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21ST CENTURY PHYSICS FOR IN-SERVICE HIGH SCHOOL PHYSICS TEACHERS

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Abstract
A distance education version of the Matter & Interactions curriculum is offered to in-service high school physics teachers to give them a contemporary perspective on introductory-level physics. The distance education course has a number of unusual technological elements, including interactive videos of lectures given in the on-campus course. Teacher reflections on the course are presented.

1. Introduction
Matter & Interactions (http://www.matterandinteractions.org; Chabay 2007) is a calculus-based introductory university physics curriculum for engineering and science students that features a contemporary perspective, with emphasis on parsimony (a small number of powerful physics principles rather than a large number of formulas) and on unification (for example, mechanics and thermal physics are treated as one integrated subject rather than two disjoint ones, and electrostatic and circuit phenomena are analyzed in terms of the same fundamental principles rather than completely different methods). The atomic nature of matter is emphasized throughout. Computational modeling is an important component of the course; students write programs using VPython to model physical systems and visualize fields.
A version of this curriculum consisting of a semester of mechanics and a semester of electricity and magnetism is now offered to in-service high school physics teachers in a technologically advanced distance education format, including innovative interactive lectures on DVD. The goal is not to train teachers to teach this university curriculum in high school (though a few teachers are now using it with students who take a second year of physics) but rather to give teachers a contemporary perspective on introductory-level physics which they did not experience when they were in college. During the distance education course teachers write reflections on their own learning, which are quite illuminating.

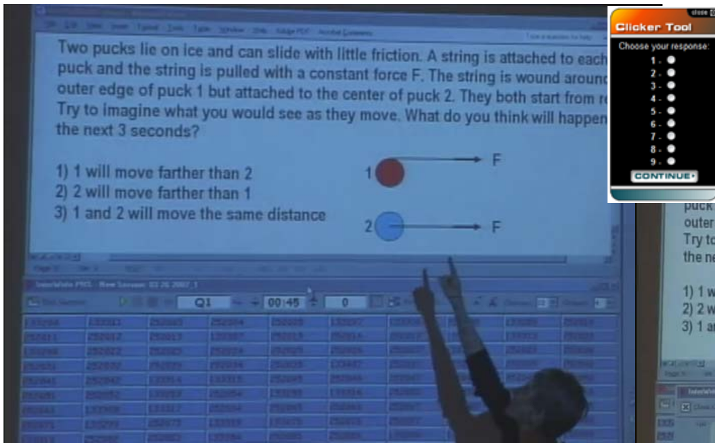
2. Components of the course
Here is a list of the major components of the distance education course, many of them technological in nature:

- Textbook (Matter & Interactions)
- Interactive video lectures
- WebAssign computer homework system
- Course web site
- Experiments (may involve video of data acquisition)
- For E&M, a desktop experiment kit (PASCO EM-8675)
- Computational physics (in VPython, see http://vpython.org)
- Course forum, including reflections
- Email
- Scan/Fax/pdf submissions of reports/tests/etc.
- Weekly teleconference (Elluminate)

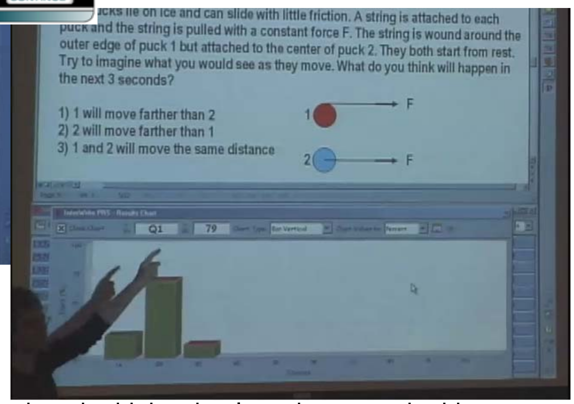
2.1. Interactive video lectures
The most novel component is the interactive video lectures, which have the following properties (see Fig. 1):

- Lectures with interactive clicker questions given by Ruth Chabay were filmed
- The video was edited and compressed; 40 lectures per DVD
- The video segments end with a clicker question on the screen
- A simulated clicker appears for the distance learner to respond
- After the response, the next segment begins with a display of the histogram of the student responses in the original classroom, with discussion
- The effect is to provide much of the interactivity of the original lectures

A clicker question is posed



The high school teacher answers, using a simulated clicker



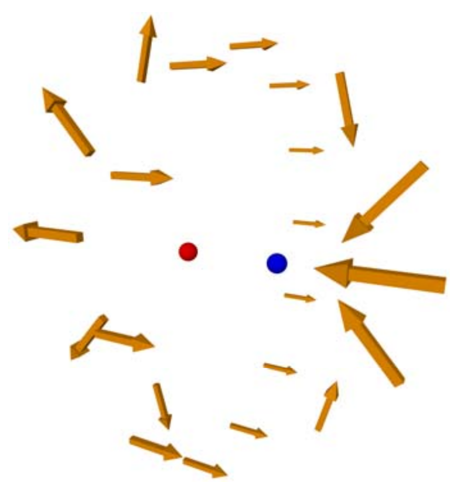
After answering, the high school teacher sees the histogram of student responses from the original classroom

Figure 1: Interactive video lectures

2.2. Computational modeling

In the mechanics course, teachers write computer programs using VPython to model physical systems, and to see the Newtonian Synthesis in action: starting from initial conditions, repetitive updates of momentum and position can predict the future. In the E&M course, teachers write programs to calculate and visualize electric and magnetic fields in 3D (Fig. 2).

A program written by a high school teacher to model a spacecraft moving near a fixed Earth and Moon (restricted three-body orbit)



A program written by a high school teacher to compute and visualize in 3D the electric field of a dipole

Figure 2: Computational modeling programs written by high school teachers using VPython

2.3. *Other components of the course*

One of the problems in distance education physics courses is the difficulty of including useful activities beyond textbook study and homework. Because the participants are high school physics teachers, in many cases they have access to equipment upon which experiments in the course are based. For an experiment on Young’s modulus which involves measuring the stretch of a long thin wire under load, which involves equipment most teachers do not have, a video is provided which shows a person taking data, and the teachers must write up an analysis of that data.

Computational modeling as described in the previous section is another fruitful activity that complements other aspects of the course. One problem is that it is easy to get stuck when writing a program in isolation, so teachers are encouraged to send drafts of programs by email for critique.

The isolation inherent in a distance education course is partially addressed by the existence of a course forum and by weekly teleconferences using Elluminate, a system which includes audio, chat, and a whiteboard upon which all can draw.

Homework is turned in to a computer homework system, WebAssign, for which a large suite of Matter & Interactions problems has been developed.

3. Teacher reflections

A recurring assignment for the teachers is to write a reflection on what they are learning, and how the new ideas might affect their own teaching. Some representative reflections follow.

On the general approach; fundamental principles plus atomic nature of matter: “Well--I am rather astonished at the number of topics related in chapter 4, where the real power of this innovative and quite unique approach really begins to bear fruit (in my humble opinion). Using the momentum principle along with macro-micro ideas to bring statics, dynamics, circular motion, the model of a solid, Young's modulus, the speed of sound in a solid, buoyancy, pressure... together conceptually is really cool. (e.g. Archimedes principle seemed so much easier to explain when inserted into the curriculum this way.) This course makes me wish I could go back again and take this for the first time -- as a physics virgin -- to carry out this dangerous analogy just a bit further -- I almost feel violated by the presentation of introductory physics I was subjected to (BS Physics in '86 -- this is so different than the presentation I was given back then-- the times they are a changin'-- in exciting ways).”

On the value of an atomic approach to matter: “I am seeing how the line between chemistry and physics is a fine one and not a solid one. In the past, I believed that most things that had to deal with atoms or at the atomic level was chemistry and I didn't need to teach it because “they would get it in chem class.” I like the thought that I can work with the chemistry teachers and hopefully help the students understand both courses better.”

On writing a VPython program to do a numerical integration of a spacecraft going to the Moon: “I am late turning in my lab but I just wanted to say COOL. I was a little frustrated with technical difficulties and time constraints in my personal life, but this was entirely awesome. I don't know if you could call what I have experienced doing this lab an aha experience or not. I have definitely developed a better conceptual understanding of the nature of the net gravitational force on the craft and its change in momentum, and effect on its orbit. I cannot wait to show this to my classes this semester. WOW!!!”

On a microscopic view of circuits: “I think what we are studying now are some really “neat” concepts. Two and a half years ago during a discussion on circuits, a colleague handed me an earlier version of Chabay and Sherwood's E&M text and said I should read chapter 18. For me it was an epiphany. I knew that the current in a series circuit was the same everywhere but had no mechanism to explain why. With my students the only explanation I could offer was “That's how it is.” or “Somehow it knows.” The two points that made it all clear to me were what we are now studying. 1. The harder it is for the charge to get through a conductor the stronger the electric field needs to be to keep the charge flow constant, and 2. Uneven surface charge distributions cause the electric fields necessary for the circuits to achieve steady state. For me, those concepts are the most eye opening I have picked up in the last two and one half years. Learning this is the reason I decided to take this course. I figured if I could learn something that “neat” from their book, there was much more to be learned. I was correct. One thing I don't understand is why these concepts are not more widely publicized. They explain so much, but I have not seen them in any other text.”

3.1. Parsimony and unification

Newton introduced the notion of reductionism into physics, that a small number of fundamental principles (parsimony) can explain a wide range of seemingly disparate phenomena (unification). The Momentum Principle (Newton's second law), plus a universal law of gravitation, made it possible to explain the motion of the planets and comets, the tides, and much else.

Reductionism was greatly strengthened in the twentieth century. Quantum mechanics seemed to change everything, yet it turned out that momentum, energy, and angular momentum were still central, giving added weight to parsimony. The discovery that the large number of "fundamental particles" could be explained in terms of a small number of quarks and leptons was another powerful demonstration of parsimony. The identification of just four fundamental interactions (gravitational, electromagnetic, strong, and weak), which then collapsed to just two (gravitational and the Standard Model), was the result of a drive for unification.

However, the twentieth century perspective on the power of parsimony and unification, which is at the core of contemporary physics, is hardly represented in physics education, as may be seen in the responses of a very bright teacher to the following question that was posed at the end of an early chapter on the iterative application of the Momentum Principle: *What (if anything) do you see as different about the way this course starts, compared with the beginning topics in a traditional introductory physics? What advantages and/or disadvantages do you see in this approach?*

She wrote, "When I first signed up for the class, I wasn't even really sure what was meant by this reductionist approach that focuses on only a few fundamental principles. What fundamental principles? Aren't there one or two fundamental principles for constant-acceleration kinematics, and one or two more for dynamics, and more for work and energy, and momentum, and…etc. Physics does seem like a bit of a jumble of equations in my mind. I may be quite proficient with these equations, but that doesn't really lead to understanding, and doesn't help me teach understanding to my students. Over the years I have pulled my hair out over students who I can tell don't really "get it", but can still manipulate equations like a pro. Now, after starting with the momentum principle and combining it with the position update formula, I can already see how far this one simple concept can take us. In addition, I'm getting glimmers of how this approach prevents good memorizers or good equation-manipulators from just jumping to a conclusion without understanding and explaining the underlying physics. If they are forced to argue from the fundamental principles (like the momentum principle) each time, and they do this while solving messy, real-world problems, some understanding is a prerequisite to even getting to a solution! Again, a powerful approach that will likely take me the entire semester to internalize, but an approach that will probably pay high dividends."

Later I asked, *"You have now been through the material on the ball-and-spring model of solids, the analysis of curving motion, and half of the first chapter on energy. What do you see as the most important concepts of that material? What if anything did you see as novel about the perspectives offered in those sections of the course? Are there aspects of your own teaching where the ideas of these chapters might play a role?"*

She wrote, "Introducing energy in terms of the Energy Principle also significantly eases the transition into thermodynamics, at least at the level I teach. The Advanced Placement test focuses on the laws of thermodynamics (and this statement of the energy principle is, I think, just a statement of the First Law of Thermodynamics – why didn't anyone tell me this when I was in school!) and on using P-V diagrams to compute work done on a system and the change in energy of a system. Both of these applications are natural extensions of the energy principle. I am curious about how this transition into thermodynamics will play out in the next few weeks in this class."

For one of the weekly teleconferences with teachers, this teacher showed up a few minutes early so we talked about general matters. I told her how much I admired her analytical comments and asked what her physics background was. She graduated in 1990 from a good four-year liberal arts college with a double major in physics and math and took some graduate courses at a good university. And yet she asked me, "Is this reductionist approach to physics something that has just been developed since I was in college? I never heard anything about this in any of my physics courses."

This is a very strong physics teacher, very analytical, very bright, reflective about her own learning, yet even she had not gotten even a hint of the real power of physics from her more than four years of undergraduate and graduate physics courses.

Later she added, “Despite taking physics as both a graduate and undergraduate student, I was never exposed to the drive for reductionism. Every topic and every course was treated as a stand-alone unit with its own special equations to describe the world. In retrospect, I guess I probably knew that theoretical physicists and other research physicists thought of physics quite differently and were actually pushing in the direction of unification, because the lay person does hear snippets about the Grand Unified Theory and the drive to combine all of physics under one big umbrella. So the question becomes, why is this reductionist perspective not really seen among physics educators? There seems to be a fundamental gap here.

With all of the recent research about learning and cognition in all of education, I thought that perhaps in the past 20 or 30 years the physics educational community had decided/discovered that the current methodology (the way physics has been taught for 100 years) was not necessarily working, and is now in the process of changing the way physics is thought about and taught. In some sense, this is what the Arizona State University modeling community is doing and what you and Ruth Chabay are doing. So even if the larger physics community has always had reductionism as a goal, is this a fairly new goal for the physics education community? And is this goal widely embraced? (It should be...)”

References

Chabay R and Sherwood B (2007) Matter & Interactions, John Wiley & Sons, Hoboken NJ, USA