Can technology really improve teaching introductory physics?

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Structure of this Talk

Problems with our intro courses

- PER claims - need for active intellectual involvement of students.
- our dissatisfaction with what they learn
- one term later they remember nothing
- low numbers of students take physics voluntarily

The Large Lecture
Rutgers' Physics Lecture Hall

Lectures

- Here is where we expound on the fundamentals of physics!

Lectures

- Here is where we expound on the fundamentals of physics!
- But the students aren't thinking about what I am saying!

Lectures

- Here is where we expound on the fundamentals of physics!
- But the students aren't thinking about what I am saying!
- And their attention is wandering. 

Lectures

- Here is where we expound on the fundamentals of physics!
- But the students aren't thinking about what I am saying!

- And their attention is wandering.
- And they don't even come any more!

Getting them active

How to get students actively intellectually involved in thinking about the fundamental ideas?

The answer is well known:

Getting them active

How to get students actively intellectually involved in thinking about the fundamental ideas?

The answer is well known:

Human tutoring (Socratic method)

Expert human tutoring has been shown to raise performance by two standard deviations,

i. e. 16th percentile ⟶ 84th percentile,
low C ⟶ B+.

No other added teaching component comes close.

The textbook

Fundamental ideas aren't easily absorbed. How do texts address this? Chapter 8 of Sears and Zemansky (now Young and Freedman)

	First Edition	12th Edition
Title	Impulse and Momentum	Momentum, Impulse and Collisions
Size of page	$6'' \times 8\frac{1}{2}''$ (51 in^2)	$8\frac{3}{4}'' \times 10\frac{3}{4}''$ (94 in^2)
Number of pages	11 (561 in^2)	27 (2538 in^2)
Ratio $\frac{\text{examples}}{\text{exposition}}$	0.45	0.96
End of Chapter	19 problems	26 discussion Q's 112 exercises 4 challenge P's

Textbook changes (cont.)

I haven't quantified the

- "Learning Goals"
- "test your understandings"
- "problem-solving strategies"
- "Activ Physics" links,
- pictures of football players and other "relevant" irrelevancies

which, of course, occur only in the 12th edition.

Does any of this work? I doubt it!

Homework

- too much plug-and-chug (single formula problems)
- too much "just like the example" problems
- students give up on challenging problems
- too much grading for instructors
- painful keeping track of grades

Exams

- grading written (open-ended) problems too much work, consistency difficult.
- computer-graded easy and objective, but:
- validity: written vs. computer-graded ?
- if computer graded: True/False, MC, or numerical answer?

How can technology help?

Biggest improvements from technology:

How can technology help?

Biggest improvements from technology:

- stick and sand (Archimedes, 287-212 BC)
- Gutenburg (1455)

- blackboards (not Blackboard) (1801)

Technology that can be used today

- Presentation: Web, PowerPoint, computer demos, ...
- Simulations.
- Computer interface in labs, demos

I am not going to talk about the above — I just don't know very much about them.
Uses I will talk about

- Clickers
- Course Management Systems
- Exams
- Homework Systems
- Tutorial Systems

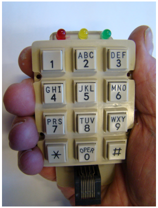
Clickers can help!

Now we talk about clickers!
Uses:

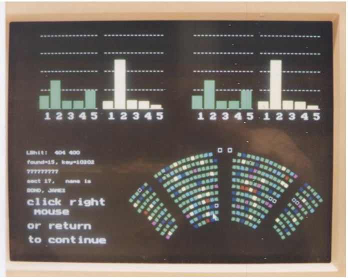
- Improve attendance
- promote active participation
- promote interaction
- give reading quiz at beginning of lecture
- real quizzes (dubious, I think)
- tells teacher if he needs to discuss something further.

Some Clicker Systems

- Littauer: Built a five-button system at Cornell 1972 from discarded HEX equipment. Pushing a button discharged a capacitor to the appropriate charge counter!
- SRS: A system I built at Rutgers

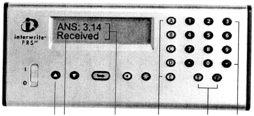
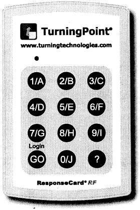


My keypad
(normally in arm-rest)



Computer screen after
double session

Commercial Clickers

PRS from GTCO CalComp	iclicker	Turning Point Response Card
		

eInstruction CPS	Meridia	h-itt IR and RF	TI-84+ Calculator
			

Clicker issues

- hardwired, IR or RF?
  - Hardwired not available commercially, takes lots of work. But provides seat info.
  - IR came first, but student clicks can interfere, doesn't work reliably enough for grading in a large class.
  - RF seems completely reliable
- feedback: none, few LEDs, or screen?
  - Students don't trust their answer has been received without feedback. Some systems show student ID on projector, but that doesn't work well in a large class
  - Even one LED is enough to show response received. But this requires transmitter to receive info.
  - A multicharacter screen is enough for sophisticated interaction, but I don't know anyone who makes use of this.

Course Management Systems

- Facilitates web posting (for novices)
- provides restrictive access
- provides discussion boards, chat rooms
- provides a gradebook
  - for your records
  - with student access to his/her own grades
  - Some systems:
    - BlackBoard
    - WebCT
    - Sakai
    - Moodle
    - Lon-Capa
- provides some homework grading / quiz facilities

Exams

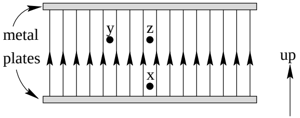
Most of us give computer-graded exams. In our department, we have a homemade system (grtex) which

- facilitates making up exams, with scrambling of answers and/or questions
- in LaTeX!
- I have been collecting such questions for years
- We have the ability to give numerical answer questions!

A LaTeX question

1. The figure shows the electric field lines due to two charged parallel metal plates. We conclude that:

   a. the upper plate is positive and the lower plate is negative.
   b. a positive charge at X would experience the same force if it were placed at Y.

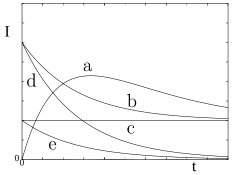


   c. a positive charge at X experiences a greater force than if it were placed at Z.
   d. a positive charge at X experiences less force than if it were placed at Z.
   e. a negative charge at X could have its weight balanced by the electrical force.

This question shows how flexibly figures can be included. Even when answers are permutted, the wrapping around the figure will work okay.

Answers on the Figures

23. You also might want to have the figure on the right of the question, with the answers (a)—(e) appearing on the figure, as with mvaquest. This question is of that type. Note that the placement adjusted for one type is unlikely to work for the other. Note also that this format requires a width as well as the file name for the figure. This question ended with \lmvaquest{2in}{mvapix.eps}

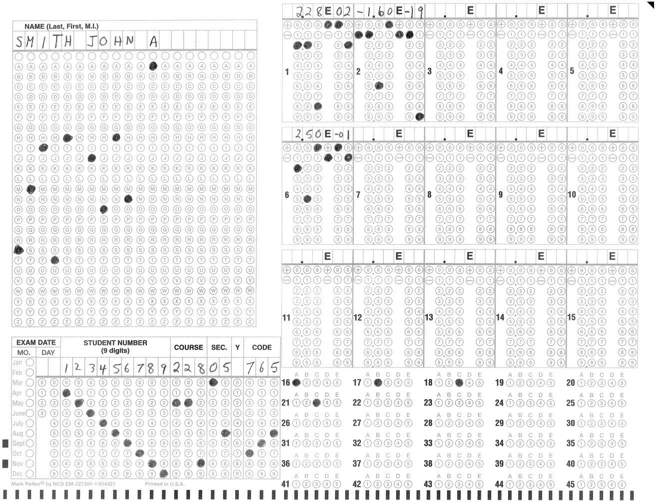


25. T
o]

Here the five choices are shown on the figure, and are permuted in different exam versions.

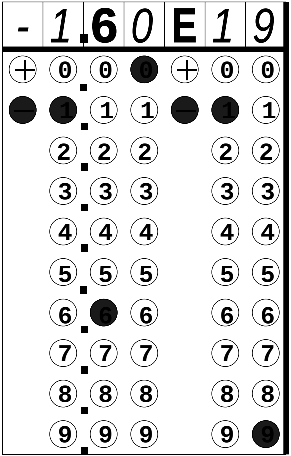
Numerical Answer Exam Questions

Need a special answer form:



One Numerical Question

What is the charge of an electron?



Are Computer-Graded Exams Good?

Computer-graded exams are

- much less painful to grade!
- objective and consistent grading
- Can they test deep understanding as well as open-ended written exams?
- Questions must be more carefully written, clear and unambiguous, with well thought-out distractors
- Some studies show that they can grade as accurately as written exams
- But possibly they fail to encourage deep-thinking studying. I don't really know.

Homework Systems

Without computers, most homework in large intro courses goes ungraded. Not good for feedback or for motivation.
So computer systems came into existence.
Non-science courses use MC or precisely specified short answers. Not good enough for us. For physics:

- Homework Service (Univ. of Texas at Austin)
- CyberProf (Univ. of Illinois Urbana-Champaign)
- WebAssign (evolved from North Carolina)
- Mastering Physics (evolved from MIT)
- Capa (Michigan State U)
- WebWork (mostly for math)

Commercial vs. Open-source

- Commercial advantages/disadvantages
  - Excellent technical support
  - Publishers support extensively with their problems
  - Cost: Uncontrolled! Webassign cost $8.50/stud-sem in fall 2002, $32.00/stud-sem now, for Wiley problems, unless purchased with new textbook.
- Open-Source
  - less well supported with publisher's problems
  - need to run your own server
  - less polished CMS and ease of use
  - minimal tech support

Both systems allow teachers to write their own questions, but none of us at Rutgers does.

Why what we have is not enough

Current homework and exam systems ask the students to present a single well-defined answer, quantitative or a symbolic expression, rather than present a full "show-your-work" solution.

My students get 95% on the WebAssign homework but 60% when asked simpler questions on the exam.

Old fashioned human grading of homework and exams could tutor on the ideas as well as the answer.

What I would like

A computer-based "intelligent tutoring system" (ITS)

- present a complex problem to student
- understand student input including drawings, sets of equations, numerical quantities (with units).
- give feedback on
  - correctness of entries
  - explanation of what is wrong with entries
  - hints for making further progress
  - possibly summary of solution
- Pipe-dream? Natural language dialog with students.

Is this possible?

We won't get there by adding hints for each problem (as done in the tutorial problems in Mastering Physics)

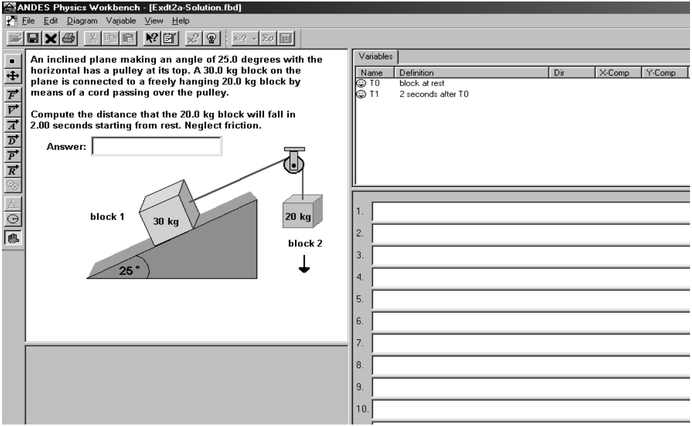
Sporadic efforts have been made: Plato, Andes

Such a system for high school algebra is rather successful, commercialized and used in many high-schools (from Carnegie-Learning)

I believe Andes goes a good way towards developing a useful system, but is not really all there. Can it get there?

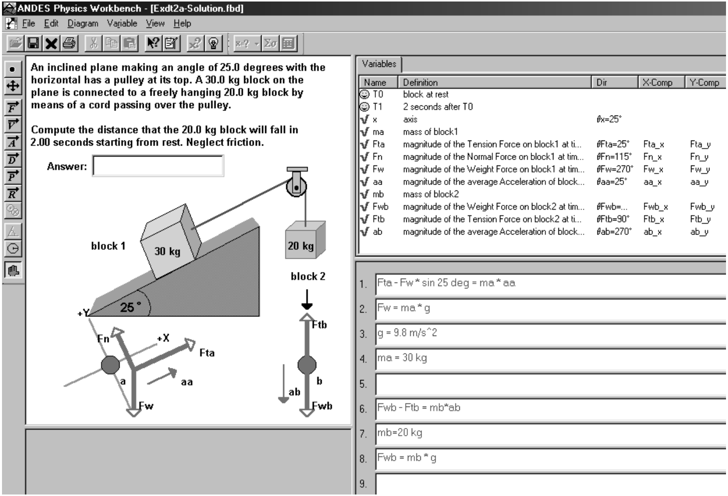
View of Andes

Opening problem presentation



Progress in Andes

Andes in mid-solution



What does such a system need

- to *understand* the physics
- a problem specification language that it can understand
- the ability to solve the problem, in all possible ways
- the ability to match what the student inputs to features of a solution
- a model of what the student already understands about the problem
- the ability to match wrong entries to some remediation
- the ability to provide "what's next" help on request
- (hopefully) a model of what physics the student knows how to use.

Needed components: 1. A user interface

- displaying text and graphics, including the problem statement
- accepting input in the form of
  - at least vectors and dots, maybe line segments, arcs, etc.
  - text: for variable names, properties, student turns in dialog.
  - equations (in symbolic form, with greek, exponents, subscripts, numbers *with units*, etc.)
  - help requests.
- display typeset-quality equations, summary of what's been done (variables defined, vectors drawn, etc)
- engaging in typed dialog with the student.
  Depending on how much natural language recognition it can handle, student input might be largely by pulldown menus and multiple choice.

2. A problem solver

Current homework systems do not understand any physics. The author writes the problem in a form that should be clear to the student, and gives the answer in a form the computer can compare to the student's answer. Maybe he gives specific wrong answers and accompanying hints. But complex problem solving does not consist of a well defined sequence of identifyable answers. The ITS needs

- production rules for making conclusions under appropriate conditions. These are physics principles and techniques for applying them
- a store of known conditions for the given problem
- the ability to know when all possible conclusions have been drawn, and when the problem has been solved.

Does this sound far-fetched? In fact, the strongest part of Andes is its ability to solve problems, given only a formal presentation of the problem.

The help system

The help system controls the interaction with the student. The problem solver provides it with solution paths, including correct equations with their justifications, and list of variables involved in the problem.

The help system needs to judge whether student entries are correct or not. For equations, a correct entry need not be among the list the problem solving component has presented, the *canonical equations*. But it should be derivable from these. A student equation could be judged correct

- if it is derivable from the canonical equations.
- if it is correct on the set of solutions to the canonical equations.

The second is much easier to check, especially on problems where that solution is a point with numerical coordinates in the space of all the variables. And it is equivalent to the first.

The algebra system

- Solves a system of equations.
- Checks the correctness of an equation.
- Determines whether a given equation is independent of a set of other equations. Needed
  - by the problem-solver to determine if a new production has supplied new information.
  - by the help system to determine which canonical equations a student equation entry entails.

The Andes tutor uses the solver not only to find the solution (which is needed to check the correctness of student equations) but also to provide a solving tool for the students. USNA professors offer the students this solving tool so they will focus on getting the basic equations, not on the algebraic manipulations on these equations to get the final answer.

The student model system

Ideally the tutor would have a model of all the knowledge and abilities we want the student to learn, and keep a record of how well each student has learned them, based on the performance on all the problems he has worked on. Even listing all such knowledge is a long way off, and using performance to accurately judge how well the student possesses this knowledge is another very long range problem.

What I would like to see happen

As I have mentioned, Andes is a step in the right direction. However

- It originally only ran on the student's identical PC, not on the web.
- It has been partially web-ized, but needs to be done more completely.
- Currently has built in some onerous pedagogic requirements. In particular, every variable needs to be explicitly and exhaustively defined by the student, which may be useful at the beginning but becomes quite painful with experience.
- The help system needs a lot of improvement in better recognition of wrong equations, better what's next hinting, etc.
- it is being used at USNA, St. Anselm College, and by Sophia Gershman in Honors Physics at Watchung Hills Regional High School.

My Group

Other than the year I spent with the Andes group, headed by Kurt VanLehn, at the Learning Research and Development Center, University of Pittsburgh,
My work has been done jointly with

- Donald E. Smith, Computer Science, Rutgers
- Chun-Wai Liew, Computer Science, Lafayette College

This is the *Watchung* Group.

We have concentrated at removing the requirement for the student to define each variable. Can a tutor know what the student equations refer to when the student chooses his own variable names and doesn't declare what they represent? Most of the time, yes!

What is to be done

Progress has been disappointing. Why?

- Simple systems can be created by a few people in a short time, tempting not to embark on a very ambitious system. Look at all the simulation packages! At the early Homework Systems!
- The Artificial Intelligence (AI) community is more interested in systems of general applicability, *i.e.* no algebra! And they are fascinated with natural language.
- Many journals insist all developments be pedagogically tested for publication. This makes development of components difficult.
- Ditto for grant agencies. If you can't develop a working system in three years, they are not interested. Andes has been in development for more than a decade!

What can we do?

I would like to see people work on components, much the way the Open-Software community has built Linux

- Someone should build an expression/equation slot, with robust ability to accept equations both in latex style and in Word style, or other reasonable form, and parse them and present them back in typeset (TEX) form, with facility for editing. And **with units!**
- Someone should work on a graphics buffer good for drawing free body diagrams and other diagrams of the kind we would like to see students draw.
- Someone should design an API for an interface, including the above components and the others I mentioned earlier, that could be united with a help system like Andes'.

(cont.)

- Someone should work on a more robust knowledge representation than what Andes has, although Andes is pretty advanced. Should it use real vectors (with vector equations, not just components)? Does it need variable functions (x(t))?
- My group has been working on variable recognition without explicit declaration. A major problem with Andes is how long it takes to do a problem because of this excessively demanding scaffolding. We have been reasonably successful, but have no way of testing our methods on real students.

References

If you go to my Home Page http://www.physics.rutgers.edu/~shapiro/, and look under “Technology and Physics Teaching”, you can find this talk, including a reference page. You can also find links to Andes, to my homemade clicker system (SRS), and to the Watchung Group home page, to our homemade exam system, and a few other things.

Warning: many of these pages are very obsolete (particularly the SRS).

I am not a plagiarist

- Sleeping student image courtesy of
  `http://www.DailyClipArt.net`
- School of Athens, by Raphael
  `http://www.odu.edu/~mcarhart/hist102/slides/athens_school.htm`
- Gutenburg bible page from
  `http://commons.wikimedia.org/wiki/Image:Gutenberg_detail.jpg`
- clicker pictures of PRS and Turning Point from their sales literature

Summary

In this talk, I have

- explained why improvements need to be made in our teaching of introductory physics
- told you some of the technological aids you could use now
- told you what I think an intelligent tutor might do in the future, and how it would need to function.
- encouraged you to jump in. But I am not responsible for the results!

Thank you for your attention. Perhaps one of you would like to work on inventing a piece of my dream system.