and g are magnitudes. Give the appropriate letter for each statement: T-true, F-false, G-greater than, L-less than, E-equal to (If for the first two, it is 'G' and the last four 'L' then enter GGLLLL).

A) T_1 *is* ... T_2.
B) The magnitude of the acceleration of M_2 is ... the magnitude of the acceleration of m_1.
C) T_1 is ... $m_1 g$.
D) The center-of-mass does not accelerate.
E) T_3 is ... $m_1 g + M_2 g$.
F) T_3 *is* ... $T_1 + T_2$.

Problem 5.

Experience with problem 5, shows that it requires both careful reading and clear thinking. It has been given to numerous undergraduate students, graduate students and to several colleagues both in research and teaching. It is remarkable how often it is missed on the initial attempt. Upon getting an 'incorrect' from the computer, the reaction is of surprise. A careful rereading of each statement follows, and the error(s) corrected. It is the statement relating T_3 to the force of gravity on the two masses which is most often missed. It is labeled E in the version above. The hint given students is:

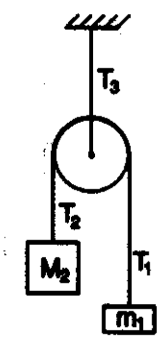
```
This problem deals with Newton's second law F = ma.
Think about acceleration and the net force on 'a body'.
A 'body' can be a set of objects connected by internal forces.
```

Of course, it helps to have discussed with students the fact that all bodies, balls, bats, cars and atoms are sets of objects connected by internal forces.

Problem 6 illustrates a follow up to problem 5. The Atwood machine in problem 6 now has a more realistic form, i.e., a pulley with mass and radius, but there is still no friction.

---

6. A pulley with mass M_p and a radius R_p is attached to the ceiling, in a gravity field of 9.8 m/s^2 and rotates with no friction about its pivot. Mass M_2 is greater than mass m_1. The quantities T_n and g are magnitudes. Select the appropriate symbol for each statement: T F G L or E (If for the first three it is 'L,' and the last three 'G' then enter LLLGGG).



A) The magnitude of the acceleration of M_2 is ... the magnitude of the acceleration of m_1.
B) The center-of-mass accelerates.
C) T_2 is ... M_2g.
D) T_3 is ... $m_1g + M_2g + M_pg$.
E) T_1 *is* ... T_2.
F) T_3 *is* ... $T_1 + T_2$.

Problem 6.

The goal was to focus the discussion on similarities and differences between the two situations. The hint is:

`The pulley has a moment of inertia; to increase its angular velocity, a net torque must act on the pulley.`

Problem 7 is simply a review of basic properties of the motion of a system vibrating in a normal mode.

---

7. A thin string stretched between two solid posts oscillates transversely in a single Normal Mode (Standing wave), (Select ALL correct answers, ie, CD, ABEF,... etc).

A) All the moving parts have the same period.
B) The wavelength depends on the harmonic number.
C) All the moving parts have the same amplitude.
D) The moving parts of the string oscillate exactly in phase or exactly out of phase.
E) The wave velocity depends on the harmonic number of the Normal Mode.
F) Moving parts of the string have differing frequencies.

Problem 7.

Problems 8 and 9 deal with elementary optics. In problem 8, some important aspects of geometrical optics for the 5 basic mirrors and lenses are reviewed.

---

8. Identify as true or false the following statements concerning images formed by a *single optical element* . The element may be a plane mirror, a concave mirror, a convex mirror, a converging lens, or a diverging lens (If the first two are 'true,' and the last four 'false,' then enter TTFFFF).

A) A mirror always creates a real image on the same side as the object.
B) Real images are always larger than objects.
C) Virtual images are always upright (i.e., of the same vertical orientation as the objects).
D) The image by a convex mirror or by a diverging lens is always shorter than the object.
E) A lens creates a virtual image on the side opposite the object.
F) Real images can be upright (i.e., of the same vertical orientation as the object).

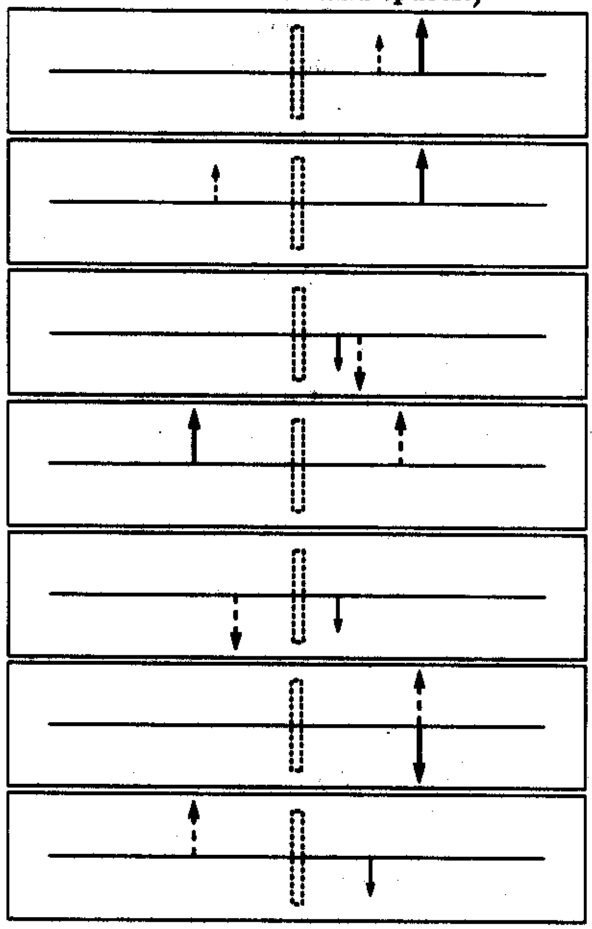
Problem 8.

The hint:

`Remember that 'real' rays traverse lenses, and are reflected by mirrors.`

Problem 9 is intended to be solved after problem 8. It is mostly an application of some basic concepts of geometrical optics previously discussed in problem 8.

9. In the diagrams, the solid arrow represents an object and the dashed arrow its image. The rectangle shows the position of an undetermined ***single optical element***. It may be a plane mirror-PM, a concave mirror-VM, a convex mirror-XM, a converging lens-CL, or a diverging lens-DL. Identify and list the elements from top to bottom. If the top 2 are convex mirrors, the next three converging lenses and the last two plane mirrors, enter: XM,XM,CL,CL,CL,PM,PM (Note: with commas and NO blank spaces.)



Problem 9.

The hint is:

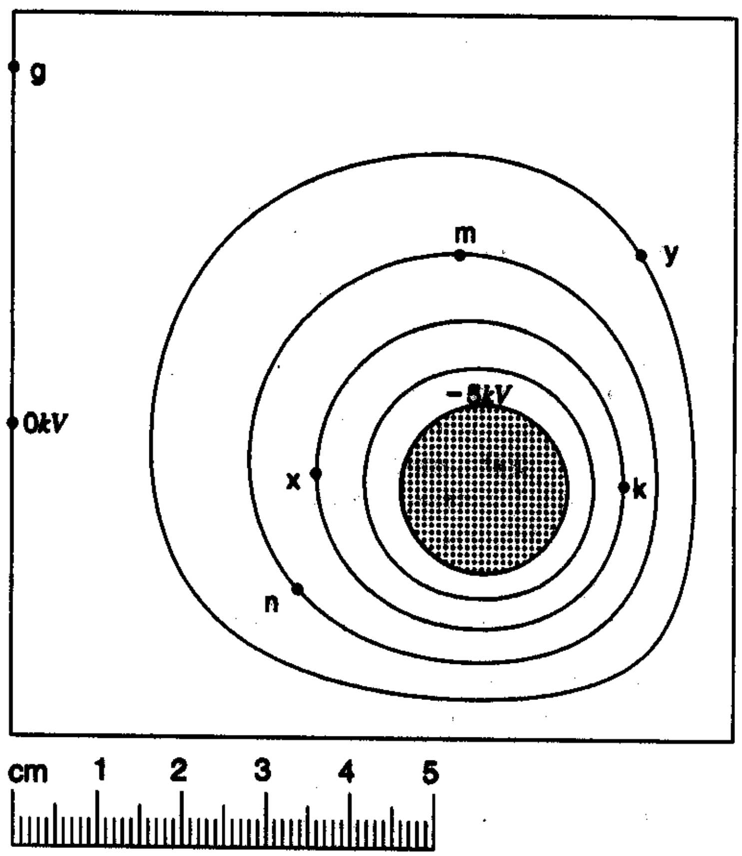
Is it a Lens or a Mirror? For a SINGLE ELEMENT, a Real image (RI) is always inverted, a Virtual image upright. Where is a RI formed by a Lens? It's on the side opposite the object. Since rays cross at a real image, light must go through. Drawing a few key rays helps.

Problem 9 has not been used in a class so far. Therefore, we have no information about how students will respond. Arriving at the solution may be both challenging and time consuming.

The next example, problem 10, is a two dimensional electrostatic configuration, and the statements in the question are for an introductory course.

---

10. The figure shows the equipotential surfaces for a long cylindrical conductor, in a long square metal enclosure.



The enclosure is at ground potential (0 *volts*), and the cylinder is at −5,000 *volts* (−5*kV*). The intermediate voltage contours are 1000 *volts* apart. The labels are on the equipotential contour lines. We have a static situation. Select ALL the correct statements. (e.g. A, BC, ABDF, ...)

A) The electric field E at 'k' points west.
B) The force on a (−) charge at 'm' points north.
C) The E field size at 'm' is larger than at 'k'.
D) The force on a (+) charge at 'x' points north.
E) The electric field E is zero inside the cylinder.
F) The electric field E at 'n' points southwest.

Problem 10.

More challenging statements would include quantitative properties of the surface charge density, of the energy density in the electric field, etc. Note that the size of the scale shown is randomized and used for related quantitative numerical questions not included here. For example, in order to calculate the magnitude of the electric field, each student must use the given scale to measure distances on the figure.

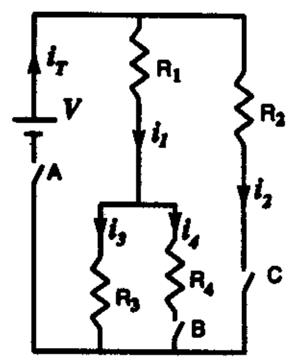
The hint given for problem 10 when used in a class for non-science majors was:

```
Recall that the electric field points in the direction
in which the electric potential decreases most rapidly.
```

Problem 11 shows the final example, a DC circuit in which there is an ideal source of Emf, i.e., a battery with negligible internal resistance.

---

11. The circuit in the diagram starts with all switches in their closed positions, so current will flow to all parts of the circuit. The source of Emf is assumed to be an ideal battery, with no internal resistance, as shown. For each of the following statements fill in the blank with I-increase, D-decrease, or S-stay the same.



(If the first and last answers are increase and the middle three are stay the same, enter ISSSI)

A) When switch B is opened, i_1 will ....
B) When switch B is opened, i_3 will ....
C) When switch B is opened, i_2 will ....
D) When switch C is opened, i_3 will ....
E) When switch C is opened, i_T will ....

Problem 11.

The hint is:

```
Use Ohm's law. To predict if a current will increase or decrease,
consider what opening a switch does to the potential at EACH end
of the resistor.
```

In a complementary version of the problem not included here, the circuit is changed by adding a resistor in series with the battery. The statements involved are also somewhat different.

As indicated earlier, the order of the individual statements in one problem are varied. By rewording a particular statement, or changing the value of the variables within a statement, the multiplicity of versions generated is increased significantly. The multiplicity can also be increased by including alternate versions of figures. For example, in problem 11 the branch with R_1 can be interchanged with the branch with R_2 in the circuit, leaving the order in which the switches are labeled unchanged. As the multiplicity is increased, writing the problems, even with the pre-coded examples discussed earlier, becomes more challenging.

When a student is certain of all but one or two answers, the computer can be used to discover the remaining correct selections. However, the numerous possible combinations usually make complete guessing an unproductive strategy. Students are encouraged to discuss their assignments. The communication of appropriate answers to statements is an additional learning experience. It must be done by content, since for example 'I entered ABF in *CAPA* and got it right' is of no help. Vigorous discussions among collaborating students is commonly observed, indicating the presence of a good educational environment. [7, 14]

The above examples do not include questions which deal directly with understanding lecture demonstrations. Such questions have been used to increase the impact of the lecture demonstrations on the understanding of the subject.

III. CONCLUSION

There are a number of computerized assignment systems which facilitate the handling and processing of large numbers of student assignments, and they share the basic variability of parameters in numerical problems. [15, 16, 17, 18] An expanded range of questions in *CAPA* includes challenging conceptual and qualitative questions to benefit students in large classes. This also makes the system more suitable for fields other than the physical sciences, further encouraging communication across disciplines.

IV. ACKNOWLEDGEMENTS

D. Johnson of the National Superconducting Cyclotron Laboratory has provided many beautiful PostScript graphics. Three of the authors (NHP, WLS, and SLW) were part of the National Science Foundation REU program at MSU. Initial versions of problems 1 and 2 were written in collaboration with J. Rapaport of Ohio University. The College of Natural Sciences and the Office for Computing and Technology at Michigan State University have supported and provided the resources for the development of the system, and the system software is available through the Office of Computing and Technology. Finally we thank M. Lack-Weiser for many helpful comments.

References

[1] *The Initial Knowledge State of College Physics Students*, I. A. Halloun and D. Hestenes, American Journal of Physics **53**, (11)1985, 1043-1055.

[2] *Cognitive Research-What's in It for Physics Teachers?*, J. Mestre and J. Touger, The Physics Teacher **27**, (6)1989, 447-456. Issues addressed include communication among educators, the recognition of students' misconceptions and their effect on learning, and the need for active engagement of students.

[3] *Toward a Modeling Theory of Physics Instruction*, D. Hestenes, American Journal of Physics **55**, (5)1986, 440-454.

[4] *Learning to Think Like a Physicist: A Review of Research-based Instructional Strategies*, A. Van Heuvelen, American Journal of Physics **59**, (10)1991, 891-897.

[5] *Overview, Case Study Physics*, A. Van Heuvelen, American Journal of Physics **59**, (10)1991, 898-907.

[6] *The Undergraduate Physics Major*, N. B. Abraham, J.B. Gerhart, R. K. Hobbie, L. C. McDermott, R. H. Romer, B. R. Thomas, American Journal of Physics **59**, (2)1991, 106-111. Includes a recommendation from a panel of the Association of American Colleges that physics faculties work to increase their dialogue with mathematics faculty members to reconnect the traditional link between physics and mathematics.

[7] *Calculus-based Physics without Lectures*, P. W. Laws, Physics Today **44**, (4)1991, 24-31.

[8] *Modeling Instruction in Mechanics*, I. A. Halloun and D. Hestenes, American Journal of Physics **55**, (5)1986, 455-462.

[9] *CAPA, An Integrated Computer Assisted Personalized Assignment System*, E. Kashy, B.M. Sherrill, Y. Tsai, D. Thaler, D. Weinshank, M. Engelmann, and D.J. Morrissey, American Journal of Physics **61**, (12)1993, 1124-1130.

[10] *Using Computer-Assisted Assignments in Freshman Chemistry*, D.J. Morrissey, E. Kashy, and Y. Tsai, Journal of Chemical Education, In-Press.

[11] *Using Computer-Assisted Assignments in Large Physics Classes*, M. Thoennessen and M.J. Harrison, manuscript in preparation, (private communication).

[12] *Computer-Assisted Personalized Assignment System*, C. Tsai, presented at the Third Conference on the Teaching of Calculus, Ann Arbor MI, June 4, 1994.

[13] *Private Universe*, Distributed by Pyramid Film and Video, Santa Monica, CA 90406.

[14] *Studying Students Studying Calculus*, U. Treisman, The College Mathematics Journal, **23**, (1992)362. Numerous studies have shown the importance of collaboration among students in enhancing the learning process. This well known work has been emulated at numerous other institutions.

[15] C.B. Chiu and C.F. Moore, *Centralized Computer System for Engineering Physics*, Manual, University of Texas at Austin. Both the UT and *CAPA* systems can process very large numbers of assignments and examinations. In the UT system, feedback to the instructor comes after the due date while for the students, the multiple choice format of the answers provides guidance and grades posted later provide feedback. With *CAPA*, feedback to the instructor (and students) is on-line. *CAPA* is a more integrated system, involves less paper (remote login of answers vs bubble sheet MC format),.has fewer individuals involved in administration, and gives the instructor full control of every aspect.

[16] *Personalized Homework Pioneer*, Letter by J.H. Connell, American Journal of Physics **62**, (7)1994, 585. Connell comments on the results published in ref.9 and relates similarly good results obtained earlier by H. Salz with individualized homework at Springfield Technical Community College.

[17] *Computer Assignments and Problems Classes for Physics Students*, R.A. Lewis, B.M. Harper and M. Wilson, Computers Educ., Vol. 16, No. 4 (1991)349-362. The system described (RALPH) shares many features with *CAPA* and with the University of Texas system alluded to in reference 15 above.

[18] *A Computer-based Homework System with Individual Problem Solving and Instructor Diagnostics* ('Prob'), S. Mellema, C.F. Niederriter and H.B. Thompson, Bull. Am. Phys. Soc., **38**, (1993)1004. The *CAPA* system differs in philosophy from the 'Prob' system and has more features, the optional aspect, qualitative/conceptual questions, graphics variations between assignments, correlated data sets, etc.. Both are networked and thus give instant feedback. With *CAPA*, a student gets all the information required to do the personalized assignment without having to go to a computer; and no penalty is assessed when several tries are needed to get a correct answer.

Key to the examples: 1) SVVSVS, 2) DEF, 3) CDG, 4) ABE, 5) EEGFLE, 6) ETLLLG, 7) ABD, 8) TFTTFF, 9) DL,XM,CL,PM,VM,VM,CL, 10) ABE, 11) DISSD