



## Spring 2005 Newsletter

*Karen Cummings, Editor*

### Message from the Chair: Welcome!

*Gay Stewart*

It is my pleasure to introduce a new feature to our newsletter and mention some exciting things that are happening.

Our new feature is a section with articles on teacher preparation. The Physics Teacher Education Coalition (PhysTEC), an APS/AAPT/AIP program, will be soliciting these articles and organizing this section. PhysTEC provides dramatic improvement of science preparation of physics, physical science, and elementary teachers, developing programs that work at a wide range of institutions. Our thanks to Chance Hoellwarth, from the California Polytechnic State University (Cal Poly) PhysTEC site, who agreed to serve as the editor for this section!

The “Excellence in Physics Education Award” will be the first APS award to recognize this important area. Placing excellence in physics education in the same spotlight as excellence in research will help keep funding for research! FED Executive Committee Past Chair, and Chair of the subcommittee for this award, Wolfgang Christian, brings us up-to-date through his discussion in the *News and Announcements* section on the next page. A contribution form is on the last page of this newsletter. We hope you will support the award.

Each issue has a primary theme, and this issue covers the important and controversial topic of teaching thermodynamics.

As my term as Chair of the Executive Committee comes to an end, I can only say that the members of this committee do good work, and it has been a pleasure to work with them. If you care about physics and where it is going (we need excellent education if the field is going to continue to grow), I suggest getting involved with this committed group. Make sure you vote, as this year’s slate is already up. Further, please feel free to suggest yourself or someone else you know who cares deeply. The new Vice Chair from this year’s election will chair the Nominating Committee for next year, so get in contact!

My next task will be as Chair of the Fellowship Committee. Please feel free to bring candidates to my attention. [gstewart@uark.edu](mailto:gstewart@uark.edu). Thank you!

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## News and Announcements

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### ***Support Excellence in Physics Education and Honor a Teacher***

*Wolfgang Christian*

The *Excellence in Physics Education Award* has been approved by the APS and the Forum on Education has started a fundraising campaign to endow this award. Not only will your donation help establish this Award, but any contribution over \$100 can be designated to honor a teacher or mentor who has been influential in your professional training. A letter will be sent by the APS to the honoree or the honoree's family informing them of your gift.

The establishment of an APS education award is long overdue. There is no other APS award that recognizes and honors physics education. The Excellence in Physics Education Award will recognize and honor a team or group of individuals (such as a collaboration), or exceptionally a single individual, who have exhibited a sustained commitment to excellence in physics education. Such a commitment may be evidenced by, but not restricted to, such accomplishments as:

- Outreach programs
- A specific program or project that has had a major ongoing influence on physics education at the national level
- Outstanding teacher enhancement or teacher preparation programs over a number of years
- Long-lasting professional service related to physics education that has had a demonstrated positive impact

The *Excellence in Physics Education Award* campaign has already raised \$30,000 of our \$100,000 goal. In addition, the Forum's Executive Committee will match up to \$30,000 in contributions from APS members so your contribution is doubly important. With your help, we can endow the Award in 2005 and the first award can be given in 2006. After our goal has been met, an Excellence in Physics Education Award of \$5,000 will be given annually.

A pledge form is on the last page of this newsletter. Additional information, including downloadable and electronic pledge forms are available on the Forum's web page:

<http://www.aps.org/units/fed/>

Thank you in advance for your consideration of this request.

### ***Activity Based Physics Faculty Institutes***

*David Sokoloff, Ronald Thornton, Priscilla Laws*

Are you interested in making learning in your introductory physics courses more active? 2-year college, 4-year college and university faculty are invited to attend one of the NSF-sponsored Activity Based Physics Faculty Institutes to be held at the University of Oregon and Dickinson College the next four summers. While the deadline for applications for the June, 2005 institutes at Oregon has passed, it is not too early to consider attending June, 2006 at Dickinson College in Central Pennsylvania, or June, 2007 at Oregon. These one week Institutes will encourage faculty to use active learning strategies and computer-based tools and curricula--based on physics education research--in their introductory physics courses by 1) giving them hands-on experience with the materials in the Activity Based Physics Suite, 2) assisting them with modifying those materials for use in their own courses, and 3) providing continued follow-up support for the five years of this project. The institutes will be taught by Priscilla Laws (Dickinson College), David Sokoloff (University of Oregon), Ronald Thornton (Tufts University) and Patrick Cooney (Millersville University). Faculty from doctoral/research universities and from institutions that serve under-prepared and under-represented populations, are especially encouraged to apply. Expenses on campus will be paid, and travel grants are available for those who demonstrate need. For more information, please visit our web site: <http://darkwing.uoregon.edu/~sokoloff/physcourse.htm>. If you are interested in applying for Summer, 2006, please send an e-mail to [jgarrett@uoregon.edu](mailto:jgarrett@uoregon.edu), and you will be informed by e-mail when the 2006 application form is available online.

### ***New APS Director of Education and Outreach***

Ted Hodapp is the new APS Director of Education and Outreach. He can be reached at [hodapp@aps.org](mailto:hodapp@aps.org).

### ***Letter to the Editor***

11 January, 2005

Regarding the request on today's APS Forum On Education for articles on thermodynamics, I don't have an article but instead have a suggestion. When you write up something on this subject and get to the topic of "entropy" I suggest that after the theoretical treatment you provide some concrete examples of this very "non-intuitive" topic. The one which comes to my mind most readily is one from cosmology which I've thought a lot about as a result of recently reading "The Fabric of the Cosmos" by Brian Greene.

I think wrestling with the concept of entropy in this application will imprint it forever on a student's tender mind. In fact I think something like this discussion might be used as a possible argument against a perpetually oscillating universe --- an interesting use of a rather abstract [to some] concept.

*Edward Apgar*

*eapgar@rcn.com*

**Letter to the Editor**

31 Dec 2004

Jim Nelson's fine article "Where are the Science Candidates" (Fall 2004) appeals to physicists to produce a more physics-literate public, to make physics education more relevant to students' needs and interests, and to educate the policy-makers who can provide support to the physics enterprise.

Physics educators cannot accomplish these goals by continuing to focus overwhelmingly on traditional math-based high school and college introductory courses for the small fraction of our students who might someday be like us, namely professional physicists. What about the other 99 percent?

Every high school and college needs to teach physics courses geared to the needs and interests of non-scientists. It's fairly obvious, I think, that such courses should be conceptual (little or no algebra), interactive (use inquiry techniques), and include societal topics (global warming, the process of science, pseudoscience, etc.) and modern topics (quantum entanglement, general relativity, strings, the big bang, etc.) that are relevant and exciting to students. I have tried to follow these principles in my conceptual introductory textbook "Physics: Concepts and Connections" (<http://physics.uark.edu/hobson/>).

Most important, essentially all non-science students, rather than the small fraction that currently enroll, should take a conceptual physics course. Such courses should be far larger than the math-based courses! If our nation is ever to become scientifically literate, "physics for the few" needs to become "physics for all."

Furthermore, all science students, and especially the future physicists, should take such a physics literacy course before enrolling in their first math-based course. A big part of the problem described by Nelson arises because of the narrow technical orientation of most physicists. A first course in physics that is interactively taught and that emphasizes the concepts of physics, the connections of physics to society, and the mind-blowing scope of contemporary physics, should go a long way toward making future physicists more effective in pursuing Nelson's goals.

*Art Hobson*

*University of Arkansas  
ahobson@uark.edu*

**Browsing the Journals***Thomas Rossing*

☞ "Primal Inquiry: Making Stuff Work": is the title of a thoughtful guest editorial by Dick Peterson in the February issue of *The Physics Teacher*. In this age of LabView and sophisticated computer control, it is the "nuts and bolts" of experimental physics that help make it such a satisfying discipline. Many students get the biggest kick out of building apparatus and making it work.

☞ Einstein's life and work are the theme of the February issue of *Physics World*. His five 1905 papers, which we celebrate, are given special attention, as are his contributions to special and general relativity. A short essay discusses his love for music.

☞ A thoughtful editorial by Roger Bybee and Donald Kennedy on the "Trends in Mathematics and Science Study" (TIMMS) tests for 2003 appears in the January 28 issue of *Science*. Comparative data for both grades 4 and 8 reveal a virtual monopoly on high scores by Asia, including Singapore and Korea. Several European nations cluster below them, with the US falling well below. Scores of 8<sup>th</sup> graders in the US showed improvement between 1995 and 2003, and the performance by African-American and Hispanic students demonstrated a greater improvement. The results suggest giving greater emphasis to voluntary national standards for math and science education.

☞ Over the last decade many universities in the United Kingdom have closed their physics and chemistry departments for financial reasons. Now less than half of all UK universities offer undergraduate chemistry degrees, according to a report in the February 4 issue of *Science*. Physics has suffered a similar decline. Although lack of funding is a major factor, physical sciences are not as popular among prospective university students as they once were. Britain's school system has long had a problem attracting science graduates into teaching. As a result, few high school pupils are taught physics and chemistry by teachers with degrees in these subjects.

☞ The January 20 issue of *Nature* includes a 50-page supplement on the World Year of Physics celebration. The supplement includes commentaries, essays, and review articles by leading scholars. "In search of symmetry lost" by Frank Wilczek is especially impressive, and the supplement winds up with comments on Einstein's search for a unified theory ("a theory of everything") by Gerard 'tHooft, Steven Weinberg, Roger Penrose, and others.

☞ Women in physics match men in success, according to a story in the February 22 issue of *The New York Times*. An AIP report suggests that after they receive a bachelor's degree in physics, American women are just as successful as men at making their way up the academic ladder. Statistics show no indication of discrimination in the hiring of female physicists or women dropping out of the field at a higher rate than men. The main reason fewer women make it to the top in physics is simply that fewer start at the bottom. At top-tier universities, the percentage of female physics professors is low because many current professors earned the PhDs in the 1970s or earlier when the field was almost entirely male and have not yet retired.

The sex disparity arises earlier in the pipeline, between high school and college. Nearly half of students taking high school physics are girls, but fewer than a quarter of the bachelor's degrees in physics go to women. The situation appears to be different in some other sciences, such as chemistry, where women earn a larger percentage of doctoral degrees but leave academia at a higher rate than men.

## Investigation of Student Reasoning Regarding Concepts in Thermal Physics

David E. Meltzer

Decades of research have documented substantial learning difficulties among pre-university students with regard to heat, temperature, and related concepts.<sup>1</sup> However, it has not been clear what implications these findings might have with regard to the learning of thermodynamics. Studies reported in several European countries in recent years have indicated significant confusion among university students regarding fundamental concepts in thermal physics.<sup>2</sup> The recent investigation of Loverude *et al.*<sup>3</sup> strongly suggested that a large proportion of students in introductory university physics courses emerge with an understanding of the fundamental principles of thermodynamics that is insufficient to allow problem solving in unfamiliar contexts. In related work, the Iowa State University Physics Education Research Group has been engaged since 1999 in a research and curriculum development project aimed at improving thermodynamics instruction in the introductory university physics course. In this short report I will summarize some of the initial findings of our ongoing investigation into students' reasoning regarding concepts in thermodynamics.<sup>4</sup>

Our data for this initial phase of the investigation were collected during 1999-2002 and were in two primary forms: (1) a written free-response quiz that was administered to a total of 653 students in three separate offerings of the calculus-based introductory physics course; (2) one-on-one interviews that were conducted with 32 student volunteers who were enrolled in a fourth offering of the same course. All testing and interviewing was done after students had completed their study of the relevant topics. Results of all the various data sources were quite consistent with each other.

We found that students' understanding of process-dependent quantities was seriously flawed, as substantial numbers of students persistently ascribed state-function properties to both work *and* heat. Although most students seemed to acquire a reasonable grasp of the state-function concept in the context of internal energy, it was found that there was a widespread and persistent tendency to improperly over-generalize this concept to apply to both work and heat. This confusion was associated with a strong tendency to believe that the net work done and the net heat absorbed by a system undergoing a cyclic process are both zero.

The written quiz consisted of a  $P$ - $V$  diagram on which curving lines represented two separate expansion processes involving a fixed quantity of ideal gas. The initial and final states of the two processes were identical, but the areas under the curve differed in the two cases. Students were asked to compare the amount of work done by the system during the two processes, and also the amount of heat transfer to the system during the same two processes. About 30% of all students asserted that the work done would be equal in the two cases, although the areas under the curve were clearly different. Similarly, 38% of all students claimed that the heat transfer to the system would be the same in both processes, although a straightforward application of the first law of thermodynamics shows that the heat transfer must be different in the two cases. (This incorrect response regarding heat was almost equally

popular among students who gave the *correct* answer to the work question, as it was among those who claimed that the work done was equal in the two processes.)

During the interviews, students were shown diagrams portraying a three-step cyclic process involving a cylinder containing a quantity of ideal gas. The diagrams showed an isobaric expansion followed by an isothermal compression, followed finally by a constant-volume cooling. (The net work done by the system and the net heat transfer to the system during the complete cycle were negative.) After slowly and methodically working through and discussing this process (the typical interview lasted over one hour), 75% of the students asserted with great confidence that either the net heat transfer to the system during the complete cycle, the net work done by the system during the cycle, or both of those quantities, would have to be equal to zero. The interviews also disclosed unanticipated levels of confusion regarding the definition of thermodynamic work, as well as difficulties in recognizing the existence of heat transfer during isothermal processes involving volume changes.

Consistent results over several years of observations involving both written quizzes and oral interviews enabled us to make a high-confidence estimate that approximately 80% of students in the introductory calculus-based physics course emerged with only a very weak ability to apply the first law of thermodynamics to solving problems in unfamiliar contexts. This result was consistent with findings of Loverude *et al.*

Although it is not entirely clear *how* students arrive at their ideas regarding thermodynamics, some of the more widely shared ideas seem to have an understandable basis. It seems that a fundamental conceptual difficulty is associated with the fact that heat transfer, work, and internal energy are all expressed in the same units, and all represent either energy or *transfers of energy*. Many students simply do not understand why a distinction must be made among the three quantities, or indeed that such a distinction has any fundamental significance. One of the subjects in our interview sample, when invited to explain what he found particularly confusing about the heat-work-energy relationship, offered this comment: "How is it acceptable for something called 'work' to have the same units as something called 'heat' and something called 'energy'?"

Part of this confusion stems from the ubiquitous and well-documented difficulty students have in making a clear conceptual distinction between a quantity and the *change* or *rate of change* of that same quantity (for example, that between velocity and acceleration).<sup>5</sup> Many students do not learn that heat transfer and work both represent *changes* in a system's internal energy, and that they therefore are not properties associated with a given state of a system but rather with the transition between two such states. This problem is exacerbated by the use in colloquial speech of the terms "heat" or "heat energy" to correspond to a concept that is actually closer to what physicists would call "internal energy". However, our findings corroborated those of Loverude *et al.*<sup>3</sup> that an even more significant difficulty was that related to mastering the work concept in a *mechanics* context, let alone within the less

familiar context of thermodynamics. Significant difficulties in understanding work persisted from students' studies of mechanics, and hampered their ability to master the related ideas in the context of thermodynamics.

Students do learn well that there exist quantities that are independent of process, and that (internal) energy of a system is one of these quantities. Perhaps due to their already weak grasp of the concepts of heat and work, many students improperly transfer, in their own minds, various properties of state functions either to heat, or work, or both. Certainly, the fact that mechanics courses frequently highlight the path-independent work done by conservative forces may contribute to this confusion, as may extensive use of the equation  $Q = mc\Delta T$  in calorimetry problems.

Another area of confusion might be traced to the limiting approximations frequently – and often tacitly – invoked regarding idealized processes. Experienced physicists automatically “fill in the dots” when describing, for instance, an isothermal process and the meaning of a thermal reservoir. The overwhelming majority of textbook discussions treat these and similar idealized processes only very cursorily; our data suggest that for most students, such treatments are inadequate.

### Implications for Instructional Strategies

Loverude *et al.* have pointed out that a crucial first step to improving student learning of thermodynamics concepts lies in solidifying the student's understanding of the concept of work in the more familiar context of mechanics, with particular attention to the distinction between positive and negative work.<sup>3</sup> Beyond that, it seems that little progress can be made without first guiding the student to a clear understanding that work in the thermodynamic sense can *alter* the internal energy of a system, and that heat or heat transfer in the context of thermodynamics refers to a *change* in some system's internal energy, or equivalently that it represents a quantity of energy that is being transferred from one system to another.

The instructional utility of employing multiple representations of physics concepts has been demonstrated.<sup>6</sup> The results of our study suggest that significant learning dividends might result from additional instructional focus on the creation, interpretation, and manipulation of *P-V* diagrams representing various thermodynamic processes. In particular, students might benefit from practice in converting between a diagrammatic representation and a physical description of a given process, especially in the context of cyclic processes.

Our results demonstrate that certain fundamental concepts and idealizations often taken for granted by instructors are very troublesome for many students (for example, the relation between temperature and kinetic energy of an ideal gas, or the meaning of thermal reservoir). The recalcitrance of these difficulties suggests that it might be particularly useful to guide students to articulate these principles themselves, and to provide their own justifications for commonly used idealizations.

It is worth noting another one of our observations that corroborated reports from other researchers. We found that students often used microscopic arguments both as a basis and as a justification for incorrect reasoning regarding thermodynamic phenomena. (This is identical to a finding reported in Ref. 3, and in other references cited in both Refs. 3 and 4.) The extent to which this faulty student reasoning was actually initiated or catalyzed by instruction involving microscopic concepts is uncertain. However, our research serves as a caution that merely incorporating a strong

instructional emphasis on the microscopic, molecular viewpoint in thermal physics is unlikely, *in itself*, to dramatically impact students' understanding. Indeed, our ongoing research indicates that many key concepts emphasized in a microscopic approach are very challenging even for physics majors in their third and fourth years of study.<sup>7</sup>

### Acknowledgments

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3. Michael E. Loverude, Christian H. Kautz, and Paula R. L. Heron, “Student understanding of the first law of thermodynamics: Relating work to the adiabatic compression of an ideal gas,” *Am. J. Phys.* **70**, 137–148 (2002).
4. A full report may be found in: David E. Meltzer, “Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course,” *Am. J. Phys.* **72**, 1432–1446 (2004).
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7. David Meltzer and Warren M. Christensen, “Development of student reasoning in an upper-level thermal physics course,” *AAPT Announcer* **34**(4), 97 (2004).

David E. Meltzer is Assistant Professor of Physics and Astronomy at Iowa State University.



## Truth is Beauty Beauty is Thermodynamics (with due apologies to John Keats)

*James Hurley*

I'm not quite sure what Keats had in mind in his Ode on a Grecian Urn when he wrote, "Beauty is truth, truth is beauty,—that is all ye know on earth..." While this is certainly not a universal truth, there came a time when I felt it had a certain application to my understanding of thermodynamics, the poor relations among the fundamental disciplines of physics.

In choosing to focus this issue on the teaching of thermodynamics, the Forum has made the perfect choice. There is no branch of physics more in need of rehabilitation than the teaching of thermodynamics.

As a student, many years ago, my initial impression of thermodynamics as a subject worthy of study was very low. I recall thermodynamics as that branch of physics in which one deliriously performed partial derivatives until the answer emerged as an apparition. It drove me adiabatic. It took a back seat to every other subject. But I was able to do the homework, solve the problems, and grunt my way through.

Alas, as I took up a career in teaching, I was faced with the tedious task of teaching the subject myself. It was a low point in my career. I confess that I taught the subject for many years before I developed any real understanding of it. I felt a need to reimburse those poor students who suffered under my tutelage.

So the energy was a state function, a function of a few fundamental physical parameters. So the entropy was a state function also. So what? There existed a whole menagerie of state functions: *Energy, Entropy, Enthalpy, Gibbs* and *Helmholtz Free Energies*, etc. Maybe, as in elementary particle theory, I could discover a new thermodynamic particle, a new state function, the *Hurley* I would name it; I would be famous. I was so naïve.

Needless to say, I felt badly about my ignorance. I had a nagging suspicion that I was missing the boat entirely. And then that day of enlightenment dawned when I came upon the work of J. Willard Gibbs. It was a revelation. Suddenly I understood, understood at a fundamental level, and began to appreciate that there is a beauty in thermodynamics, just as there is beauty in any synthesis, any reduction of diverse and divergent results to a single unifying principle. And in thermodynamics, that principle is intuitive! Glorious, astonishing, beautiful! Thermodynamics now stood apart from all other disciplines in physics as the only discipline in which we can understand the fundamental laws on an intuitive basis.

### ***Why is there an Equilibrium State?***

So how should thermodynamic law be introduced? No physical law should be divorced from the natural phenomena that it is meant to encompass. It is both a curse and a blessing that the phenomenon from which the postulates of statistical physics are best derived is so commonplace. Familiarity breeds oversights. The phenomenon of which I speak is that of the existence of the equilibrium state.

### *Observation:*

*In the course of time, confined, isolated systems with large numbers of particles will reach an equilibrium state in which the macroscopic observables remain constant in time.*

Understanding the physical basis for this phenomenon is the foundation of all statistical physics. The postulates of statistical physics grow out of the very existence of the phenomena to be studied, the existence of the equilibrium state. It must be recognized that this phenomenon—macroscopic variables of systems with large numbers of particles exhibiting an equilibrium state behavior—is something worthy of study and not a tautology.

So thermodynamic systems come to an equilibrium state. We therefore take for our first law (for a simple system): There exist equilibrium states of macroscopic systems that are completely characterized macroscopically by the internal energy, the volume, and the number of particles of the various constituents.

This seems like an unlikely physical law. First of all, there is no equation. Second, it is not obvious that it passes the basic test for a physical law: Can it make quantitative predictions on untried experiments? So what predictions can we make from the first law of thermodynamics without any equations?

### *Experiment:*

*Take any macroscopic system. Heat it, compress it, cool it, expand it, but eventually bring it back to its original energy and volume and keep the particle numbers the same.*

### *Prediction:*

*All macroscopic observables will return to their original values, not just the energy, volume and particle numbers.*

Another way to look at the first law is that it describes the dimension of the thermodynamic state space. By dimension I mean the number of independent variables.

The first law of thermodynamics establishes the playing field, but we need a second law to determine the rules of the game. To see what the game is and how this second law will help, imagine two blocks with given internal energies brought into thermal contact; how is the energy shared between the two blocks when the equilibrium state is reached?

Let us approach the distribution of energy problem from a statistical point of view. The first law tells us only the relevant variables—those variables that determine the macrostate. We need a law that predicts how these variables change after the two blocks are brought together and come to a new final state.

Here we make a conjecture as to the reason for the equilibrium state. The first law recognized the existence of the equilibrium state. The second law expresses a rationale.

**Observation:**

For most large systems there is one macrostate that is associated with a great many microstates, while other macrostates are associated with comparatively few microstates. As the system evolves in time from one microstate to another, it will more often than not be found in the macrostate with the most associated microstates. Since the system is most often found in the same macrostate, it will be in a steady state, or equilibrium state. The equilibrium state is the macrostate with the most associated microstates.

Can we postulate a second law of thermodynamics that will encompass this speculation? We can, and that law is the second law of thermodynamics: For all macroscopic systems there exists a function (called the entropy and denoted symbolically by  $S$ ) that is defined for all equilibrium states, i.e., all possible values of the energy, volume, and particle numbers. The entropy of a composite system is the sum of the entropies of the components. In the absence of an internal constraint, the values assumed by the energies, volumes, and particle numbers of the components in a closed system are those that maximize the total entropy.

Or, the short form: The entropy of the system in the equilibrium state will be as large as the constraints allow.

The reason an equilibrium state is reached is that there is one macrostate with a very large number of associated microstates. All we have really done is substitute the word *entropy* for the phrase *number of associated microstates* and assumed that the measure of the number of microstates is a function of the variables that determine the macrostate and that the measure can be made additive.

In general we stand in awe of the laws of nature. Although we may be able to articulate these laws, we have no fundamental understanding of their origin. We know not why light resolutely, indeed jealously, travels with a fixed speed, which no other may exceed and that this speed appears to be the same for all observers regardless of their relative motion. It is a wonder to behold but not as yet understood. We know not why matter is quantized and is willing to subject itself to something so bizarre as a wave equation. And why gravity? Why do bodies exhibit gravitational attraction proportional to their inertial properties? And what is energy? Feynman said, "It is important to realize that in physics today, we have no knowledge of what energy *is*." We stand in awe of such wonders, but we do not yet understand them at a *fundamental* level.

But the second law is different. It is every man's law. Every poker player, every housekeeper has a feeling for it. It follows from the laws of probability. The only mathematics required to understand this law is the ability to count. Frequency of occurrence is proportional to the probability. Throw a hundred coins in the air and every person can predict the likely outcome: about the same number of heads and tails without knowing anything about gravity or the laws of motion governing tumbling coins. There are a lot more ways of achieving half heads and half tails than any other ratio. The second law of thermodynamics is all about counting. It is the only law of nature for which we have this level of intuition.

I have said nothing about energy conservation as thermodynamic law. Thermodynamics deals only with statistical law. There is nothing statistical about energy conservation, just as there is nothing statistical about the conservation of mass, momentum, or electrical charge.

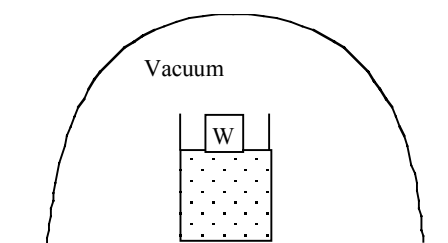
**How is Entropy Measured?**

We have said that the entropy in the equilibrium state is as large as the constraints allow. We know how to use this law to predict the results of experiment. For example, when we put two bodies at different temperatures together and allow them to exchange heat, we can predict that they will eventually come to the same final temperature and we can determine what that temperature will be by maximizing the entropy functions—provided of course that we know the entropy functions of the two bodies. But there's the rub. There is nothing in our statement of the second law that appears to *define* the entropy—all we know is that the entropy of any system in equilibrium is as large as the constraints allow. (It's something like Newton's laws of motion. There is no definition of force except  $F = ma$ . So where is the law? It should be that the observable, so defined, is a state function, a function of the kinematic state of the system. But I digress.)

We need to show that that is enough. We need to devise an *operational* procedure by which we might measure the entropy of any system for any values of its thermodynamic variables. Knowing this entropy function, we may use it to determine how this system will interact with any other known system.

I shall make this very brief, first proving that  $dS = dQ/T$  for a simple system and then showing how this equation may be used to determine the entropy. We will use only the fact that the entropy is a maximum in the equilibrium state..

Consider a substance, a gas for convenience, confined to a cylinder with a weight  $W$  on the lid. See figure below. When the equilibrium state is reached the entropy will be a maximum, i.e.  $dS = 0$  for any displacement compatible with the constraints, perhaps a slight elevation in the lid.



Since the entropy depends only on the energy and volume—a consequence of the first law—we know that the resulting change in entropy due to a change in energy and volume is given by:

$$dS(E, V) = \frac{\partial S}{\partial E} dE + \frac{\partial S}{\partial V} dV$$

We define  $T$  by the equation

$$\frac{\partial S}{\partial E} = \frac{1}{T}$$

and  $p$  by the equation:

$$\frac{\partial S}{\partial V} = \frac{p}{T}$$

For the moment these are *only definitions*.

(It is a simple matter to show that the entropy will be a maximum for two systems that can exchange energy when the value of  $T$  is the same for both systems. Likewise we can show that the values of  $p$  will be the same for two systems that can exchange volume. Therefore  $T$  and  $p$  are not unreasonable candidates for temperature and pressure.)

With these definitions we may write:

$$dS = \frac{dE + p dV}{T}$$

Now when the piston is in the equilibrium state, the entropy is a maximum and so  $dS = 0$  or

$$dE + p dV = 0$$

Since energy is conserved:

$$E + W z = \text{constant}$$

where  $z$  is the height of the weight  $W$  above the chosen ground level. For an infinitesimal change in the height of the piston,

$$dE + W dz = 0$$

We also know from the second law that

$$dE + p dV = 0.$$

Since  $dV = A dz$  where  $A$  is the cross sectional area of the piston, it follows that

$$p = \frac{W}{A}$$

But, by definition, the pressure within the cylinder is just the force per unit area on the piston so that we have finally

$$p = \text{pressure}$$

and we have a most important identification. We now know that

$$p = \frac{\frac{\partial S}{\partial V}}{\frac{\partial S}{\partial E}} = \text{pressure}$$

and so the ratio of these partial derivatives is a measurable quantity.

We have come part way in our quest for measurable entropy. We have

$$dS = \frac{dE + p dV}{T}$$

for *arbitrary changes* in internal energy and volume. But now  $dE$ ,  $p$ , and  $dV$  are measurable. We don't yet know how to measure  $T$ .

It is customary to separate the change in energy of a thermodynamic substance into two parts: one due to heat

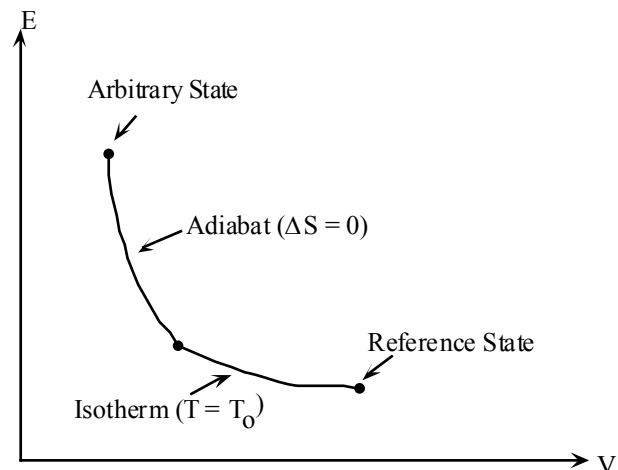
energy ( $dQ$ ) added to the substance, and one due to mechanical work, in this case  $-p dV$  done on the substance. We may write

$$dE = dQ - p dV$$

This equation should properly be regarded as a definition of  $dQ$ . (If there are variations in molar numbers, we must include the sum of  $\mu_i dN_i$ .) The entropy change can then be written:

$$dS = \frac{dQ}{T}$$

perhaps the most familiar relation in the mathematical expressions of the second law of thermodynamics. In this equation we can measure  $dQ$  but not  $T$ —yet. But this is quite straightforward. Choose any reference state and define its temperature to be  $T_0$ . Since  $dQ$  is measurable, one can determine the entropy along the isotherm through the reference state—see the figure. The entropy of any arbitrary state along the adiabat will be equal to the entropy at the point of intersection with the isotherm through the reference state.



Having determined the entropy *everywhere* we can evaluate the temperature *anywhere* by calculating the partial derivative of the entropy with respect to the energy. We have therefore succeeded in our task: We have shown that  $dS = dQ/T$  where  $dQ$  and  $T$  are measurable. We have used only the defining property of the entropy: It is that function of the energy  $E$  and the volume  $V$  that is a maximum in the equilibrium state.

I have taught thermodynamics from this point of view at the introductory level (see *Principles of Physics* by James Hurley and Claude Garrod (1978), the upper division level (course notes: *Statistical Physics* 1987) and finally in a possibly futile attempt at the level of the interested, perhaps obsessive, layman in *A Paradox in Time* by James Hurley (2004). This last book, however, focuses on a resolution of the time-asymmetry paradox.)

*James Hurley is Professor Emeritus at the University of California, Davis. He can be reached at [jhurley@infs.net](mailto:jhurley@infs.net). A Paradox in Time is available at [Amazon.com](http://Amazon.com).*



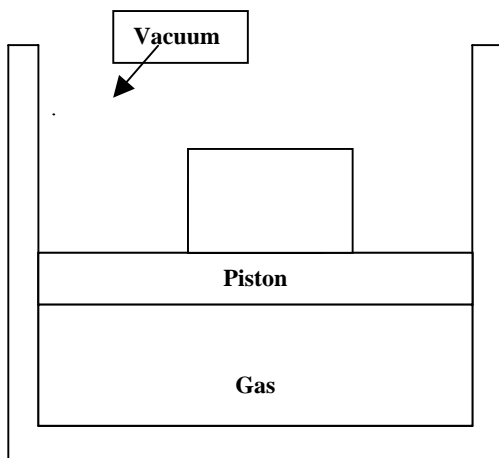
## The Proper Definition of Pressure-Volume Work: A Continuing Challenge

*Eric A. Gislason and Norman C. Craig*

Although thermodynamics is a mature discipline, some of its foundations are insecure. Two significantly different approaches to work and heat are in widespread use. Often the student is left in doubt about which approach is being used. We have been examining the two formulations of work and heat and the relationships between the two formulations. We now make a strong recommendation for using only one of the formulations [1-3].

There are two approaches in use to define pressure-volume work  $w$ . One, which the present authors strongly favor, is to define  $w$  (as well as the heat  $q$ ) by making measurements in the surroundings before and after the process [1]. These definitions are referred to as “surr-based”. In general, the surroundings are made up of several parts, such as a piston, a calorimeter, the atmosphere, and an electrical system. The change in each part must be examined to determine  $w$  and  $q$ . Thus, a proper treatment of a process requires examination of the entire universe of the experiment (that is, the system plus all parts of the surroundings involved in the experiment) and leads naturally to the global formulation of thermodynamics [1,4,5], a powerful approach to thermodynamics. The alternative, system-based approach to determining  $w$  and  $q$ , which is also widely used, is to make measurements in the system before, during, and after the process to define both  $w$  and  $q$  [3]. These are referred to as “sys-based” definitions. More details for both approaches are given below. Here we simply note that authors using the surr-based approach [6] typically define pressure-volume work  $w$  as  $-\int P_{\text{ex}}dV$ , where  $P_{\text{ex}}$  is some pressure external to the system,  $V$  is the volume of the system, and authors using the sys-based approach [7] define  $w$  as  $-\int PdV$ , where  $P$  is the system’s pressure.

Let us now consider a specific example. An apparatus that will allow us to treat pressure and volume as independent variables is shown below:



The gas is the system. It is assumed that the piston can move up and down inside the containing cylinder, and there is a vacuum above the piston. There may be friction between the piston and cylinder. When the gas and piston are in mechanical equilibrium, the pressure exerted by the piston on the gas is

given by  $mg/A$ , where  $m$  is the mass of the piston plus additional weights put on top of the piston,  $g$  is the acceleration due to gravity, and  $A$  is the cross sectional area of the piston. Thus,  $P = mg/A$ . We see that the equilibrium pressure  $P$  of the gas can be varied by varying  $m$ . Alternatively, we assume that the piston can be locked at any given height  $h$  above the bottom of the cylinder. In that case, the volume of the gas is given by  $V = hA$ , and the volume of the gas can be set to any given value by moving the piston up or down and then locking it into place. An alternative to the apparatus depicted in the figure is to have the atmosphere acting as the piston. This alternative description could apply to liquid and solid systems.

Let us consider a process that involves the piston moving from a lower height  $h_1$  to a higher height  $h_2$ . In what follows forces rather than pressures are initially used because frictional forces are difficult to picture as pressures. Nevertheless, the entire analysis can be recast in terms of pressures by dividing each force by the cross-sectional area  $A$  of the piston. There are three forces that act on the piston as it moves [1]. First,  $F$  is the instantaneous force exerted on the piston by the system, i.e., the gas. Note that  $F > 0$ , i.e.,  $F$  is exerted upwards. By Newton’s third law,  $-F$  is the force exerted by the piston downwards on the system. If the system is at equilibrium, then  $F = PA$ , where  $P$  is the equilibrium pressure of the system. If, on the other hand, the piston is moving, the quantity  $F/A$  is often referred to as  $P_s$ , the instantaneous pressure exerted by the system on the *surface* of the piston. It must be emphasized that  $F$  and  $P_s$  are, in general, not measurable as the piston moves. The second force acting on the piston is  $-mg$ . The third force is  $F_{\text{fr}}$ , which includes all nonconservative (frictional) forces exerted on the moving piston by the surroundings. In the present case, at the very least, it would include any frictional forces between the piston and the cylinder. In all cases  $F_{\text{fr}} < 0$  when the piston is moving up, and  $F_{\text{fr}} > 0$  when the piston is moving down. The forces  $F$  and  $F_{\text{fr}}$  are normally not known unless the piston is at rest. Further discussion of these three forces is given in the earlier paper [1].

Now consider a process where the catch is removed, and the piston moves from height  $h_1$  to  $h_2$ . We assume that the initial pressure of the gas exceeds  $mg/A$ , so the piston rises rapidly, overshoots  $h_2$ , then falls, rises again, and oscillates until coming to rest at  $h_2$ . In the general case the piston could have kinetic energy  $K_1$  when at  $h_1$  and  $K_2$  at  $h_2$ , but we assume here for simplicity that  $K_1 = K_2 = 0$ . A well-known theorem of classical mechanics [1] states that the total work  $W_{\text{tot}}$  done on the piston by all of the forces during the process equals the net increase of kinetic energy of the piston.  $W_{\text{tot}}$  does *not* represent the thermodynamic pressure-volume work in either the surr-based or sys-based definition. For this experiment the theorem can be written

$$W_{\text{tot}} = K_2 - K_1 = 0 = \int_{h_1}^{h_2} (F - mg + F_{\text{fr}}) dh. \quad (1)$$

The total change in energy of the piston, which is purely mechanical, is given by

$$\Delta E(\text{piston}) = mg(h_2 - h_1). \quad (2)$$

This result for the piston involves only energy changes in the surroundings and is, in fact, the negative of  $w$  for this process obtained in the *surroundings-based* definition of  $w$  [1]. Thus, Eqs. (1) and (2) can be combined to give

$$w(\text{surr-based}) = -\Delta E(\text{piston}) = -\int_{h_1}^{h_2} F dh - \int_{h_1}^{h_2} F_{fr} dh. \quad (3)$$

The last term on the right does not correspond to a traditional thermodynamic work term. Rather, it represents a conversion of some mechanical energy from the surroundings into thermal energy. This thermal energy is initially created in the surroundings but can end up in the surroundings or the system or partially in each. With surr-based definitions [1] it can be shown that the fraction of the thermal energy that ends up in the surroundings contributes to  $q$ , and the fraction that ends up in the system does not contribute to either  $q$  or  $w$ . By contrast, with sys-based definitions [3] the fraction of the thermal energy that ends up in the system contributes to  $q$  but not  $w$ , and the fraction that ends up in the surroundings does not contribute to either  $q$  or  $w$ .

The *system-based definition of pressure-volume work* for the process considered here is [3]

$$w(\text{sys-based}) = -\int_{h_1}^{h_2} F dh = -\int_{V_1}^{V_2} P_s dV, \quad (4)$$

where the second integral uses the definition  $P_s = F/A$  discussed earlier. This definition is used by a large number of authors [7]. Equation (3) can now be rewritten as

$$w(\text{surr-based}) = w(\text{sys-based}) - \int_{h_1}^{h_2} F_{fr} dh. \quad (5)$$

It is apparent that surroundings-based and system-based definitions will not always give the same values of  $w$ , but they will when  $F_{fr} = 0$ . In a reversible process  $F_{fr} = 0$  and  $P = P_s$ . Consequently, Eqs. (4) and (5) give

$$w(\text{sys-based, rev}) = w(\text{surr-based, rev}) = -\int_{V_1}^{V_2} P dV. \quad (6)$$

The last term in Eq. (5) is positive, since  $F_{fr}$  has the opposite sign from  $dh$  whether the piston is moving up or down. Consequently,

$$w(\text{sys-based}) \leq w(\text{surr-based}), \quad (7)$$

where the equality holds if and only if  $F_{fr} = 0$ , i.e., a frictionless piston. For most real processes  $F_{fr} \neq 0$ , so system-based and surroundings-based work values will be different. An important exception is when the atmosphere acts as the piston and  $F_{fr} = 0$ .

A first impression about Eq. (7) might be that one of the two definitions of  $w$  must be wrong, because the first law requires that

$$\Delta U = w + q. \quad (8)$$

In fact, the proper conclusions to draw are that the two definitions of  $q$  are different as well and that Eq. (8) is always valid. The surr-based and sys-based definitions of  $q$  are given in our recent papers [1,3]. Combining Eqs. (7) and (8) allows us to write for a given process that

$$q(\text{sys-based}) \geq q(\text{surr-based}). \quad (9)$$

If the apparatus shown above is placed in a large water-bath calorimeter and has good thermal contact with it, then for the expansion process considered above [1]

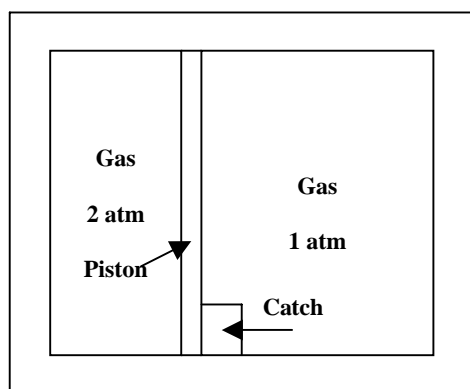
$$q(\text{surr-based}) = -C_p(\text{cal})\Delta T = -\Delta H(\text{cal}), \quad (10)$$

where  $C_p(\text{cal})$  and  $H(\text{cal})$  are the constant-pressure heat capacity and enthalpy function of the calorimeter, and  $\Delta T$  is the temperature change in the calorimeter. This definition is consistent because the calorimeter is in the surroundings. Note that  $q(\text{surr-based})$  is given by the change in a state function of the calorimeter. From Eqs. (9) and (10) we immediately conclude that  $q(\text{sys-based})$  cannot be related to a change in temperature of a calorimeter except in the special case where  $F_{fr} = 0$ .

A more complete discussion of the two approaches to defining  $w$  and  $q$  are given in the author's recent paper [3]. There we have fully developed the sys-based definitions and have given a number of reasons why surr-based definitions of work and heat are preferred. We highlight three here. First, in the definition of  $w(\text{sys-based})$  in Eq. (4) the integral of  $P_s$  usually cannot be evaluated for irreversible processes, which means that  $w(\text{sys-based})$  often cannot be determined. By contrast,  $w(\text{surr-based})$  does not require the evaluation of that integral and  $w(\text{surr-based})$  can be determined for irreversible processes. Second,  $w(\text{surr-based})$  and  $q(\text{surr-based})$  always require the evaluation of changes in thermodynamic state functions in the surroundings. In general, these quantities are straightforward to determine [see Eqs. (2), (3), and (10)]. By contrast, the integral  $\int P_s dV$  in Eq. (4) does not represent the change in any state property of the system. Third, we have shown [3] that  $w(\text{sys-based})$  does not always satisfy the theorem of maximum work, which states that for a constant-temperature process  $-w \leq -\Delta A$ , where  $A$  is the Helmholtz free energy of the system. By contrast  $w(\text{surr-based})$  always satisfies the theorem of maximum work.

The superiority of surr-based definitions is illustrated by the following example. In 1964 Bauman [8] posed a simple thermodynamic process and challenged people to determine the work in the process. There was much discussion at the time [9-11] and one author [11] argued that the work could not be determined. In fact, we have determined the value for  $w$  [1], but it remains the only solution to date for this problem. The experiment is shown below. Two portions of an ideal gas at temperature  $T$  inside a closed cylinder of constant volume are separated by a *massless, frictionless piston* held by a catch. The piston has negligible heat capacity and can conduct thermal energy between the two subsystems. In addition, all surfaces of the rigid container are adiabatic so that the two samples of gas plus the piston are completely isolated from the rest of the universe. This arrangement guarantees that the two gases have the same final temperature  $T$ . There is 1 mol of gas on each side of the piston; one gas is initially at 2 atm and the other initially at 1 atm. When the catch is released, the piston initially moves toward the lower pressure gas but then

oscillates back and forth with diminished oscillations around its final resting place. At the end each gas has a pressure of  $4/3$  atm and temperature  $T$ . A complete analysis is given in the earlier paper [1]. Here we simply note that if the high-pressure gas is the system, then  $w(\text{surr-based}) = -RT \ln(4/3)$  and  $q(\text{surr-based}) = RT \ln(4/3)$ . In addition,  $\Delta A = -RT \ln(3/2)$  for the high pressure gas, so  $-w + \Delta A = RT \ln(8/9) < 0$ , as required by the theorem of maximum work. By comparison,  $\int P_s dV$  cannot be evaluated, so  $w(\text{sys-based})$  and  $q(\text{sys-based})$  cannot be determined. It is clear, then, why no other solution of this problem has appeared in the literature.



In conclusion, we emphasize two points about the development in this paper and other papers in this series [1-3]. First, work and heat can be defined using either surr-based or sys-based definitions, but the two sets of definitions often given different results. Nevertheless, the first law in the form of Eq. (8) is valid for both sets of definitions, and thermodynamics can be developed using either set of definitions. Since the definitions do give different results, it is critical that the definitions be clearly stated and used consistently. It is not acceptable to compute  $w$  from a surr-based definition and  $q$  from a sys-based definition or vice versa. Second, the authors strongly advocate using surr-based definitions [1] for work and heat. These definitions are more general and can be applied to irreversible processes where sys-based definitions cannot give either  $w$  or  $q$ . Handling real (that is, irreversible) processes is essential to a full realization of thermodynamics.

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*Eric A. Gislason is Professor of Chemistry at the University of Illinois at Chicago.*

*Norman C. Craig is Emeritus Professor of Chemistry at Oberlin College, Oberlin, OH 44074*

## Activity-Based Statistical Physics for First Year Physics Students

Mark B. Schneider

### Introduction

Over the past 12 years, I have developed and taught at Grinnell a two-semester general physics course that has attempted to merge the techniques of Priscilla Laws' Workshop Physics<sup>1</sup> (no lecture, hands-on, discovery-based group learning) with the goals of the Introductory University Physics Project<sup>2</sup> (a more contemporary and manageably sized set of topics). The result has been a full set of activity guides that include a number of modern physics topics. The first semester includes roughly a third of the semester devoted to quantum and statistical physics. This material is approached in a theoretical manner, rather than the historical approach (e.g. Bohr atom) usually used for quantum topics or the phenomenological approach (e.g. thermal expansion) typically used for thermal physics.

At Grinnell, we do not teach an algebra based physics course. A couple of decades ago, we dropped the algebra based course when it was discovered that even among the dwindling enrollment in that class, fewer than a handful of students failed to have the minimal calculus co-requisite. I don't think Grinnell's faculty is unusual in being pleased with that change; algebra based physics is forced to rely on *ad hoc* introduction of too many under-motivated formulas, whereas calculus based physics has the power to explain many complex phenomena with a few simple principles. I see the goal of our approach to statistical physics in a similar vein: present a few reasonable fundamental principles that allow us to derive a range of concrete and practical results. I also hope to surprise students that the definitions of temperature and thermal equilibrium are not as simple as they have been led to believe.

Our study of statistical physics comes at the end of the first semester, where it builds on a basis of quantum physics that is just previously established in the course. Students already know about quantized energy levels, the quantum particle in a box, and the basic features of the hydrogen atom. In the four lab-based sessions that follow these topics we introduce the fundamentals of statistical physics: microstates, entropy and temperature, the Boltzmann factor and ensemble averages.

### The Activities

The first session deals with a two-state system, couched in the language of choices among equal probability configurations. The students are confronted with the question of what keeps the air so uniformly distributed in a balloon if the molecules "choose" randomly whether to be on the left side or the right side. We model this by rolling large numbers of dice (flipping coins would work as well); each die represents a molecule and a result of 1, 2, or 3 corresponds to the left side and 4, 5, or 6 the right. Each group has ten dice that they roll ten times; they then histogram the results to give a frequency distribution of left/right splits for a ten-molecule system. Combining data from all eight groups gives the equivalent data for an eighty-molecule system, or can be combined differently

to give 80 samples of the ten-molecule system. Students readily observe that the distribution becomes smoother with more data, and narrower for more molecules. Students then analytically describe all possible combinations and use a spreadsheet program to model those distributions. In particular, they verify that the relative width of the distribution is inversely proportional to the square root of the number of molecules, explaining the lack of fluctuations in macroscopic samples.

The second session extends the two-state system to define macrostates and microstates. The concrete analog used involves coins; the macrostate property reflects only the number of heads and tails, whereas the microstate identifies the state of each coin (penny, nickel, dime, quarter serve as convenient markers for this, although one could also use minting date, etc.). We revisit the probability discussions of the previous session in this new language: the probability of a macrostate is proportional to the number of microstates. I use a short diatribe on the difficulty of very large numbers to motivate the use of the logarithm to tame them, leading to the definition of the entropy. We calculate entropies of two-state systems using the Stirling approximation. At this point we touch base with quantum physics, and note that different quantum states in general have different energies, and adopt energy as our default macrostate marker. We then examine what happens to two systems that are allowed to exchange energy, using spreadsheet modeling. With the assumption that equilibrium occurs when probability (and therefore entropy) is maximized, we arrive at the standard statistical definition of the temperature as the inverse of the derivative of entropy with respect to energy. I take pains to point out this is *not* the same as average kinetic energy per atom.

The third session takes the definition of entropy and the assumption of probability being proportional to the number of microstates to derive the Boltzmann factor as the relative probability of two quantum states. This is found by taking the two-system model of the previous session and decreasing one of the systems to a single two-state atom, and expanding the other system to be so large as to make the average energy changes negligible. We then do several examples of converting relative probabilities for two-state and few-state systems into absolute probabilities, and name the normalizing factor the partition function.

The final session takes the notion of absolute probability and uses that to calculate an ensemble average energy. First this is done analytically for a simple two-state system, and then done computationally (using a spreadsheet) for the energies of a quantum particle in a one-dimensional box. This energy is convincingly close to  $1/2NkT$  and avoids unpleasant integrations that most introductory-level students are unprepared to appreciate. It is argued that extension to three dimensions involves summation of three identical columns of weighted energies instead of just one, so the energy of the ideal monatomic gas is found. We relate energy changes to pressure as  $\Delta E = P\Delta V$ , and the ideal gas law is derived. Students then experimentally verify this law (or equivalently, measure absolute zero) with some commercially available apparatus to measure pressure as a function of temperature.

### **Results and Future Directions**

The question is naturally raised: do the students “get it?” Do they leave the course with an appreciation for the conceptual underpinnings of statistical physics? And do they learn a few practical results? Our experience leads us to answer with a qualified yes. There is no question that the students seem at least as capable of dealing with the abstract concepts of statistical physics as with other abstract concepts in introductory physics (electric fields and potentials come to mind). Certainly the effort to show that large numbers of particles convert scattered, random results (like rolling a die) into virtual certainty (like the uniformity of density of the air in a balloon) is successful. Students do seem to have an understanding of concepts such as the increase of entropy, the ideal gas law, and the Boltzmann factor, but many of our students have been exposed to these in other classes, either in high school, or in introductory chemistry (which most of our students take prior to this course).

Nevertheless, I believe the approach to these perhaps already familiar topics taken in this course is so fundamentally different from that provided in introductory chemistry as to provide useful insights into the underpinnings even for students who are quite familiar with the use of these concepts. Moreover, roughly half of our students will go on to see a more advanced treatment of statistical mechanics presented either in a physical chemistry or statistical physics class, and this approach gives an “ $F=ma$ ” style introduction to the basic principles that leads usefully into a more advanced course. Our course also presents the unusual situation of having introduced the quantum particle in a box energy levels before approaching thermal physics. This is essential for the derivation of the ideal gas results.

Where might we go from here? It would be easy to lead from the results we develop in the four sessions to another session that deals with macroscopic effects such as efficiencies of heat engines, incorporating ideal gas results and inferring work from  $PV$  diagrams. One could also take a more fundamental (if less practical) step and connect the three major themes of the course (Newtonian mechanics, quantum

mechanics, and statistical mechanics) and show how a combination of the latter two predicts the statistical results of the former, that is, that mechanical systems spend a larger fraction of the time at higher energy states (e.g. the harmonic oscillator spends more time at the extremes of motion where the velocity is low), even as dissipative processes cause them to settle into lower energy states. We are investigating each of these possibilities, although the already tight scheduling of the course makes an extensive expansion of the statistical portion of the course difficult without cutting other elements.

### **Acknowledgements**

The activity guides (workbook-like materials) for the statistical physics section of the course, as well as all activity guides for both semesters of the course, are available as PDF files on the web<sup>3</sup> or directly from the author. Early developments of activity-based statistical physics at Grinnell benefited from contributions by Dr. Andrew McDowell and Prof. Paul Tjossem.

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- <sup>1</sup> Priscilla W. Laws, “Workshop Physics,” *Physics Today* **44**, 24-31 (Dec 1991). The Dickinson group also maintains a website related to the course [http://physics.dickinson.edu/~wp\\_web/WP\\_homepage.html](http://physics.dickinson.edu/~wp_web/WP_homepage.html)
- <sup>2</sup> A good retrospective is available from L. A. Coleman, D. F. Holcomb, and J. S. Rigden, “The Introductory University Physics Project, 1987-1995: What has it accomplished?” *Am. J. Phys.* **66**, 124-137 (1998).
- <sup>3</sup> All of the activity guides are available at the Grinnell College Physics Department curriculum development web site <http://www.grinnell.edu/academic/physics/curricdev>

*Mark B Schneider is Associate Professor of Physics at Grinnell College.*

## **No Child Left Behind: An Update for Physicists**

*Stan Jones*

A short while ago, I wrote an article in this newsletter expressing my concern about the potential impact of the No Child Left Behind (NCLB) Act. My concern ran along two lines: (1) where will high schools find “highly qualified” physics teachers? and (2) how will teachers become “highly qualified teachers (HQT)” in more than one area, in order to work fulltime in schools that only offer one or two physics classes? My innate pessimism seems to have been misplaced. New, more flexible, policy guidelines from the US Department of Education make for a substantially more reasonable approach to filling our high school science classes with truly qualified teachers. But there may be loopholes.

Consider the following quote taken from the NCLB website:

*No Child Left Behind requires states to fill the nation's classrooms with teachers who are knowledgeable and experienced in math and science by 2005. The president supports paying math and science teachers more to help attract experience and excellence.*

I hate to sound optimistic, but this policy (it is not new, just overlooked) does seem promising. There is unquestionably a shortage of qualified teachers of physics in our high schools. To attract more physics teachers, higher salaries are clearly needed. This market-driven solution has already been applied

in colleges and private sector compensation practices. NCLB may be the motivating factor for improving the salaries of high school science teachers on a large scale.

On another issue:

*Under this new policy, teachers in eligible, rural districts who are highly qualified in at least one subject will have three years to become highly qualified in the additional subjects they teach. They must also be provided professional development, intense supervision or structured mentoring to become highly qualified in those additional subjects.*

The problems of rural schools, whose physics teachers must often also teach math, chemistry, or another academic discipline, seem also to have been addressed by the new, more flexible policies adopted by the federal government. Realistic procedures for attaining highly qualified status in multiple subjects, short of earning a degree in each subject, are now in place. The states must take advantage of this new policy.

But here is a possible loophole:

*Now, states may determine--based on their current certification requirements--to allow science teachers to demonstrate that they are highly qualified either in "broad field" science or individual fields of science (such as physics, biology or chemistry).*

What does "broad field" mean? My state (Alabama) has a certification for "Comprehensive Science" that requires only 12 hours of physics. If this policy is allowed to continue under NCLB, then we will have made no progress at all. Currently, most science education majors in Alabama earn this certification, and are poorly prepared to teach physics.

For those teachers seeking separate certification as HQT in different subjects, the new policy below is helpful:

*Under the new guidelines, states may streamline this evaluation process by developing a method for current, multi-subject teachers to demonstrate through one process [rather than separate procedures for each topic] that they are highly qualified in each of their subjects and maintain the same high standards in subject matter mastery.*

Is there room for pessimism? Of course. This is education, after all. The main source of concern is the budget. School districts need to find resources in order to pay the higher salaries demanded by the market. The US government, through NSF and the Department of Education, is providing substantial grant money through its Partnership program; this will help to develop new teaching excellence. It will not, however, provide salaries. The nation's citizens must recognize the need for science education, and come to the table with more tax dollars.

I have done, via Google, a nonscientific survey of salary policies around the Internet, and have yet to find a school district offering differential salaries depending on subject. I would be very interested to know whether there are schools offering higher salaries in order to recruit physics teachers.

I am aware of school districts that offer "bounties" to science teachers. One-time signing bonuses of \$6000 are offered to science teachers by the Mobile, AL school district, as an example. Other districts are doing the same, and placing pressure on those schools that cannot compete.

Interestingly, the new demands on teacher preparation, and the expectation that higher salaries will be needed, may lead to the much-needed professionalization of the K-12 teaching corps. Looking back at articles written by Ken Heller and by myself in the Spring and Summer 2001 issues of the FED Newsletter, I note that competitive salaries, and a greater command of academic subjects, are two of the criteria set forth for establishing teaching as a true profession. Teachers who are expected to be knowledgeable in their subject, and who are treated accordingly, will enjoy a higher status in our society. If we want to attract our top students into the teaching field, this is the direction we must move.

What do we, as physicists, need to do now that the NCLB policies have been more clearly defined? We cannot expect things to change automatically. It takes a long time for perceptions to change, and most physics students today have a negative perception of the teaching field. We need to recruit students into the teaching profession, and we should provide appropriate undergraduate curricula to prepare them. Many colleges have a separate track for the physics major leading to high school teaching certification. More of these are needed, and we need to advertise them in order to recruit good students.

We also need to lobby our school boards to take advantage of the new policies. Establishing clear and realistic procedures for teachers to attain highly qualified status in multiple disciplines is a responsibility for the state boards of education. We should be involved in the process of developing these procedures. Establishing competitive salaries is typically a local school board responsibility. We need to do what we can to make this happen.

*Stan Jones is Professor of Physics and Astronomy at the University of Alabama.*





## Section on Teacher Preparation

### Welcome to the New Teacher Preparation Section

*Chance Hoellwarth-Editor*

Welcome to a new section of the APS Forum on Education Newsletter, one devoted to teacher preparation. The purpose of this new section is to showcase and explore ways the physics community can help prepare K-12 science teachers.

Preparing science teachers may seem like a strange endeavor for the physics community, but it is important for our future. Teachers influence the science literacy of the general population, which influences the funding of science. Elementary teachers prepare and influence the students who enter (or don't enter) high school science classes. High school science teachers prepare and influence the students who enter (or don't enter) our university physics programs. University physics teachers help prepare and influence future teachers and physicists. Future teachers go back to influence students and the cycle is complete. Thus the future of science both in terms of future scientists and support depends on how well we prepare future science teachers.

Many of us already believe teacher preparation is important. Last year, 259 physics departments endorsed a statement saying they were committed to preparing better science teachers (<http://www.aps.org/educ/joint.cfm>). Maybe your department signed; maybe it didn't. Either way, you (as a member of the physics community) have an interest and a part to play in the preparation of science teachers.

Which brings us to the real issue: How does one better prepare science teachers? Preparing teachers is a daunting task. Luckily, you don't have to figure out how to do it alone. Members of the physics and education communities are already successfully preparing future science teachers. The purpose of this section of the newsletter is to tell their story so that you (and your institution) can take the ideas and the tools that they have developed and implement them at your institution in order to improve (or begin) your teacher preparation effort. Therefore, if you have stories to tell, let me know about them.

What if I told you there are people near you who are interested in preparing science teachers? Wouldn't that be great news? The fact is these people do exist. They are your local K-12 teachers. Many of them are passionate about teaching and they want to help you prepare teachers. It is possible to partner with local teachers and form what is called a Teacher Advisory Group (TAG). In this issue we will hear from three institutions that have done this: University of Arizona, University of Colorado, and Ball State University. They each have a different story to tell.

*Chance Hoellwarth is Assistant Professor of Physics at California Polytechnic State University (Cal Poly), San Luis Obispo.*

### An Advisory Group to Provide Input in the Preparation of Future Teachers

*David Grosnick*

With the advent of the Physics Teacher Education Coalition (PhysTEC) program [1] at Ball State University in 2001, a Teacher Advisory Group (TAG) was formed to provide ideas and guidance to the members of the PhysTEC team in the training of pre-service science teachers. In addition to university faculty, individuals were selected to be members of the TAG because they were external to the university, yet at the same time knowledgeable about the science teacher preparation curriculum and program at Ball State. The TAG has provided assistance in a variety of aspects related to the implementation of the PhysTEC goals, such as course revision, assessment techniques, and the induction and mentoring of new teachers.

A major problem that faces the science-education community is that a large fraction of science teachers leave the profession. Data show that as many as 40% of these teachers leave within the first 5 years [2]. The PhysTEC program was initiated in part to address this problem. The goal is to increase the number of well prepared pre-service teachers and to actively follow their progress in their first few years of teaching. Since it is a common belief that teachers "teach the

way they were taught," a revision of the science content courses, as well as the science education courses, toward more active, student-centered learning methods was implemented.

One of the goals of the PhysTEC program is to bring together university faculty in the schools of education with those in the content courses (specifically in physics departments). All too often there is a lack of communication between the schools. This can hinder progress toward better educating prospective science teachers. Through discussion in the TAG, each group has an opportunity to view how the other operates and to make suggestions regarding the goal of improving science education.

Our TAG was originally formed in the spring of 2002 with the goal of planning implementation of the major components of the PhysTEC program, but its role has since evolved to addressing broader issues. It is modeled on the Department of Physics and Astronomy's Industrial Advisory Committee, a group that offers insight into local and state industrial concerns and gives advice on how the university's program might better prepare students for those markets. It is further based on the model of advisory groups that exist in large particle-physics

experiments, where regular technical reviews are common for overseeing the feasibility and readiness of complex detector components.

Another essential aspect of the PhysTEC program, which has greatly enhanced the TAG, is to bring a high-school or middle-school master science teacher into the university environment for one year as a Teacher-in-Residence (TIR). The tasks of the TIRs are many and diverse, but they include: identify and mentor the pre-service and recently-graduated science teachers; assist in the college classroom and in the course revision process; serve as a resource for classroom demonstrations; and together with students to provide outreach to the science teaching profession.

At Ball State University, each TIR has had his own emphasis and imprint on the PhysTEC program. Initially, the TIRs were active in course reform, designing more inquiry-based laboratory activities. A later TIR was actively engaged in the induction and mentoring of pre-service and new teachers (mostly at the high-school level). During his time as TIR, he rode a circuit throughout the state in support of this activity. This has fit in especially well with the new state program in mentoring new teachers. Another TIR at Ball State was interested in initiating research programs at the high-school level, such as analyzing seismic data, and involving high-school students in research at an early stage.

The TIRs have been an integral part of the TAG. Since they are a liaison between the university and high schools or middle schools, have extensive experience in the classroom, and have the necessary background in both education and science content courses, they serve as leaders of the TAG and often guide the discussion. They have set the programs for the TAG meetings, often linking these programs to their own interests and specialties. The TAG has also served as an opportunity for prospective TIRs to become familiar with the PhysTEC program and to meet current and past TIRs.

Members of the TAG have been selected from diverse backgrounds in order to provide a variety of opinions and advice. At the university level, members are selected from the physics department, science-education faculty, and Teachers College (the latter is where the education faculty and students reside, while the science-education faculty are part of the Department of Biology). Current and past TIRs are also members of the TAG, as are some of their in-service teacher mentees. Other important members are in-service teachers from the area who have extensive knowledge of the teacher education program. Some have been graduates of Ball State University's science-education program. Members of the Department of Education in the state of Indiana have also served on the TAG, including a member of the state Professional Standards Board and the state science consultant. Several guests have joined the TAG meetings from time to time. These have included the PhysTEC leadership team, the state consultant on induction and mentoring, and several of the pre-service teachers who were students in the PhysTEC-

influenced classes. One of the most recent TAG members, now a high-school science teacher, served as the Teaching Assistant for the very first introductory physics class under the PhysTEC program. The number of members on the TAG is normally between twelve and fifteen.

The TAG meetings have consisted of discussions covering a wide range of topics. In the beginning, brainstorming sessions were held on how to implement the PhysTEC program and meet its goals. Plans were made not only for the university, but for a possible outreach to former students, who are now teaching in schools throughout the state. Questions such as developing an introductory physics course solely for pre-service teachers were debated, along with issues related to course reform. Another TAG meeting included several of the pre-service teachers in order to solicit their opinions and suggestions about the science content courses and the science education program in general. At yet another TAG session, the TIR, along with a guest consultant, presented information on the induction and mentoring of in-service teachers, the new state program in that area, and methods used to improve retention.

We have discussed ways to assess progress in the different areas of the PhysTEC program. An assessment template was developed and passed along to the national PhysTEC program. The most recent meeting featured presentations of possible research projects in which high schools may become involved with universities or national laboratories. Typically, the TAG meets once during the semester.

The Teacher Advisory Group has been a valuable resource for the science-teacher education program. Suggestions, opinions, and insights from this diverse group have greatly enhanced the quality of science teacher education at Ball State University.

### References

[1] For more information on PhysTEC, please see the website, <http://www.phystec.org>, or <http://www.ptec.org>, and references therein.

[2] Richard M. Ingersoll, "Turnover Among Mathematics and Science Teachers in the U.S.," Report to the National Commission on Mathematics and Science Teaching for the 21<sup>st</sup> Century, Chaired by John Glenn, (February, 2000). (<http://www.ed.gov/inits/Math/glenn/compapers.html>)

*David Grosnick is Assistant Professor of Physics and Astronomy at Ball State University.*

## Partners in the Preparation of Secondary Science Teachers

*Ingrid Novodvorsky*

### **Overview of College of Science Teacher Preparation Program**

The College of Science Teacher Preparation Program (TPP) was established at the University of Arizona in 1999, to provide preparation for prospective middle and high-school science teachers within the College of Science. Faculty members in the program are affiliated with various content departments, including physics, chemistry, molecular and cellular biology, astronomy, and biochemistry. They also function as members of an interdisciplinary team in managing the program, teaching its courses, and advising students. Students in the program have two different degree options that lead to eligibility for teacher certification. They may remain in their science-degree programs, and take an additional 30 credits of coursework in science teaching, or they may enroll in a B.S. degree in Science Education, with concentrations available in biology, chemistry, earth science, or physics. Each of the concentration options includes the 30 credits of science-teaching coursework, and at least 45 credits of science coursework.

The 30 credits of science teaching coursework are spread among seven courses, including a semester-long student teaching experience. Four of the courses that students take prior to student teaching include field experiences in area middle and high schools. These field experiences range from 20 hours of observations in the first two courses, to 8-week internships in the last two courses. Thus, students participate in approximately 140 hours of field experience before they begin their student teaching.

While the program faculty is responsible for teaching the on-campus courses in the program, it was clear from the very beginning that we needed the support and assistance of area secondary science teachers. During the planning stages of the program, the initial faculty members invited area teachers to a series of forums designed to gather their input on an ideal science teacher preparation program. These forums also served to begin building valuable partnerships with area science teachers, a partnership that continues to support the program on many levels.

We have hired three experienced science teachers, following their retirement from area schools, to work with the program as adjunct instructors. In addition, we have secured grant funding to hire Teachers-in-Residence, who leave their classrooms to work on campus for a year at a time. The presence of experienced teachers in key program roles has provided credibility in the eyes of science teachers in the community, which has strengthened their willingness to work with the program. In addition, area science teachers have a great deal of ownership in the program, further strengthening this important partnership. The following sections describe how these partnerships were established, how they are maintained, their impact on the program, and future directions.

### **Creation and Nurturing of Partner Group**

During the summer of 2000, prior to the first semester of enrolling students in the TPP, we obtained funding to form a teacher advisory group, identified as Partners in the Preparation of Science Teachers (PEPST). The funding was provided by the Arizona Board of Regents through the Eisenhower Math and Science Education Act, and included stipends for participating in the summer workshop and attending monthly meetings during the school year. The goals for the first year of PEPST were

- 1) Formation of a professional learning community of teachers and science teacher educators,
- 2) Construction of a set of tasks for use when preservice teachers observed mentor teachers' science classrooms, and
- 3) Development of a written philosophy regarding the preparation of future science teachers.

To begin building that professional learning community, we spent much of the first summer workshop writing observation tasks for the introductory science-teaching course. Those tasks, which have been refined over the years, are still used today, and mentor teachers uniformly recognize their value in giving these classroom observations a purpose and directing our students' attention toward aspects of the classroom that they might not otherwise notice.

The summer workshops, which continued during three subsequent summers, each focused on pertinent needs of the program as it developed. The outcomes for the second year were:

- 1) Ongoing development of a partner "study group" focused on excellence in mentoring preservice science teachers,
- 2) Revision of a set of inquiry-centered teaching tasks developed and piloted in PEPST teachers' classrooms during the project's first year, and
- 3) Documentation of the preservice teachers' performance on the PEPST-designed teaching tasks.

In addition to the products that resulted from the workshop, we continued to increase our pool of PEPST partners, and thereby, the pool of classrooms in which we could place our students for their field experiences and student teaching. By the third summer workshop, we were ready to focus more on the professional development of our mentor teachers. The foci of the third year were:

- 1) College of Science TPP study to re-review the program
- 2) A professional study of the roles and responsibilities of successful mentor teachers,
- 3) A professional study of pedagogical content knowledge (PCK), and
- 4) A professional study of the mentoring and development of preservice teachers' PCK

In the final summer that these workshops were funded, we divided the workshop into two parts. First, we invited new PEPST partners to meet with us for three days to learn about the program and what we ask of our mentor teacher partners. Second, new and returning PEPST partners spent a week developing tasks based on videos that had been filmed in their classrooms. These tasks are used in all of the science-teaching

courses, and illustrate important aspects of communication, classroom management, and teaching strategies.

In addition to the summer workshops, we invite our PEPST partners to monthly meetings during the school year. At these two-hour meetings, we ask the partner teachers for feedback on the students they are currently mentoring and input on program decisions, as well as provide professional development. For example, we have provided them with samples of our students' work and asked them to analyze these samples for evidence that the students understood the rationale behind a teacher's instructional decisions.

### ***Impact of PEPST***

The impact of our PEPST partners on the TPP has been substantial. The partner teachers have provided valuable advice on all aspects of the program, much of which we have incorporated into the program. Because of this, the PEPST partners believe themselves to be equal partners in science teacher education, and they have become enthusiastic advocates of our program. As a testament to this, at our monthly meetings during the academic year held at 4:00 p.m. on a Friday typically 30-40 teachers attend. This feeling of being connected to the program is also conveyed in teachers' responses to post-workshop questionnaires.

As a direct result of PEPST partners' impact on the program, they are eager and willing to have our students in their classrooms. We utilize approximately 70 area science teachers each semester for our field experiences, and some 50 of those are PEPST partners. Our partners are free to choose the level of involvement that best fits with their needs each semester; i.e. observers, interns or student teachers. In addition, many PEPST partners report that they have declined to accept preservice teachers from other programs in favor of TPP students. (Mentor teachers also receive a stipend for working with our preservice teachers; these are paid with TPP operation funds.)

Another aspect of the impact of PEPST is our ability to recruit Teachers-in-Residence to work with the TPP. A Teacher-in-Residence (TIR) joins us for a year to co-teach classes, supervise field experiences, and participate in program management. We currently have funding through the Physics Teacher Education Coalition (PhysTEC) to support a physics TIR, and through the Howard Hughes Medical Institute to support a biology TIR. The teachers that apply for these positions have all been PEPST partners, and their work with the program in that capacity provides the encouragement they need

to leave their classrooms for a year to work on the university campus.

### ***Future Directions***

We are committed to maintaining a strong community of mentor teacher partners to work with our preservice teachers and advise us on the TPP. Thus, one critical future direction is to recruit more science teachers into the PEPST partner group. While we recognize the increased value of placements in classrooms of teachers who know the program and what we expect, as our program has grown, we have had to place students in the classrooms of non-partner teachers. In addition, our mentor teachers need an occasional break from mentoring preservice teachers, so we need to expand the pool in order to accommodate that. We have learned that simply sending invitations to join the partner-teacher group is not very effective in recruiting busy professionals. Thus, we will be restructuring the work of our adjunct instructors to focus attention on going out to area schools to recruit additional mentor partners.

The summer workshops and monthly meetings have become a core aspect of the program for our teacher partners. Unfortunately, we did not have funding to continue them last year. Nonetheless, teachers requested opportunities to meet with TPP faculty members and other mentor teachers to continue their work with the program. Thus, securing funding to continue to support the PEPST activities is another critical future direction for our program.

Our partnership with area science teachers has reaped several benefits for the TPP. We have developed a cadre of mentor teachers eager to work with our students, and who are familiar with the program and feel a sense of ownership in it. We have greatly improved relationships between our TPP and area schools because we welcome and utilize teacher input. And, we have built a professional community of science teacher educators willing to work together to provide exemplary experiences for preservice science teachers.

*Ingrid Novodvorsky is Assistant Professor of Physics at the University of Arizona.*

## **CU Physics Education: Recruiting and Preparing Future Physics Teachers**

*Noah Finkelstein, Michael Dubson, Christopher Keller, Steven Pollock, Steve Iona, and Valerie Otero*

Over the past several years, the University of Colorado at Boulder (CU-Boulder) has dramatically expanded its efforts to recruit and nurture the highest caliber future high school physics teachers. With the formation of the Physics Education Research Group at Colorado (PER@C)<sup>1</sup>, the STEM-Colorado Teacher Preparation program<sup>2</sup>, and the newly initiated Physics Teacher Education Coalition (PhysTEC)<sup>3</sup>, CU-Boulder has

brought together faculty and students from the Department of Physics and School of Education to partner with local pre-college teachers, informal science educators, and K-12 students.<sup>4</sup> This collaboration has provided a rich venue for research, support for local communities and classrooms, and a coordinated recruitment, preparation and induction program for future K-12 teachers. One of the hallmarks of the CU-Boulder program is the notion that the preparation of future physics teachers begins in the physics department. Not only do undergraduate students have the opportunity to engage in teaching experiences early in their studies, but also this approach emphasizes the modeling of best teaching practices in

the undergraduate physics courses. Thus, we purposefully blend the mastery of physics content, pedagogy, and authentic practice.

Several CU-Boulder programs provide students the opportunity to engage in structured educational experiences to develop a comprehensive understanding of physics teaching and to engage in teaching opportunities. As part of an NSF-sponsored course reform effort<sup>3</sup>, we have introduced *Tutorials in Introductory Physics*<sup>5</sup> into the physics-majors' sequence, and observed increased student mastery of content and improved attitudes and beliefs about the subject and educational process.<sup>6</sup> The success of the reforms has required additional staffing of the Tutorials which has been supplied in the form of undergraduate Learning Assistants (LAs). LAs come from two pools, the STEM-Colorado Program (described below) and a new upper-division/ graduate-level physics course, Teaching and Learning Physics. Thus, this increased demand for staff has provided an opportunity to introduce capable students to teaching. Two programs, STEM-Colorado, and Colorado PhysTEC support these efforts through strong partnerships with local high school teachers, a Teacher Advisory Group and a Teacher-in-Residence program.

The PhysTEC-Colorado Program has been able to build on STEM-Colorado's collaborative program involving several departments at the University of Colorado focused on Teacher Preparation. The goals of STEM-Colorado include reforming introductory undergraduate courses to include student and learning centered approaches, enhance the use of technology within the courses, and utilize trained undergraduates to assist the instructors in facilitating student learning. These Learning Assistants are undergraduate students with a strong content background who have an interest in teaching. During the semester, these LAs are awarded a stipend to work 10hrs / week' with the lead instructors in the courses (Astronomy, Physics, Applied Mathematics, Biology) and with faculty from the School of Education. As part of the STEM-Colorado and PhysTEC grants, a high school science teacher is supported part-time to work with the education faculty to help introduce the LAs to educational issues, learning theory, instructional techniques, and experiences working in K-12 schools. As part of an associated course LA's receive course credit in the School of Education.

The program has been quite successful in attracting candidates into the teacher licensure programs at the university. In three semesters of the program, 13 Learning Assistants from participating departments in mathematics and science have committed to becoming teachers and are enrolled in a certification program at CU-Boulder. Most of these students did not initially intend to become teachers. The School of Education typically recommends an average of approximately 20 mathematics and science students for certification each year. This program provides the LAs with a supportive environment to investigate, develop, and practice their teaching skills. Therefore, the Learning Assistants practice and develop skills in a learner-centered environment and are monitored by science and educational faculty. Our undergraduate LA's consistently report the experience as a strongly positive one, and the word has spread; applications for LA's outnumber positions 3:1 in physics and the program is attracting some of our best undergraduates who would not have otherwise considered a career in pre-college teaching.

The community has grown to include summer workshop experiences for local high school teachers. During our first

Summer Workshop about 20 teachers participated in sessions that allowed the university faculty to showcase their reformed courses and share web-based resources that have been developed. The high school teachers described some of their experiences with state testing and the impact of content standards on their schools. More importantly though, the workshop provided a forum for high school and university teachers to share experiences and learn more about the challenges facing each group.

The PhysTEC-Colorado Program has capitalized on these experiences by incorporating some of the summer workshop teachers as well as other invitees to form a PhysTEC Teacher Advisory Group (TAG). The group meets quarterly in the late afternoon for about 3 hours. Discussion topics have included facility tours, curricula, implementation of novel computer simulations from the Physics Education Technology Project (PhET)<sup>7</sup>, and employment options within the Teacher-in-Residence and PhysTEC Fellows program. The TAG provides regular communication with a cadre of high school faculty in several surrounding school districts, it enlightens the CU Physics faculty about "life in high schools," and it expands the network of concerned physics educators. A critical component of the TAG program is that it serves as a starting point for placing students in productive and engaging K-12 environments. Students get a positive and safe exposure to real pre-college classrooms, while teachers benefit from the added human resources and content expertise of the college students. These TAG teachers have formed the nucleus of school-based contacts for the semester projects for students enrolled in the Teaching and Learning Physics class.

In the first semester of the university-high school partnerships with the TAG, we have established placements for students in half a dozen schools (placing student for teaching experience), informal science environments (from science outreach workshops to the planetarium), and teacher in-service professional development opportunities. Finally, it is through the TAG that we will recruit teachers and increase teacher participation at CU-Boulder. Currently we are interviewing teachers for next year's Teacher-in-Residence Position (TIR) as well as a PhysTEC Fellows program. The TIR will continue to support campus-based efforts and liaisons with local schools, while the Fellows program will house two teachers for one month at CU-Boulder to work with the PER@C group and promote university-community collaboration.

More information may be found at in the reference to the PhysTEC [3], CU Physics Education Research Group [1], Colorado STEM [2], and the Department of Physics<sup>8</sup>.

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- 1) The Science Technology Engineering and Mathematics (STEM)- Colorado Program: <http://cosmos.colorado.edu/stem>; National Science Foundation Grant DUE-0302134
- 2) <http://phystec.colorado.edu/>
- 3) NSF, Course Curriculum and Laboratory Improvement Program, #0410744
- 4) These efforts build on longstanding commitments to education at CU, including the Wizards Program, the Saturday Physics Series, CU Science Discovery, and the pioneering work of many scholars including Frank Oppenheimer, Al Bartlett, John Taylor, and many others. [1] <http://per.colorado.edu>

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*Noah Finkelstein, Michael Dubson, Christopher Keller and Steven Pollock are in the Department of Physics at the University of Colorado at Boulder. Steve Iona is STEM-Colorado /PhysTEC Teacher-in-Residence. Valerie Otero is in the School of Education, University of Colorado at Boulder*





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American Physical Society, One Physics Ellipse, College Park MD 20740
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