Overview: When teaching, particularly in introductory level courses, it is well established that "interactive engagement" techniques are effective and indeed essential to improve student learning. For the more traditional introductory classes, a broad spectrum of materials, curricula, and techniques already exist, built on a framework of physics education research results: e.g. student interviews and validated assessment tools. In other less conventional courses, the research base can be much more sparse, and materials and assessment tools are harder to find. Without such materials, the best one can do is rely on established but broader principles of student learning to begin engaging the students, and start collecting student data. This summer project represents some first steps in developing and pulling together materials and assessments for two such classes: Phys 3070, Energy and the Environment, and Phys 1240, Sound and Music.

Background and specifics: Last year, as their summer FTEP teaching improvement project, Scott Parker and Allen Hermann developed an Instructor's Manual for Phys 1240 (Sound and Music), a large undergraduate non-majors course which satisfied the A&S Natural Science core requirement. Their manual is a helpful first step for new instructors teaching this course, with suggested demos, readings, and course sequence. However, such a first step can be developed considerably further. Adding materials to this instructor's manual that would include a complete set of concept tests, group (in-class) activities, interactive lecture demonstration questions, concept-based homework problems, and some sort of pre/post assessment, all suitable for the large-lecture environment of Phys 1240, would considerably ease the burden for future instructors of this course. The FTEP summer teaching improvement project provided support for me to start to develop such a set of materials, to be incorporated into the class this coming Fall '05. This will build upon, and complement, the work started by Scott and Allen, fleshing their notes out with a more complete set of teaching materials. This is an ongoing project, to be compiled after the end of the Fall term. I am teaching Phys 1240 now and have used this FTEP project to develope a pre/post content survey and some classroom materials. I will be using regular online "Just in Time Teaching" surveys to collect supplemental student data throughout the term. I will also be collecting data on the results of in-class clicker questions, an essential first step in the refinement of such materials for the future.
The second major component to this summer FTEP project involved putting together the same sorts of materials I began developing last spring (Sp05), for another large undergraduate non-majors course, Phys 3070, "Energy and the Environment". This course caters in many respects to a similarly diverse student population, and also satisfies the CU natural science core requirement. I had already been working on the same type of data collection and concept-test and curricular development there, and took the opportunity provided by FTEP to compile those materials into a web collection suitable for use by faculty teaching this course in the future. Indeed, this project has already yielded a productive result - this term (Fa 05), Jerry Peterson has begun using some of these materials in his Phys 3070 course. This includes a set of computer-based, personalized homework (CAPA) assignments I coded for that course.

**Outcomes:**

**Physics 1240 component:**

Although Sound and Music does not have the research base of Phys 1110/20/2010/20, there has been a small amount of work done researching student beliefs. The most significant work can be found at [http://perlnet.umephy.main.edu/research/sound.htm](http://perlnet.umephy.main.edu/research/sound.htm)

These materials provided the basis for a conceptual pretest survey, developed over the summer and first given in class in Phys 1240, Fa 05. Additional work over the summer resulted in drafts of concept tests for roughly the first third of the course. This work is ongoing, and continually updated resources can be found at [http://www.colorado.edu/physics/phys1240/phys1240_fa05](http://www.colorado.edu/physics/phys1240/phys1240_fa05)

(In particular, see the "reading" link)

At the end of the term, matching the work done for Phys3070, I anticipate a zipped directory of (easily editable) powerpoint documents with concept tests, available to faculty on our per.colorado.edu web page. Pretest web forms (including data collection scripts) will also be available online at [http://www.colorado.edu/physics/phys1240/phys1240_fa05/particip_n_done.htm](http://www.colorado.edu/physics/phys1240/phys1240_fa05/particip_n_done.htm)
Physics 3070 component: This is the principle practical outcome of this project to date. A 1 Meg, zipped folder containing sub-folders with concept tests organized by topic, class activities, pre/post tests, exams, and more, is compiled at

www.colorado.edu/physics/EducationIssues/SharedMaterials_energy_environment.zip

Summary of these materials:

Teaching materials for "Energy and the Environment" (standard text: Ristinen and Kraushaar). Lecture notes and web page (with a links page you can use) available at http://www.colorado.edu/physics/phys3070/phys3070_sp05

1) Concept Test folder: I used "clickers", and asked 2-5 Concept Tests each class. There are far more concept tests in these folders than I used. NOTE: Many thanks to Prof. Tom Murphy at UC San Diego for assisting with some of these questions, see http://physics.ucsd.edu/~tmurphy/phys12/

Important comment: Many concept tests in introductory physics are built on research into student misconceptions and difficulties. However, these concept tests for Phys 3070 are NOT research based (yet) I have only just begun collecting data on student ideas during the teaching of this class, and will be iterating on these concept tests, but in the meantime, caveat emptor. In the absence of a research base, we use broader knowledge of student learning in introductory physics to develop concept tests that will get students engaged and thinking, challenge their ideas, and stimulate conversation.

2) InClass Activities folder: I had several "worksheets" done as in-class activities in small groups. They are again not directly research-based, it's a first iteration.

3) Exams Folder: For ideas and reference. *PLEASE* DO NOT just "reuse" these exams.

4) PrePost tests: I had some surveys and questions, many of which I asked at the beginning and end of the semester to see what the students took away. Many are "factual" and not conceptually focused enough, this needs a lot of work still.
5) **CAPA Homework sets** are available through the Physics CAPA server (contact me directly for hard copies and software access.)

6) **Weekly pretests** are also available online. They have been "hidden" from students, but can be accessed by going to

http://www.colorado.edu/physics/phys3070/phys3070_fa05/particip_n_done.html

where n is an integer from 1 to 11.

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I did some PER literature searching, but there is no established research base for conceptual surveys in this domain. Thus, the Phys 3070 course did not have a pretest developed at the start of the term, but I developed a first pass of questions through the weekly online pretests. (Compiling these results into a post-test given in class at the end of the term, I obtained a pre-post normalized learning gain of 41%)

**Bottom line:** This summer FTEP project complements ongoing departmental efforts to document student learning with pre-post conceptual surveys, and to develop curricular materials which can facilitate active learning in large lecture classes. Most of the parallel efforts in the department (especially in the Phys 1110/20 sequence) build on a strong, published research base of curricular materials and validated surveys. In the more "peripheral" courses (like Phys 1240, and Phys 3070), this base is practically non-existent (albeit slightly more for Sound and Music than for Energy and Environment), and we are therefore building from a less well-informed starting point. Nonetheless, the data collected and compiled in Phys 1240 and 3070, resulting in a complete set of concept tests, surveys, some interactive lecture materials, and computer-based homework problems, along with pre and post content questions, provide a stronger starting point for future efforts to assess learning in these courses. This work is ongoing, and will be compiled in the same way as 3070 was when the term is over. A more comprehensive effort would require student interviews leading to research-based conceptual surveys, but for the moment, we take a simpler and more practical approach, using materials from other related courses and studies. The efforts in Phys 1240 are even more preliminary, as we have no student data to work with yet. In the appendices which follow, some course goals and
surveys are attached. Additional work to compile and summarize the outcomes of the concept tests and pretests is still to come.

Some useful references:

Summary of PER results for intro physics:

Statistical demonstration of effectiveness of active engagement:

Student understanding of wave and sound phenomena:
APPENDICES:

Some course goals for 1240 (sound and music):

**Overall Course Goals (taken from Phys 1010!)**
1. To see that (and how) much of sound and music is governed by physics principles. (Develop the capability to analyze, explain, and predict the properties and applications of sound and music.)
2. To understand that the universe is predictable rather than incomprehensible.
3. To appreciate how scientific understanding (particularly physics) is based on careful experiments and critical reasoning.
4. To learn to think logically in order to solve problems.

**Topic/content goals:**
Sound and music as arising from a source, propagating, and then being detected.
Instruments as sources of sound (essential features of string vs wind vs percussion)
Properties of waves: e.g. frequency, amplitude (linear, non-dispersive,...)
Ear as detector of sound. (Some physiology)

Musical structure: harmony, melody, scales, keyboard, reading basic music
Harmonics/octavoids (AND connection to instrument physics)
Room acoustics
Computers and music - synthesis, reproduction,

**Mathematical goals:**
Reading graphs, including both (x,t) dependence
Numeracy/order of magnitude/Estimation/units.
Scaling, equations as relationships rather than "templates".

**Affect goals:**
Enjoy class, enjoy science, enjoy physics
Believe they can do and discuss physics productively
Reducing fear of mathematics
Increased confidence in estimation and basic quantitative arguments
Material makes sense, not black boxes/formula crunching.

**Learning/metacognitive goals:**
Ability to generalize understanding from one application to another (see 1 above)
Ability to estimate/approximate, and understand margins of error. (See 1 and 2 above)
Critical analysis of arguments, use of exp't, logic and quantitative methods (see 1, 3 and 4 above)
Problem solving skills - think about how to set up the problem, What is known/needed. What approach to use? How do you decide if you're making progress? Mathematical tools. Does the answer make sense? (see 1, 4 above)
Collaborative learning skills improved. (see 2, 4 above)
Some course goals for Phys 3070 (energy and the environment):

**Overall course goals:**
1. To see how many issues of energy and the environment are governed by physics principles. (Develop the capability to analyze, explain, and predict the properties and applications, and problems of energy or environmental physics.)
2. To understand that the universe (and in particular questions of local and global energy use) is predictable rather than incomprehensible.
3. To appreciate how scientific understanding (particularly physics) is based on careful experiments and critical reasoning.
4. To learn to think logically, in order to solve practical problems. As a carry-on, an improved ability to combine factual information, and basic principles of physics, to solve "order of magnitude" problems
5. Improved store of factual information, as well as ability to assessment such information - where to go, how to decide what to believe, comparing with common sense estimations.

**Topic/content goals:**
- Physics concepts of energy and power
- Factual information: Finite oil resources, Hubbart Curve, Uses of fossil fuels, energy mix in US,
- Physics of Solar cells: costs, limitations,
- Physics of windmills: costs, limitations,
- Physics of nukes: costs, limitations,
- Pollution and global warming

**Mathematical goals:**
- Unit conversions
- Numeracy/large numbers
- Reading graphs
- The exponential function
- Order of magnitude estimations

**Affect goals:**
- Enjoy class, enjoy science, enjoy physics
- Believe they can do and discuss physics
- Reducing fear of mathematics
- Increased confidence in estimation and basic quantitative arguments
- Material makes sense, not black boxes/formula crunching.

**Learning/metacognitive goals:**
- Critical analysis of arguments, use of logic and quantitative methods
- Assess reliability and analyze bias of sources
- Learn how to find facts (and evaluate them)
- Problem solving skills - think about how to set up the problem, What is known/needed. What approach to use? How do you decide if you're making progress? Mathematical tools. Does the answer make sense? [See Schoenfeld, what's all the fuss about metacognition]
- Ability to generalize understanding from one application to another (transfer)
- Ability to estimate/approximate, and understand margins of error.
- Collaborative learning skills improved.
Physics of Sound and Music Diagnostic  This diagnostic does not count towards your grade in any way!! It's designed to help me know where you're all starting from. Feel free to guess, but, if you have no idea at all, you may choose "no idea". Just do your best, enjoy the "puzzles". Please BUBBLE YOUR NAME and ID on the bubble sheet, Do not write on this page. (thanks)

For the first 4 questions, consider changes made to a single violin string. In all cases, choose your answers from:
A) The pitch goes up       B) The pitch goes down          C) The pitch is unaffected                 D) I really have no idea

"What happens to the pitch of the sound you hear from a violin string if...
1. ... you decrease the string tension?
2. ... you replace the string with a much more massive one (keeping tension the same)?
3. ... you put your finger down halfway along the string?
4. ... you rub the bow across the string faster?

For questions #5 and 6, it's the same as above, but now considering changes to an organ pipe. What happens to the pitch if ...
5. ... you double the length of the organ pipe?
6. ... you cool the room temperature (including the air in the pipe) by a significant amount?

7. When you turn up the volume on your stereo...
   A) the speaker cone oscillates back and forth more often, completing more cycles per second
   B) the speaker cone oscillates back and forth less often, completing fewer cycles per second
   C) the speaker cone makes larger oscillations, traveling back and forth farther on each cycle
   D) the speaker cone makes smaller oscillations, traveling back and forth less on each cycle
   E) I really have no idea.

8. If a stereo is playing at 30 decibels, and you crank it up to 60 decibels, the sound intensity...
   A) increases just slightly (i.e. much less than double)       B) Doubles in intensity
   C) Goes up 30 times in intensity                          D) Goes up much more than 30 times in intensity.       E) No idea

9. Consider the following pairs of experiments. Pick the one that you think would give the better (more convincing) evidence that sound is a wave.
   A) Experiment 1: Two side-by-side speakers play the same pure tone. A listener in front of the speakers hears the sound make a pattern of "louder"-"softer"-"louder"-"softer" as she moves from side to side.
   Or
   B) Experiment 2: One speaker plays a steady tone, and you measure that the intensity of sound decreases steadily as you move away
   C) if you think both provide equally good evidence that sound is a wave
   D) if you think neither provides any evidence at all that sound is a wave                  E) No idea

10. Can a single string produce sounds of more than one definite pitch at the same exact time?
   A) Yes, this is what a normal string does                                                                                B) No, this is physically impossible
   C) Maybe, but you would have to play it in a weird way or do some really fancy tricks       D) No idea

11. What is the most significant difference between the same note played on two different instruments? (E.g. if you play "concert A", 440 Hz, on a flute and on a bass guitar)
   The bass guitar's "concert A"..
   A) ... has a totally different tempo than the flute.                   B) ... has a totally different mix of harmonics than the flute.
   C) ... is always a totally different intensity than the flute.      D) ... is always a totally different frequency than the flute.
   E) There is no noticeable difference if you really play the same note

12. Sound travels...
   A) essentially infinitely fast (it doesn't really "travel" as much as it is just there)       B) at (or very near) the speed of light
   C) at "jet plane" kind of speeds                        D) at "fast car" kind of speeds       E) no idea

13. How can a good opera singer shatter a glass with her voice?
   A) This is an urban legend, it's not possible
   B) She has to sing at a nearly perfect, steady pitch which matches the natural resonance of the glass
   C) She has to sing as loud as possible, so that the glass vibrates hard enough to shatter (kind of like windows breaking when a nearby bomb goes off)
   D) She has to sing as high as possible, so that the glass vibrates fast enough to shatter.
   E) No idea
14. For rich sound in a concert hall, with good acoustics for everyone in the audience, which would you most prefer in your design of the room?
   A) An odd shaped room with lots of varied reflecting surfaces
   B) As close to a square (cube) as you can make it
   C) As close to a hemisphere as you can make it
   D) The shape of the room has essentially no major impact on the acoustics - it's really all about the quality of the speakers.
   E) No idea

15. Is it possible for two loud sounds to "cancel out" right at your ears and sound very quiet?
   A) No, two loud sounds will always add up to a much louder sound
   B) No, two loud sounds will sound about the same as either one individually
   C) Yes, this is what always happens if two equally loud sounds reach your ear together.
   D) Yes, it's possible, but you need carefully controlled circumstances
   E) No idea

16. If an astronaut sets up speakers on the moon, can she hear them from 20 feet away?
   (Let's assume she has a new moon helmet that provides oxygen to her mouth and nose, but leaves her ears exposed)
   A) Yes, in fact, it would be slightly louder than on earth.
   B) Yes, but might sound a little distorted
   C) No, she would not hear them because of the lack of air on the moon
   D) No, she would not hear them because of the low gravity on the moon.
   E) No idea.

17. As you move up the musical scale to higher pitches, does the sound from the instrument travel to your ear faster?
   A) No, higher pitches travel to you slower than lower ones
   B) No, all pitches travel at essentially the same speed
   C) Yes, higher pitches travel to you faster than lower ones.
   E) No idea

18. Suppose I am speaking, and the sound is traveling through the room to you. Which would you say best describes/explains the physics of what is going on...
   A) Sound particles travel through the empty spaces between air molecules from me to you
   B) Sound particles travel from air molecule to air molecule, bouncing or interacting with the air along the way
   C) There are no "sound particles": air molecules travel directly all the way from me to you
   D) There are no "sound particles": air molecules push and bounce against one other, sending along a traveling "disturbance"
   E) None of these/something quite different/no idea

19. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.

Suppose you want the simplest way to find out whether the length of the string has an effect on the time it takes to swing back and forth. Which strings would you use to find out?
   A) only one string
   B) all three strings
   C) 2 and 3
   D) 1 and 3
   E) 1 and 2

20. ...because
   A) you must use the longest strings.
   B) you must compare strings with both light and heavy weights.
   C) only the lengths differ.
   D) to make all possible comparisons.
   E) the weights differ.
21. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).

Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. How high would this water rise if it were poured into the empty narrow cylinder?
A) to about 8
B) to about 9
C) to about 10
D) to about 12
E) none of these answers is correct

22. ... because
A) the answer can not be determined with the information given.
B) it went up 2 more before, so it will go up 2 more again.
C) it goes up 3 in the narrow for every 2 in the wide.
D) the second cylinder is narrower.
E) one must actually pour the water and observe to find out.

This semi-log graph shows the number of people in a city as a function of time.

23. How many people live in the city in 1940?
A) A hundred
B) Three hundred
C) A thousand
D) Ten thousand
E) One hundred thousand

24. How many years did it take for the population to increase by a factor of 100 after 1920?
A) 1 year
B) 10 years
C) 20 years
D) 40 years
E) No idea