'Plasma Camp': A Different Approach to Professional Development for Physics Teachers

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ABSTRACT

The Plasma Physics and Fusion Energy Institute ('Plasma Camp') was inaugurated in 1998 as a way to address two areas of concern in the professional development of high-school physics teachers: involving teachers in the theory and methods of a current area of research in physics *and* connecting the research experience back into the classroom. The Institute, run jointly by a scientist and a teacher, immersed high-school teachers from across the country in laboratory investigations and in pedagogical projects for two weeks at Princeton University's Plasma Physics Laboratory. The goals, structure, and initial outcomes of the Institute are discussed.

1. The Impetus Behind 'Plasma Camp'

Professional development opportunities for high-school physics teachers very often take one of two main forms: a research apprenticeship in a laboratory or the creation and dissemination of new pedagogical techniques for teaching traditional physics topics. Both of these approaches certainly have merit: university and government labs have engaged in the former, bringing teachers into experiences with current frontiers in physics; the burgeoning use of calculator-based labs or constructivist classroom practices are examples of the latter, bringing new pedagogical techniques or contemporary technologies into the classroom. However, a real need also exists for building a bridge between these two approaches, one which enhances the expertise of secondary-school math and science teachers in current physics research and which also explicitly ties those ideas back into the high-school classroom. The Plasma Physics and Fusion Energy Institute was inaugurated in the summer of 1998 with that dual goal in mind.

The Institute (whose working name was 'Plasma Camp') was a two-week residential program for high-school physics teachers held at the Princeton Plasma Physics Laboratory (PPPL), a national research facility funded by the Department of Energy and administered by Princeton University. The Institute's participants were selected from a nationwide pool of applicants on the basis of two main criteria: a sufficient background in physics to be able to understand the subjects under investigation in the Institute and a demonstrated willingness to develop innovative or open-ended curricula in which to involve students. The learning experience for the teachers was designed to be as inquiry-based and hands-on as possible, and our expectation was that the curricula developed would retain that flavor as well.

The subject matter in Plasma Camp presented some unique challenges from the beginning. Plasma physics is a subject often not covered by many college physics departments and scarcely mentioned in most introductory textbooks. As a result, plasmas and fusion are almost completely unknown disciplines either within the physics-teaching community or by the public at large. (None of the Plasma Campers had had any prior experience with plasmas.) Furthermore, current educational trends mitigate against the incorporation of plasma physics into high-school curricula: the only role that plasmas and fusion play in contemporary science standards or on standardized exams is an occasional mention of fusion reactions as one of the ways in which nuclei combine. Unbeknownst even to most physics teachers, however, is the enormous role plasmas play in our everyday lives. Plasmas (hot, partially ionized gases) are what keep fluorescent light bulbs, parking-lot lights, neon signs, and helium-neon lasers lit; plasmas 'etch' the chips used in computers and the electronics industry; plasmas make radio communication between remote locations possible and show up in nature in lightning bolts and the aurora borealis. Fusion energy research uses plasmas as the 'fuel' to develop perhaps the only viable long-term source for our future energy needs. And since the sun and all other stars are made of plasma, it follows that the overwhelming majority of the mass of the observable universe is in the plasma state. Plasmas are often referred to as the 'fourth state of matter', but evidently the origins of that tag had at least a little to do with the fact that we inhabit a world that is mostly too cool and dense for plasmas to exist routinely.

Ideas from fusion and plasmas illustrate many different concepts in introductory physics, like electricity and magnetism, thermodynamics, atomic and nuclear physics, and waves, to name a few. The curriculum-development projects (explained below) undertaken by the Plasma Campers were constructed so as to take advantage of the opportunities encountered throughout the year for incorporating plasma physics ideas into a typical high-school course. Our goal was to show the relevance and usefulness of plasma physics to a wide range of topics and applications in the high-school classroom and *not* to develop simply another 'unit' to append on to already overcrowded syllabi. The fact that the curricula were to be created by classroom teachers would make them, ideally, both accessible the physics-education community at large and amenable to use in a wide range of classroom situations.

2. Plasma Camp Logistics

We developed four components to help achieve our goals for Plasma Camp: experiments in a graduate-level laboratory plasma physics course, lectures from leading scientists at PPPL and elsewhere, the development of plasma-based pedagogical tools, and the public presentation of the results of both the experiments performed and the curricula developed. A typical day during Plasma Camp consisted of a morning lecture (on topics such as space plasmas, fusion reactor design, or plasma processing of materials) followed by several hours of lab work or curriculum development. Plasma Camp participants were also expected after the conclusion of the Institute to disseminate their work via physics teachers' meetings, workshops, and conference presentations. The curricula developed during Plasma Camp are available to the physics-teaching community on PPPL's website (Post-Zwicker, 1998). In addition, 'follow-on' grants of up to $3,000 are available to Institute participants for the purpose of buying (or building) plasma-related equipment that would otherwise be unaffordable and for the purpose of paying travel expenses to regional or national AAPT meetings.

The laboratory experiments were modifications of PPPL's 'Grad Lab', an experimental introduction to plasma physics for beginning graduate students. (Grad Lab is offered as a semester-long course under the auspices of Princeton University's Astrophysical Sciences Department during the academic year.) Experiments investigated the transition of a gas to the plasma state, spectral analysis of plasmas, and characterization of plasmas using microwaves (Figure 1), among other issues. The four-part pedagogical projects consisted of developing (1) laboratory experiments; (2) test, quiz, and homework questions; (3) lecture demonstrations; and (4) more open-ended student investigations. These curricular materials needed to touch on some aspect of the ideas considered in the lectures and labs. Curricula could include the use of extant materials (commercially-made educational equipment, simulation software, internet exercises, or common plasma-based light sources), or they could be entirely of a participant's own devising. Attention was paid to the fiscal constraints under which many schools operate, so most of the curricula developed by Institute participants could be replicated at minimal cost at other schools. Attention was also paid to some of the more political constraints in teaching, such as urban school-district initiatives and current science-education benchmarks. The curricula developed range from a computer simulation of charged-particle orbits along magnetic field lines in a tokamak fusion reactor (Figure 2) to an investigation of the effect of plasma-based light sources on plant growth.

3. Feedback

The response of the participating teachers to Plasma camp was overwhelmingly positive. Responses to an end-of-camp questionnaire included: "One of the best workshops I've been to," "I don't think one wants to underestimate what a good teacher can take away from this program," "I have at least ten new demos and experiments for class," and "I worked harder at this Institute than at any other summer project I have been involved with. But ... it was worth the effort. I was sorry to see the two weeks end." From those surveys and from formal and informal discussions with the participants, three main factors seem to have contributed to the success of the Institute. The first was the opportunity to do nontrivial investigations in an area of contemporary physics to which the participants had had little or no prior exposure. The Grad Lab experiments, although somewhat 'canned', are actually quite representative of the tools and techniques used by plasma physicists in their research[#]. They helped to develop a genuine physical intuition ("At the same pressures and electrode spacings, would you expect air to have a higher or lower breakdown voltage than argon, and why?") about an area of physics about which the Plasma Campers had had no prior exposure. Grad Lab also exercised the Campers' analytical and experimental skills ("Which of the three pressure-gauge ranges is calibrated best, and how do you know?") by using both equipment and techniques that were largely unfamiliar to them. In short, the Campers learned about plasma physics by *doing* it first-hand rather than simply by hearing about it in lectures or by reading about it in the scientific press. Second, the Institute covered an area of current physics research of inherent interest and beauty that carries with it great scientific, social, and economic importance as well. The role that fusion may or may not have in the world's future energy supply, the mechanics of the hydrogen bomb, and the density of semiconductors on current and future computer chips were all discussed along with the aesthetic appeal and scientific principles of glow discharges, fluorescent light bulbs, and decorative 'plasma globes'. Third, the Institute was specifically constructed to connect what the participants learned at PPPL back into their classrooms at home. The research experience would have been of rather transitory benefit had the teachers involved not been focussed from the beginning on ways to use the ideas from plasmas and fusion in the classroom. The hardware with which they were sent home (including a plasma globe, a half-coated fluorescent light bulb, magnets, and so forth), the hardware they are authorized to borrow from PPPL, the plasma- and fusion-related material developed for the Internet, the expectation that they will disseminate their projects, and the 'follow-on' grants available to buy or build plasma-related equipment all speak volumes to the classroom teachers about the commitment of PPPL to extend the benefits of the Institute well beyond the two weeks in which the participants were in residence.

4. Portability

We would like to think that Plasma Camp is more than a way of reaching a handful of teachers with the wonder, beauty, and usefulness of plasmas. Although a continuation of the

Institute is planned for future years (with the veterans from the inaugural Plasma Camp invited back for a second session, along with a crop of newcomers, extending the initial idea of staff-directed teaching into peer teaching), a more fundamental question is whether or not the Plasma Camp model can be ported to other subfields of physics and other institutions. The answer to that question would reveal the more fundamental reasons for the initial success of the Institute as currently formulated. From what we can tell, the essential features of the Institute are the following:

a) **Challenging, but workable, experiments** Having graduate-level (or advanced-undergraduate) experiments on which the participants could work was crucial to the success of Plasma Camp. The participants rated the Grad Lab as the most valuable part of the experience and the most helpful to them as classroom teachers. The experience of wrestling with unfamiliar ideas, equipment, and techniques is very illuminating both intellectually (as they learn something substantial about a current research area in physics) and professionally (as they experience anew what our students feel in taking physics for the first time). Advanced-undergraduate or beginning-graduate level experiments (sufficiently debugged for safety and distilled to be feasible in a limited amount of time) are certainly available at other institutions in other disciplines, so this part of the Plasma Camp experience ought to be reproducible elsewhere. We were fortunate that PPPL has a well-developed instructional lab available which has been through a sufficient number of iterations as to make it both safe and educational for its users.

b) **Budgetary support** The first time through an effort like this is always the most expensive, because development costs are immediately obvious in crafting a prototype. Future years' Institutes will provide a better time-averaged estimate for carrying out this kind of professional opportunity. We did pay for the teachers' travel, provide a small stipend, underwrite lodging costs, provide classroom hardware, and make the follow-on grants available. Although these items may seem like luxuries, they actually emphasize the commitment made by the Institute to the participants and, in most cases, made attending Plasma Camp financially possible for the Campers.

c) **Staff who are both experienced in the field and committed to education** The recruitment of the appropriate staff for this kind of teacher-development program is critical. Plasma Camp was run by a research scientist (APZ) with a doctorate who had the time, interest, and inclination to devote a few months to an educational project like this. The other staffer (NRG) is a high-school teacher with significant research experience in physics who could keep the goals of the Institute tied into the realities of the secondary-school classroom. This combination worked well in creating the Institute. Both the research and the educational emphases need to be made possible in selecting staff to run similar opportunities at other institutions.

In addition, we found the following to be highly desirable:

d) **A residential experience** The informal interaction of Institute participants after hours in (or out of) the Princeton dormitories was one of the most professionally and personally rewarding parts of Plasma Camp. Campers could compare tips and techniques for teaching physics, work on lab or curricular presentations, and explore the University community together by living on campus during the Institute. While not strictly necessary in the same sense that staff and funding are necessary, it is clear to all involved that Plasma Camp would have had an entirely different tone without its residential component. Similar efforts could, of course, be made on a local level for specific districts or regions of the country without temporarily uprooting individuals or families, and a more local version of the Institute certainly has much to recommend it. Most participants, however, expressed a strong preference for a residential experience.

e) **A scientific 'hook'** Not only is plasma physics an area of current professional investigation in physics, but its beauty, utility, and societal implications make it inherently very interesting to physics teachers and students. Although most high-school teachers would appreciate any experience in modern physics research, areas the spark the imagination as well as the intellect are likely to have more enthusiastic participants from among the pool of secondary-school physics teachers.

f) **Follow-up** One cannot underestimate the appreciation among the Campers of the continuing financial and moral support from PPPL long after the Institute is over. The follow-on grants, support for travel to conferences, and continued contact between staff and participants extends the resources of the Institute into the support of classroom teaching over a long time period. Most teacher-training or research experiences do not include this kind of partnership, yet it is very important if contemporary issues in physics are to make any meaningful inroads into the introductory classroom.

Earlier this year, Professor Jonathan Reichert (1998) lamented in an American Journal of Physics editorial about the great divide between teachers and researchers in physics: "It may not be too much of an exaggeration to say that we are turning out high-school and community college teachers who know how to teach but don't know physics and young [university] faculty who know physics but haven't a clue how to communicate it." Although never pretending to be a comprehensive solution to this problem, the professional development model offered by Plasma

Camp does begin to address this and other issues in the teaching and practice of physics. The high-school teachers who attended the first Plasma Camp were eager learners of the physics research being undertaken at PPPL, and their expertise in curriculum development was put to use in bringing the ideas they encountered back into the high-school classroom, a feat that only a few researchers in this (and other) fields of contemporary interest in physics seem to have the time and the inclination to attempt[*]. We believe that ideas from current physics research are accessible and interesting to high-school students and teachers and appropriate in high-school classrooms. The Plasma Science and Fusion Energy Institute was our way of beginning to put those beliefs into practice. It is only one model for bringing contemporary physics to the physics-teaching community, but the need for that overall goal is very large. We hope for the future that other institutions will see the benefits of a program like this one and begin to involve high-school teachers in the development of other educational resources in contemporary physics research.

References

Post-Zwicker, Andrew P. (1998). *Plasma Physics and Fusion Energy Institute* [Web Site] URL http://ippex.pppl.gov/ippex/summer_institute/

Reichert, J.F. (1998) Jack Spratt. *American Journal of Physics* 66, 664-5

Footnotes

The Grad Lab experiments are certainly not entirely 'canned'. One of them, a spectroscopic investigation of atoms sputtered off a metal surface in a magnetron plasma device, was the subject of a recent doctoral dissertation. Wang, Z. (1998) *A Hollow Cathode Magnetron: Its Characterization and Energetic Nitrogen Atom Diagnostics* Ph.D. thesis, Princeton University (unpublished).

- The efforts of the Contemporary Physics Education Project (of which both authors of this paper are members) provides a notable exception. Barnett, Michael R. (1998) *Contemporary Physics Education Project* [Web Site] URL http://pdg.lbl.gov/cpep.html

Figure 1: Marc Sabb (Canyon del Oro High School, Tucson, AZ), standing, and Richard Nestoff (Normandy High School, Parma, OH), seated, investigate microwave diagnostics of plasmas in the Grad Lab during Plasma Camp.

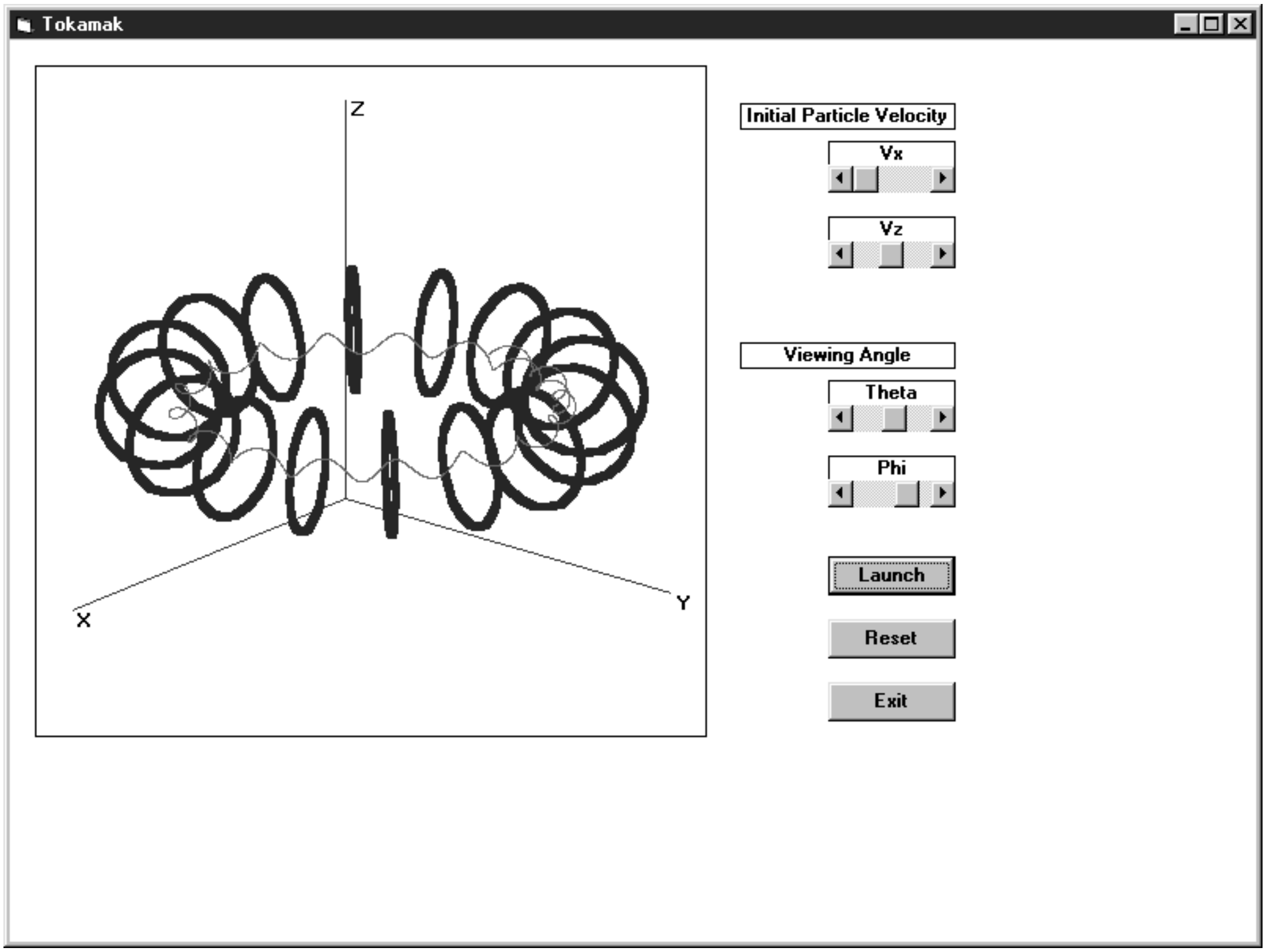

Figure 2: Computer-generated plot of a helical orbit (gray curve) of a charged particle in the magnetic field of a tokamak fusion reactor. The program was written as part of the pedagogical project during Plasma Camp by Father Michael Liebl (Mount Saint Michael Benedictine High School, Omaha, NE).