APS physics™

Forum on Education
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Summer 2016 Newsletter

Richard Steinberg, Editor

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From the Chair

Tim Stelzer, University of Illinois - Urbana

This summer newsletter offers an opportunity to see where we have been and where we are going with physics education. Our community can be proud of the role physics educators have played in transforming science education by emphasizing conceptual understanding using active learning and interactive engagement strategies. Indeed, the active participation by our members in the Forum on Education illustrates the value the physics community places on education. Our new newsletter editor Richard Steinberg has noted that one hundred years ago, in 1916, the great pioneer and tireless advocate for improving physics education Arnold Arons was born. Arons helped lead the way to Physics Education Research, identifying the importance of active learning and conceptual understanding over 50 years ago. In recognition of his contributions, Richard suggested we include Aron's work as a theme for this newsletter, which seems like a brilliant idea. We are certainly fortunate to have Richard as our new newsletter editor.

This spring also marks the annual transitions in the Forum's Executive Committee. I would like to thank Mike Fauerbach for his outstanding service on the Chair line of the Executive Committee. His enthusiasm for the Forum is quite inspiring and I am counting on his continued active participation in the Forum. I would also like to thank Randy Knight for his excellent leadership as Chair this past year. Fortunately we will have Randy's expertise available to us as he serves as Past-Chair, and Chair of the Fellowship Committee. John Stewart is now the Chair-Elect, working hard to assemble an inspiring set of talks for the March and April (this year held in January) meetings. Congratulations to Larry Cain who begins his first year in the Chair line as Vice Chair. Welcome to Luz Martinez-Miranda as our new Member at Large and Toni Sauncy as our APS-AAPT Member. I would like to thank Beth Lindsey for the fantastic job she has done editing the newsletter for the past four years. Finally, thank you to Heather Lewandowski and Geoff Potvin for your invaluable service on the committee these past three years.

The Forum can only be meaningful and successful if we are all actively engaged. In particular, I encourage you to help us recognize outstanding contributions to physics education by submitting nominations to our Forum sponsored awards https://www.aps.org/units/fed/awards/. Finally, I encourage you to contact any of the members of the Executive Committee or the Newsletter Editor if you have suggestions or contributions to our missions.

Tim Stelzer

Tim Stelzer is Chair of the Forum on Education. He is a Professor of Physics at the University of Illinois, Urbana.

From the Editor

Richard Steinberg, City College of New York

It is with enthusiasm that I begin my term as editor of this Newsletter. This has allowed me to have stimulating interactions with a diversity of colleagues and to reflect on how I can contribute to the community. I thank many people who have made my transition relatively painless, particularly outgoing editor Beth Lindsey, Past Chair of the Forum on Education Randy Knight, and Teacher Preparation section editor Alma Robinson.

I was fortunate to begin my career in Physics Education working for Lillian McDermott at the University of Washington. It was there that I met Arnold Arons, a scholar and physics education pioneer for whom I have great admiration. Since 2016 happens to be the 100th anniversary of Arons' birth, I decided to make my first Newsletter a tribute to him. I instantly thought of three individuals I am confident he would have been happy to see contribute. I am delighted that all three agreed to share their thoughts and perspectives. Gerald Holton was a colleague of Arons and reflects on his memory of him. Lillian McDermott writes on her joining Arons at the University of Washington and the growth of Physics Education there. Tiffani Kolozian is an undergraduate physics major preparing to go into teaching high school physics upon graduation and already a fan of the work of Arons. Tiffani is also a descendant of Arons in a way as she is a student of mine, as I was of Lillian, and Lillian was of Arnold. I hope that Arons would be proud to see this piece of his legacy.

Call for Nominations for FEd Executive Committee

Larry Cain, Davidson College

It is time once again to elect new members to the executive committee of the Forum on Education (FEd). We have five executive committee positions that will be open: vice chair (who, in subsequent years, becomes chair elect, chair, and then past chair), secretary/treasurer (3-year term), councilor (4-year term - also a member of the APS Council of Representatives), member-at-large (3-year term), and APS-AAPT member (3-year term). All nominees must be members of the FEd. The APS/AAPT Member-at-Large must also be a member of AAPT.

The executive committee plans education-related sessions at APS meetings, nominates new APS Fellows, and presents FEd awards. They represent the goals and concerns of the FEd membership to the APS Council of Representatives. Serving as a FEd officer is also an excellent way to learn about APS and its educational missions and to influence science education at the national level.

The nominating committee will convene later in the summer to create a list of nominees for each position and a ballot. New officers begin their service at the end of the executive committee meeting next year, except for the councilor whose service begins on January 1, 2017.

Please send suggestions nominating yourself or a colleague to:
Larry Cain (lacain@davidson.edu), FEd Vice Chair and Chair of the Nominating Committee, Davidson College, Department of Physics.

Director's Corner

Theodore Hodapp

574. That was the number of pre-proposals submitted to the NSF in its recent solicitation to address Broader Participation in STEM education. (NSF INCLUDES, which true to government-speak is actually an acronym, although what the actual words are escapes me.) The solicitation specifically called for approaches that could address sticky problems in education from an organized, multifaceted approach. The realization being that isolated interventions do not touch enough of the issues that drive complex problems like underrepresentation in physics. One might affect localized impact, but truly "fixing" a problem requires an approach that addresses various aspects of complex social issues to be identified and collectively addressed.

Reading the solicitation, we kept saying — Gee, that is exactly how we run PhysTEC or the Bridge Program — trying to implement solutions in complex environments with lots of human interactions messing up our nice clean physics. But of course, that is why education is also so much fun and so challenging — just try and get someone who doesn't think like you to understand a complex abstraction that, while it predicts nature, forces you to think in ways that confront your perceptions of reality.

This is probably where US Supreme Court Chief Justice John Roberts mistakenly thought that physics was just about equations. Sure, it has equations, but it has people too, and those people think differently, and learn differently, and if we want them to understand how to solve Lagrangians or the Navier-Stokes equations, we also need to understand how they approach learning these in the first place. In this regard, it does matter what your background is, and it does matter if you have a support network helping you. I hope our discipline is up to the challenge of understanding those cultural differences, those human differences, those "I'm not quite like you" differences that sometimes get in the way, and sometimes create new things where there was nothing before. Diversity brings new challenges, but it also brings new approaches.

Oh yes, I was also happy to see in the INCLUDES solicitation a mention of a model program that prospective applicants should consider: "*a disciplinary organization launches a major initiative designed to significantly improve the diversity of PhD graduates in that discipline,*" the APS Bridge Program! I think maybe our discipline is up to the challenge.

Arnold Arons: A Life Truly Worth Living

Gerald Holton, Harvard University

The first and most powerful concept that comes to my mind when thinking about Arnold Arons is that he was the very exemplar of what it meant to be a faculty member of a Liberal Arts College: Devoted to teaching, mentoring, and aiming to make the students love the subject of the course; constantly thinking about better ways of doing it; writing as a scholar and educator, also on subjects beyond an early, narrow professional definition; being an honored and honorable role model; and all this with highest standards for his College, his students and himself — without sentimentality.

I recall with pleasure several telling episodes in which Arnold and I collaborated. The first was early in my career. Still as an Instructor I had to teach one of those large introductory physics courses at Harvard, but rebelled against the use of the usual narrow physics texts for the students. Instead, I wrote my own, emphasizing the humanistic aspects, including the history and philosophy of science.

Out of the blue, Arnold contacted me from Amherst, where he said he was using my book for his course. At his invitation I went there to give a lecture in his physics course. From the moment I entered the class room with him, I could sense that there was a special, warm rapport between Arnold and his students. It was an enjoyable event for all. Above all, it was my introduction to Arnold, and we quickly became good friends.

Some years later, Arnold had a sabbatical leave, and decided to spend it writing his own text book. He suggested, and I quickly agreed, that he do so while on a long visit to Harvard. I was glad to have him share my office with me. In fact, he asked if he could incorporate the three chapters on philosophy of science of my text into his. It was gladly done.

More years later, when I started the national curriculum called The Project Physics Course, again on the model of my first book, Arnold kindly accepted the invitation to come to Cambridge to join our team and help with the writing of the new materials.

Finally, on his invitation, my whole family came to Woods Hole on a memorable visit. He piloted his ship to the Elizabeth Islands. My family still reminisces about Arnold's generosity, his expertise on oceanography, and his stories and insights of the maritime surrounds on that day.

To the memory of a man who made his life count.

Gerald Holton is Mallinckrodt Professor of Physics and Professor of the History of Science at Harvard University, Emeritus. He is a Fellow of the American Physical Society, the American Philosophical Society, the American Academy of Arts and Sciences, and several Learned Societies in Europe.

The Legacy of Arnold B. Arons

Lillian C. McDermott, University of Washington

Arnold B. Arons' perspective on the teaching of physics is reflected in the instructional methods and intellectual criteria that have characterized the work of the Physics Education Group (PEG) at the University of Washington (UW). He had a major impact on my life that was both personal and professional. On being invited to contribute an article in his honor by Richard Steinberg, I realized that I could not completely separate these two aspects.

A. Relevant History Before 1973

In 1968 Ronald Geballe (UW Physics Department Chair) invited Arnold Arons (Physics Professor, Amherst College) to develop a course at UW to prepare prospective elementary school teachers to teach physical science. I offered to help (1969-1970). I could volunteer because I had lost my part-time teaching positions at UW and Seattle University due to the 'Boeing bust,' an economic downturn in the local economy.[1]

My initial incentive to conduct research in physics education (*PER*) resulted from my experience as a volunteer instructor in Arnold's course. Pat Heller (then a Master's physics student), Jim Minstrell (a high school physics teacher and graduate student in the College of Education), and a few graduate physics TAs were also on the teaching staff. Instead of teaching by telling as most physics instructors do, I gradually started to teach by asking questions and listening to answers by students as I had seen Arnold do. Although I had been aware of the Socratic method from studying philosophy in college and ancient Greek history before then, I had not thought of applying this method to the teaching of physics. I found it challenging to listen carefully to responses by students, to try to determine how they were thinking, and then to ask a series of questions designed to lead them to a correct understanding of the physics involved.

In 1970 I helped Arnold write an NSF proposal for a series of summer programs in Physical Science and Biology for K-6 in-service teachers and some support to write a book. When it was funded, I became a part-time Lecturer in Physics. Our first NSF Summer Program took place in 1971.[2] Arnold began writing *The Various Language*.[3] (This was the "ancestor" of *Physics by Inquiry* and *Tutorials in Introductory Physics*, our group's two research-based and research-validated curriculum development projects).[4,5] Arnold, I, and our TAs gradually became known as the Physics Education Group. At his request, I began to develop an academic-year course for prospective high school physics teachers. I also admitted students from his course for pre-service elementary school teachers who wanted to continue learning physics.[6] Both groups met in the same room and benefited from their interaction. The future high school teachers found that formulas would not satisfy their pre-service classmates who had taken Arnold's course.

During 1972-1973, Arnold was offered a position at the Woods Hole Oceanographic Institute. He negotiated a retention offer from UW that included a new tenure-track faculty position in physics education either in the Provost's Office or in the Physics Department. Because the physics faculty did not want physics taught outside of the Department, it was decided that the appointment would be there. The position was advertised. Since the anti-nepotism policy had been revoked as unconstitutional in 1972, I could apply. As one of the three finalists, I gave a Physics Department Colloquium and was offered the position of Assistant Professor.

B. Research and Curriculum Development by UW PEG after 1973

My first teaching assignment in my new position was the "combined course" that I had started to develop. I had begun by 1973 to write worksheets suggested by some activities in the Study Guides included in *The Various Language*. In 1977, I instituted a special preparatory course for students in the *UW Equal Opportunity Program (EOP)* and others underprepared to succeed in introductory physics, a gateway course for admission to a medical or engineering program. The emphasis in the new course was on reasoning, not formulas. Explanations were required on examinations. When similar qualitative questions were later asked in courses for science majors, many of the same difficulties surfaced. This observation helped motivate me to conduct research in physics education. Although he did not want to undertake such research himself, Arnold enthusiastically encouraged me to do so. The outcome has been the growth of the UW Physics Education Group and widespread adoption of our published curricula.

Perhaps the best way to illustrate Arnold Arons' influence on our group's development of curriculum is through illustrations. Three examples follow.

1. Development of the Concept of Density

The Various Language and the PbI module, Properties of Matter, guide students in formulating operational definitions for mass, volume, and density. The statement that density equals the mass divided by the volume *($D = M/V$)* is often a memorized formula that sometimes results in the query "Is it $D = M/V$ or $D = V/M$?" Students measure the mass and volume of several objects of different shapes made of homogeneous substances. They find that for a given substance the result of dividing the mass by the volume is the same. When they plot corresponding values of mass and volume, they obtain a straight line with a slope equal to the density. They interpret the ratio as the number of grams for each cm^3 of the substance and recognize *density* as a characteristic *property* of a substance that helps identify it. (For many students, "grams *per* cubic centimeter" often does not carry the Latin meaning of "for each.")

2. **Development of Ability in Proportional Reasoning: π = C/d**

   A question that Arnold often posed as an example of the application of proportional reasoning is based on the relationship of π (~ 3.14) as the ratio of the circumference (C) to the diameter (d) of all circles. Students are told to imagine a rope wrapped tightly around the earth's equator (~ 25,000 miles), then lengthened by about six feet and held at a uniform height. The question asked is:

   Which of the following (an amoeba, a bumble bee, a cat, or a camel) would fit under the rope? Explain your reasoning.

   Few people immefiately recognize that $C = \pi\, d$ implies $\Delta C = \pi\Delta d$. Therefore, if the circumference increases by 6 feet, the diameter increases by about 2 feet and the radius by 1 foot. Thus, a cat is the largest creature that would fit.

3. **Development of a Conceptual Model for Electric Current**

   The development of a model for electric current from concepts students construct as they investigate the behavior of batteries and bulbs was included in *The Various Language*. Development of a laboratory-based curriculum was expanded in *Physics by Inquiry* and *Tutorials in Introductory Physics*.[7]

C. Summary

Recognition of research in physics education as an important field for investigation in physics departments has grown greatly in recent years. Today, Peter Shaffer, Paula Heron, and I are Professors in the UW Physics Department. Suzanne Brahmia will join our faculty in 2017.

I am deeply grateful to Arnold B. Arons for his guidance when I first began teaching K-12 teachers and for his later support for my research in physics education. He planted the seeds that led to our group's success. For me, his legacy continues to grow.

Lillian C. McDermott is a Professor of Physics at the University of Washington. A Fellow of APS, AAPT, and AAAS, she received her Ph.D. from Columbia University in 1959 for research in experimental nuclear physics. Since 1973 her research has been in physics education (PER). Under her leadership, the Physics Education Group has conducted research on the learning and teaching of physics and developed instructional materials that are both research-based and research-validated. Since 1979 more than 25 graduate students in the group have earned a physics Ph.D. for PER.

(Endnotes)

1. My husband, Mark N. McDermott, was on the physics faculty. Strict anti-nepotism rules precluded a position for me.
2. These have evolved since then into Summer Institutes in Physics and Physical Science for K-12 in-service teachers.
3. A. Arons, *The Various Language: An Inquiry Approach to the Physical Sciences* (Oxford U. Press, NY, 1977).
4. L.C. McDermott and the Physics Education Group at the U. of Washington, *Physics by Inquiry* (John Wiley & Sons, NY, 1996).
5. L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics, First Edition* (Prentice Hall, Upper Saddle River, NJ, 2002) and *Instructor's Guid*e (2003). Prentice Hall was subsequently acquired by Pearson International, which will publish the *Second Edition* in 2016.
6. L.C. McDermott, "Combined physics course for future elementary and secondary school teachers," *Am. J. Phys*. **42**(8), 668 (1974).
7. See, for example, L.C. McDermott and P.S. Shaffer, "Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding, *Am. J. Phys*. **60** (11). 994 (1992) and P.S. Shaffer and L.C. McDermott, *ibid*., Part II: Design of instructional strategies, *ibid*., *60* (11), 1003 (1992).

Arnold Arons and Changing the Way to Learn to Learn the Way to Teach

Tiffani Kolozian and Richard N. Steinberg, City College of New York

My name is Tiffani and I study physics with a focus in secondary education at The City College of New York (CCNY). I have been involved as an apprentice teacher in various middle and high schools around the city. By the end of this year, I will be certified to teach high school physics in New York.

During my time at CCNY, I've had the opportunity to take a few physics courses specifically for teachers. These courses, known as "Development of Knowledge in Physics," have transformed my understanding of the learning and teaching of physics. In the midst of our study of astronomy during the first of these courses, I was given the assignment to read an article titled *Cultivating the capacity for formal reasoning: Objectives and procedures in an introductory physical science course* by Arnold Arons.[1] I also recognized that this enlightening course was a manifestation of Arons' approaches to science and education. I continued to read Arons' works and I realized that he was perfectly articulating the goals I had for my future physics students — preparing them to be true scientific thinkers as opposed to becoming skilled at plugging values into formulas that they barely understand.

As I continued through these courses, I was convinced that everyone should have the opportunity to learn science in this way and that it is my obligation to provide this for my future students. However, it would be quite a challenge as most of my experiences in physics classes were in contrast to the methods I now understood to be fundamental in achieving genuine scientific literacy. This includes understanding the process of science, knowing how to operationally define terms, being able to distinguish an observation from an inference, and knowing how to develop and test a scientific theory.

As I look back at my first experiences with learning physics, I can see how much my awareness of scientific literacy has progressed. Throughout two years of high school physics, I thought, "I know so many fancy terms and formulas — I'm learning so much!"

Looking back now, I realize that the pace and volume of these classes were illogical. "The relativistic model of instruction is based on the premise that, if one starts with an enormous breadth of subject matter but passes it by the student at sufficiently high velocity, the Lorentz contraction will shorten it to the point at which it drops into the hole which is the student mind."[2]

I eventually figured out that this relativistic model of instruction does not work. I had forgotten much of the physics I had learned because I never truly understood the concepts. While I was taking my physics courses at CCNY, I noticed that I was becoming very skilled in solving complex problems, but was lacking a deep understanding of some basic concepts. For example, I could easily manipulate and solve a Lagrangian, but often did not have enough understanding of the basic physics concepts to simply set up the Lagrangian. I can now look back and understand what my learning of physics was lacking, especially in relation to what I learned about scientific literacy from Arons. For instance, it did not register that the "fancy words" I was using were just names given to ideas that we needed to use often. We were presented with definitions and applied these terms to various situations but we needed to be involved in the shared experience of coming across the idea (and only then assigning it a technical term) for these concepts not to seem as though they were random "acts of human imagination and intelligence."[3] Along with this, we needed to be given the chance to discuss and investigate the questions "How do we know…? Why do we believe…? What is the evidence for…?"[1] This would have supported us in developing operative or procedural knowledge as opposed to simply taking the end results on faith. End results were typically spelled out for me and, therefore, I rarely had the chance to discriminate between observation and inference. Even if we did make observations during demonstrations, many times the concept had already been explained and we were simply verifying the end result. We could have been given the chance to explore a phenomenon before it was explained, so that we could experience the chain of thoughts leading from "I observe this…" to "This must mean that…"

However, once I began learning through Arons' strategies and reading about Arons' methods, the way I approached my physics classes completely changed. I was taking modern physics alongside the first of these "Arons-like" courses. Instead of doing a variety of practice problems to get used to the procedure and trying to adapt it to the problems on the exams, I found myself searching for a deeper comprehension of the concepts and then being able to apply this to any problem I was given. This supported my transition in learning because it had more emphasis on "How do we know" questions and "forwards science."[1] When we shine light below a certain frequency, there is no current regardless of light intensity. What can we infer about the nature of light? Through this approach, I have the opportunity to "relive some of the intellectual experience" of great scientists.[3]

Since I am finally grasping how I learn physics, I have begun to develop my perspective on how I would teach physics. During my first year as an apprentice teacher, I would often give a student the answer to their question without giving them the opportunity to think. I, therefore, gave the student the impression that there was an *a priori* reason for the question they asked me. How can I lead them to the answer through Socratic questioning? I am now always reminding myself to "shut up and listen carefully to the response."[3] Of course, it was a challenge devising a follow-up question when I was not listening to the response of the student or even giving them the opportunity to respond to their fullest capacity.

As I begin to develop my own lessons, my first focus has been on allowing the students to engage in exploratory activities and discussions with their peers through guided questions. I will use an example to illuminate how I am beginning to learn how to implement Arons’ approaches in my instruction. I set up various surfaces (wax paper, sand paper, etc.), various objects on top of those surfaces (plastic containers, paper plates, etc.), and bags of coins. The students first explored the different surfaces and discussed with their peers how they could figure out which had more friction. Then, I asked them to figure out if friction depends on the surfaces involved, whether the object was moving or not, the weight of the object, and the surface area of the object. This gave the students the chance to discriminate between observation and inference and to construct their own ideas about friction. It also led the students to postulate about how we can investigate friction more quantitatively. We then built on the same activities and they found the coefficient of static and kinetic friction for different surfaces in contact. My students are responding positively to these types of activities and I have noticed an improvement in their overall discourse.

I will continue to learn from Arons’ methods and continue to enhance how I implement them in my teaching. I will always strive to have all of my students engaged in the process of science and to have them attain more formal operations than that with which they started.

Tiffani Kolozian is a Noycve Fellow, Physics Major and Teacher Education candidate in the Macaulay Honors College at City College of New York. Richard N. Steinberg is her advisor.

(Endnotes)

1. A. B. Arons, “Cultivating the capacity for formal reasoning: Objectives and procedures in an introductory physical science course” *Am. J. Physics*. 44(9), 834-838 (1976).
2. A. B. Arons, “Conceptual Difficulties in Science,” in *Undergraduate Education in Chemistry and Physics: Proceedings of the Chicago Conferences on Liberal Education*,” No. 1, edited by M.R. Rice. Univ. of Chicago.
3. A. B. Arons, *A guide to introductory physics teaching* (Wiley, NY, 1990).

Physics Teacher Education Coalition

Section on Teacher Preparation

Teacher Preparation Section

Alma Robinson, Virginia Tech

When I learned that celebrating the 100th anniversary of Arnold Arons birth was the theme for this issue of the Forum on Education Newsletter, I thought the best way to commemorate this occasion in the Teacher Preparation Section would be to demonstrate how Arons’ work has contributed to the training of our secondary physics teachers.

To that end, I reached out to educators who incorporate physics education research (PER) in their training of pre-service and in-service high school physics teachers. While general science teaching methods courses are standard for science teacher education programs, integrating disciplined-based education research into those programs is far from universal.

Jon Anderson describes how Arnold Arons has impacted his physics teaching career over the years, beginning from his first readings of *A Guide to Introductory Physics Teaching* as a graduate student studying physics education to his becoming reacquainted with Arons’ work during a physics modeling workshop. As a high school teacher, a former PhysTEC Teacher in Residence, and a Mechanics Modeling Workshop leader, Anderson has incorporated the lessons he has learned from Arons in his work with high school physics students, pre-service teachers, and in-service teachers.

Kelli Gamez Warble, the Teacher in Residence at Arizona State University (ASU), explains the PER-based teacher preparation training at ASU through a fascinating personal narrative of her experiences from a novice teacher first learning about PER to a Modeling Workshop Leader who brings PER to ASU students and in-service teachers. Because her story takes place at the birthplace of the FCI and Physics Modeling, it naturally weaves in a bit of history about the creation of those as well.

Finally, Eugenia Etkina, the creator and coordinator of the Rutgers Physics Teacher Preparation Program, outlines how the ISLE (Investigative Science Learning Environment) philosophy is incorporated into all aspects of Rutgers' physics teacher preparation program. ISLE activities are PER-based and encourage students to discover the laws of physics as practicing physicists do — by working collaboratively to observe physical phenomena, identify patterns and/or explanations for the observed phenomena, and design and test their explanations through experimentation.

My Acquaintance with Arnold Arons

Jon Anderson, Centennial High School, Circle Pines, MN

I first "met" Arnold Arons in 1992 in a course that I was taking while working on my M.Ed. in Physics Education. I was assigned two readings from his book, *A Guide to Introductory Physics Teaching*,[1] and I was immediately struck by two things. First, I was impressed (and frankly, a bit amazed) at how deeply he thought about the teaching of topics in physics. Second, as I explored other parts of the book, I was impressed by how many topics he thought so deeply about. As a physics teacher myself, I too had thought about these topics and, of course, about the teaching of them. However, until these readings, my thought process had never been given the type of structure and voice that I immediately found from reading the sections that were assigned for my M.Ed. course.

I was also struck by the discussion that these readings generated in subsequent meetings of that course. As I recall, the majority of the students in the course were practicing physics teachers with a wide range of experience. I remember thinking that these readings engaged each member of the class and provided the basis for some of the most meaningful and lively discussions that we had. In fact, in many future discussions about non-Arons readings, we (class members) often cited and referred back to the Arons readings we had done, as well as what we had learned from these readings. As both an undergraduate and a graduate student, I had read many authors and many papers. I can say that no author had more significantly impacted me than Arnold Arons.

Now, fast forward 17 years. During this period, in addition to working full-time as a physics teacher, I was raising two daughters, filling various leadership roles in my school district, working with extra-curricular activities and athletics, and putting in countless hours working on curriculum, labs, experiments, and evaluations for the courses that I teach. Additionally, during these years, I took a sabbatical leave and spent a year doing particle physics research at the Fermilab, began working as a QuarkNet Lead Teacher, took a leave to spend two years working as the Teacher-in-Residence at the University of Minnesota, and continued to take graduate courses. Throughout this time, I often thought of the Arons articles but seldom referenced them or sought out additional readings.

Then, in 2009, I took a Mechanics Modeling workshop at Florida International University and I was reintroduced to Arnold Arons. I was pleased to get reacquainted! A significant component of this workshop involved discussions of assigned readings from *Teaching Introductory Physics*.[1] These readings reminded me of what struck me the first time I had read Arons 17 years earlier, namely the depth of thought about teaching topics in physics and the breadth of those topics about which he thought and wrote. Furthermore, I was impressed with how well these readings complemented the content we were covering in the workshop. When we were working on the constant motion unit in the Mechanics Modeling workshop, we read what Arons wrote about constant motion. When we were working on accelerated motion, we read what Arons had to say about that topic. This alignment between the workshop activity and the directly related reading continued for the entire three weeks of the workshop, and I continued to be impressed. I felt that the combination of the Arons readings and the modeling curriculum gave a structure and voice, of sorts, to the approach and pedagogy that I had been using in my courses for many years.

The Arons readings also highlighted the many things that I had been doing incorrectly as a teacher. For example, when students are collecting data in constant motion and accelerated motion labs, I had always discussed their data and results in terms of position and time. Arons uses position and "clock reading". Not only is "clock reading" a more accurate description, I find that it helps students understand that this is a snapshot of the object at the instant they took the data point rather than something happening with the passage of time. Arons also emphasizes the use of multiple representations of topics in physics. I found that this was something I didn't do well when teaching energy. Since taking the "Arons approach" to teaching energy — emphasizing "energy transfer and storage," focusing on internal energy, and using multiple representations — my students learn the topic both quicker and more thoroughly.

The readings also reminded me of the many concepts that most physics students seem to struggle with. Concepts such as speed vs. velocity, acceleration, forces, circular motion, energy, etc. all pose varying degrees of difficulty/confusion for introductory physics students. I found that the readings addressed these issues and provided both the basis for rich discussions among the workshop participants and a better understanding of how best to teach these topics.

Since 2010, I have been fortunate to lead many mechanics workshops at several different locations around the country. I assign the same readings to these workshop participants that I was assigned when I was in their position and they continue to generate engaging, insightful, stimulating, and intellectually satisfying discussions. I feel fortunate to be able to continue to learn from these discussions. The readings also continue to impress the participants with how deeply and thoroughly Arons thought and wrote about the profession of physics teaching. These workshops are wonderful opportunities to spread the gospel of Arons to other physics teachers and allow them to benefit from his writings as well.

Because of the reading assignments in my graduate course, *Teaching Introductory Physics* had an impact on my teaching early in my career. Then, thanks to my participation in mechanics modeling workshops as a participant and a leader, Arons' work continues to influence my teaching. But it is only in hindsight that I have realized that the insight and writings of Arnold Arons had an impact on my teaching during the 17 years between my graduate course and the first mechanics modeling workshop. In a sense, the Arnold Arons influence on my career has come full circle. However, a more accurate description is that the influence was always there, I just needed to get reacquainted with it.

Jon Anderson has taught physics at Centennial High School near Minneapolis since 1988. He was the Teacher-in-Residence at the University of MN PhysTEC site from 2007-2009, continues to work as a consultant for the PhysTEC project, and has been a QuarkNet Lead Teacher since 2002.

(Endnotes)

1. A. B. Arons, *A guide to introductory physics teaching* (Wiley, NY, 1990).

A mechanics modeling workshop at Florida International University demonstrates that physics experiments can't be confined to a lab/classroom.

Teachers combine experimental data gathering, data analysis, and discussion at a Cal Poly modeling workshop. Note that Arons' text is on the table!

PER-based Teacher Preparation at Arizona State

Kelli Gamez Warble, Teacher in Residence, Department of Physics, Arizona State University

During the summer of 1995, I found myself in room PSH 357 at Arizona State University (ASU) alongside 25 of some of the finest high school physics teachers from the United States. Having just finished my first year as a certified teacher, I was the least experienced instructor in the group. I was feeling simultaneously awestruck and inadequate, and frankly, was suspicious that I was only invited because supporting me was cheap since I lived locally and therefore did not need precious grant money for airfare or housing.

I was participating in the *Leadership Modeling Workshop in High School Physics*, an NSF-funded program for high school physics teachers with David Hestenes as the Principal Investigator. Yes, *that* David Hestenes — co-author of the Force Concept Inventory, father of Modeling Instruction, winner of the Oersted Medal, and incidentally a top mind in the field of geometric algebra. (The same Hestenes who told me years later, “The best thing I ever did for teaching was get *out* of the classroom.”)

The FCI had only recently been published and was being used by a fairly small subset of high school and college physics teachers—indeed, university physics instructors were still arguing passionately about its efficacy. None of the teachers in room PSH 357 had ever heard the phrase “Physics Education Research.” We were oblivious to the fact that we were witnessing the insemination of a supportive community of educators that would eventually inspire a grass-roots organization that now reaches thousands of STEM teachers from across the world via the *American Modeling Teachers Association.*

I spent three summers in room PSH 357 as a workshop participant, modeling and re-modeling how to better teach physics using the classroom practices inspired by Arizona high school teacher Malcolm Wells (co-author of the FCI, and one of the first instructors in the country to document marked student gain in FCI scores). I spent about ten *more* summers in the same room as a Modeling workshop leader. In the early 1990s, the Modeling Workshop in Mechanics officially became PHY 480 Methods of Teaching Physics at ASU.

Despite my general feeling of inadequacy in 1995, I had been well-prepared. One of my fellow participants, Rex Rice, had actually been *my* high school physics teacher in Mesa, about 10 miles to the east (and 10 years back in time). Rex was one of the early Physics Training Resource Agents for the AAPT and had used many of the PER-based ideas being discussed in the 1995 workshop when I was his student in the mid-1980s. Equally important, the Methods of Teaching Physics course that I took as a pre-service teacher at Arizona State in the early 1990s was taught by the same excellent high school teacher who was leading the 1995 Modeling Workshop—Larry Dukerich. In fact, the PHY 480 Methods of Teaching Physics course at ASU was (and remains to be) quite unusual for several reasons. PHY 480 was (and still is):

- housed in the physics department rather than the education department.
- taught by an instructor who has typically had at least 10 years of experience *actually teaching* high school physics using ideas from Modeling Instruction and PER.
- one of the few science methods courses at ASU in which science *content* is addressed alongside science *pedagogy*, thereby fostering a strong foundation in what is now referred to as “Pedagogical Content Knowledge.”
- one of the few teacher preparation courses I know of where participants spend a substantial amount of class time in “student mode,” during which they are required to practice “retrograde amnesia” and behave like an introductory physics student, naïve preconceptions and all. (“Teacher mode” questions are banned until *after* the entire lab or activity has been completed in “student mode.”) I have observed that the more physics experience participants have, the more excruciating it is for them to act like a student, but their difficulty becomes fodder for very rich class discussions about typical student preconceptions.

Although ASU is the home of the FCI, we still don’t house an active research group in physics education. Instead, the ASU physics department has become a haven for *practitioners* of physics education (i.e. teachers) every summer via our Master of Natural Science (MNS) program. Students in the MNS program are typically practicing high school or community college instructors with a strong desire to become better teachers. They must complete a minimum of three Modeling Workshops, which focus upon the implementation of the latest ideas in education research and are centered around the student creation of rich mental models. Pre-service teachers at ASU also take these workshops to satisfy the “teaching methods” requirement towards their degree.

Rex Rice, the author’s former HS physics teacher, pulls a colleague while demonstrating an activity in ‘student mode’ (St. Louis, 2006).

I haven't made it very far from room PSH 357. I'm now next door in PSH 355 leading the same course as part of the ASU teacher preparation program. Current students in the class are still constructing the same series of fundamental models in mechanics, *still* splitting class time between student mode and teacher mode, and *still* becoming part of a vibrant community of educators discussing how best to prepare our students to think like scientists.

I hear criticism of Modelers, typically implying that we are a group of fanatics who "drank the Kool-Aid" of constructivism. I find this puzzling, since one of the basic tenets of every Modeling Workshop in which I've been involved has been to constantly question the effectiveness of our teaching practices, rather than mindlessly adhering to what has been done before. If anything, being part of the Modeling community finally enabled me to feel as if I belonged in physics; prior to that, I always felt out of place in an environment that seemed (almost *fanatically*) rigid and competitive rather than creative and inclusive.

Jesse Ruiz, a PHY 480 student and undergraduate Learning Assistant, makes a large lecture introductory physics course more interactive (ASU, spring 2012). After taking a Modeling Mechanics Workshop as a physics major, Jesse decided to pursue a teaching certification.

PHY 480 Methods of Teaching Physics class members at Arizona State University. Spring 2016

I just finished teaching another Modeling Workshop in Mechanics this spring in room PSH 355 (next door to the 1995 classroom). There were 29 students in the course, but only 10 were pre-service teachers, and only 2 of these pre-service teachers intend to become *physics* teachers. The rest were a mix of undergraduate physics majors, graduate students in physics and mathematics, and current high school teachers (including visiting international teachers from Kenya and Indonesia). Despite our diverse backgrounds, just like my first experience in 1995, we became a supportive community of like-minded individuals, all of whom hope to transform STEM education to better reflect the practice of *doing science*.

Kelli Gamez Warble spent 18 years as a high school physics and mathematics teacher in the Phoenix area, 16 of those years at Title I "high need" schools. She has spent her summers since 1998 leading Modeling Workshops for STEM teachers, and in 2013 led the development team which designed workshops and curriculum for Modeling Instruction in Middle School Science. In fall 2012, she became the Teacher in Residence as part of the Arizona State University PhysTEC program, where she currently teaches and coordinates the Learning Assistant program for the physics department.

Rutgers Physics Teacher Preparation Program

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The Rutgers physics/physical science teacher preparation program is a 45-credit, two-year master's program that pre-service physics/physical science teachers (PSTs) can complete in five-years, or as a post baccalaureate option. In addition to earning a master's degree, all of our program graduates also hold an undergraduate degree in physics (70%), engineering (20%), or chemistry (10%). The program, which has been in place since 2001, graduated its first teacher in 2003 and its first real cohort in 2004. Since that year the program has graduated between 5-8 teachers annually. This year it produced 10 teachers and is on track to produce 9 teachers next year. The graduates of the program form a supportive professional community that is active on Facebook (60-100 postings every month) and voluntarily meets every two to three weeks in person at Rutgers.[1]

The students in the program take 6 courses (18 credits) in which they learn to teach physics (as opposed to generic science methods) and have four semesters of clinical practice.[2] All of the physics-related coursework and clinical experiences are inspired and united by the same learning philosophy — Investigative Science Learning Environment (ISLE).[3] ISLE is a learning system that helps students learn physics through collaborative participation in reasoning processes and experimentation that is similar to the methods used by practicing physicists. ISLE students work in groups to construct their understanding of physics concepts or mathematical relations by observing carefully-selected simple physical phenomena, identifying patterns and devising multiple explanations for those patterns, and designing and conducting experiments to test their explanations — often resulting in them discovering new patterns that require new explanations. The process is similar to the differential diagnosis process used by the doctors in the television show *House*.

Rutgers Pre-service teachers learning physics as students in an ISLE activity

Rutgers pre-service teacher microteaching to his classmates

Through this method, PSTs learn how physicists discover knowledge, how to use an ISLE approach to design lessons and units, and how to assess student learning in this new environment. Using this process repeatedly not only strengthens and expands PSTs' own physics knowledge, but also teaches them to test ideas experimentally; evaluate assumptions; represent their models in different ways; and argue, collaborate, and communicate with each other. All of these practices are also major components of the Next Generation Science Standards.[4] The ISLE cycles, which include all of the concepts of a high school level physics course,[5] are developed based on how people learn[6] in general, and how they learn physics in particular. A wealth of physics education research (PER) provides us with the knowledge of the preconceptions that students bring into the classroom[7] (these emerge as possible explanations and students have an opportunity to test them immediately), what language issues we should consider,[8] how to engage students in physics practices,[9] and many other important factors concerning effective physics instruction.

During the first 6–7 classes of each physics teaching method course, PSTs engage in ISLE activities as if they were high school students. The program coordinator then has the students reflect on what physics they would have learned from participating in that activity as a high school student, as well as what they, as aspiring teachers, learned about teaching. Following those classes, the PSTs plan and teach their own lessons (in groups of two) to their peers under careful supervision of, and with immediate feedback from, the program coordinator. Having PSTs teach to their peers (called microteaching) is similar to having airplane pilots train using flight simulators. Throughout these courses, the program co-

Table 1. Program course work and clinical practice

Year/semester	General Education courses	Physics methods courses	Goals of physics methods course	Clinical Practice
1/Fall (combined with the undergrad major courses)	Educational Psychology Individual and Cultural Diversity	Development of Ideas in Physical Science	To learn how physicists developed the ideas and laws that are a part of the high school physics curriculum (mechanics, KMT, E&M, modern physics)	Teaching as lab or recitation instructor in an ISLE-based algebra-based course for science majors. (Mechanics, fluids and thermo)
1/Spring (combined with the undergrad major courses)		Teaching Physical Science	To learn how to build student understanding of crucial concepts, and how to develop and implement NGSS-based curriculum units (mechanics, fields, DC circuits)	Same as above+30 hours of observations of ISLE high school lessons (Waves, E&M, modern physics)
		Demonstrations and Technology in Physics Education	To learn how to use technology to develop and apply physics concepts and assist in course management (geometrical optics)	
1/Summer	Assessment for teachers (2 credits)	Engineering Education	To learn how include engineering projects in a physics course.	Mechanics, thermo, E&M
2/Fall	Classroom management (1 credit)	Teaching Internship Seminar for physics students	To simultaneously support PSTs teachers who are doing student teaching and to explore teaching approaches to the new concepts in the curriculum (waves)	15 weeks of student teaching internship in an ISLE based classroom. Mechanics
		Teaching Internship (9 credits)	These are the credits for doing student teaching.	
2/Spring	Inclusive Education Teacher as a Professional	Multiple Representations in Physical Science	To integrate different representations of physics knowledge into problem solving (E&M, DC circuits, optics, modern physics)	Teaching as lab or recitation instructor in an ISLE-based algebra-based course for science majors. Waves, E&M, modern physics

ordinator does not lecture about effective teaching methods, but instead lets the PSTs observe her leading these new types of lessons, encourages them to reflect on their experiences, and then has them test their ideas during their own microteaching. In this way, the ISLE philosophy, which emphasizes that ideas emerge from observations and are tested through new experiments, is extended to learning how to teach.

In addition to their coursework, PSTs have four semesters of clinical practice. In three of these, they are lab or problem solving session instructors in an undergraduate, ISLE-based introductory physics course. During the fall semester of their second year, PSTs are placed in the classrooms of former program graduates (who also follow ISLE) for their student teaching internship. Having both the course work and the clinical practice send the PSTs coherent messages supporting the ISLE philosophy helps them become teachers who will engage their students in doing physics through continuous collaboration with each other.[1] Through multiple physics teaching methods courses, the PSTs have an opportunity to learn the tools needed to teach all of the most important physics concepts (motions, forces, laws of conservation, kinetic molecular theory, electricity and magnetism, optics and modern physics), which prepares them to teach almost any physics lesson in a high school physics course. Table 1 describes the course work and clinical practice for each semester and shows what physics topics PSTs learn to teach in each course.

The program is described in detail in references 1 and 2. Anyone who is interested in the details of student recruitment, advising, or course and clinical practice design is welcome to contact the author of this paper — the creator and the sole coordinator of the Rutgers Physics Teacher Preparation Program.

Eugenia Etkina is a professor of science education at Rutgers University. She spent 13 years teaching high school physics before she earned her PhD in physics education. Since then she moved to Rutgers where she started the Rutgers physics teacher preparation program and took part in the reforms in introductory physics courses. In 2014 she received a Millikan medal for her contributions to physics education.

(Endnotes)

1. E. Etkina, Using early teaching experiences and a professional community to prepare pre-service teachers for every-day classroom challenges, to create habits of student-centered instruction and to prevent attrition, in *Recruiting and Educating Future Physics Teachers: Case Studies and Effective Practices*, edited by C. Sandifer and E. Brewe (American Physical Society, College Park, MD, 2015), 257-274.
2. For the details of the coursework and clinical practice see E. Etkina, Pedagogical content knowledge and preparation of high school physics teachers, *Physical Review Special Topics Physics Education Research*, 6, 020110 (2010) and reference 1.
3. E. Etkina, Millikan award lecture: Students of physics—Listeners, observers, or collaborative participants in physics scientific practices? *American Journal of Physics*, 83 (8), 669-679 (2015).
4. NGSS Lead States, *Next Generation Science Standards: For States, By States* (National Academies Press, Washington, DC, 2013).
5. For examples of using ISLE to help students learn traditional concepts see E. Etkina, M. Gentile, and A. Van Heuvelen, *College Physics* (Pearson, San Francisco, 2014) and for an example of experimental problem solving using ISLE approach see E. Etkina, G. Planinšič, and M. Vollmer, “A simple optics experiment to engage students in scientific inquiry,” *Am. J. Phys*. 81 (11), 815–822 (2013);
6. J. Zull, *The Art of Changing the Brain* (Stylus Publishing, Sterling, VA, 2002).
7. A. Arons, *Teaching Introductory Physics*, (Wiley and Sons, Inc,1997); L. C. McDermott and E. F. Redish, Resource Letter: PER-1: Physics Education Research, *Am. J. Phys*. 67, 755 (1999)
8. D. T. Brookes and E. Etkina, Using conceptual metaphor and functional grammar to explore how language used in physics affects student learning, *Phys. Rev. ST Phys. Educ. Res*. 3, 1 (2007).
9. E. Etkina, and G. Planinsic, Defining and Developing “Critical Thinking” Through Devising and Testing Multiple Explanations of the Same Phenomenon, *The Physics Teacher*, Vol. 53, October, 432-437 (2015).

Browsing the Journals

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- In the February 2016 issue of *The Physics Teacher* (http://scitation.aip.org/content/aapt/journal/tpt), Prentis and Obsniuk present an introductory-level discussion of how the Helmholtz free energy can be thought of as a competition between minimizing energy and maximizing entropy at equilibrium, depending on the temperature. I also learned something from the iPhysicsLabs column in the same issue about the oscillations in pressure (easily perceptible to passengers' ears) as waves are reflected from the far end of a tunnel shortly after a train enters it. The April 2016 issue has a convincing experimental demonstration that the sound produced when a camera flash is discharged next to a cymbal is due to thermal expansion of the metal upon absorption of the light, and is *not* due to momentum transfer from the reflected photons. In the same issue, Mallmann has another of his "surprising facts" articles. His second fact asks how far apart two earths would have to be to experience the same gravitational force as two ping-pong balls in contact? His third fact shows that the circle of least confusion for light focused by a lens of large diameter is at a substantially different position than the focal plane, thus explaining a common systematic error in introductory lab measurements of focal lengths of lenses.

- An article on page 113 of the February 2016 issue of the *American Journal of Physics* (http://scitation.aip.org/content/aapt/journal/ajp) analyzes videos of a uniform thin rod as it tips over starting from a vertical position to see whether the bottom end slips or not, and if so in which direction. There is also an interesting exchange of letters on pages 146 and 147 of the same issue concerning how torques are transmitted along a rigid pivoted rod connecting two point masses located at different radii from the hinge. I am interested in the role that eddy currents play in damping the tumbling of small metal-frame satellites (such as CubeSats) in earth orbit; an article on page 181 of the March 2016 issue investigates this issue computationally and experimentally. On a similar note, the comparison between experiment and an analytic solution for a spherical magnet falling through a copper pipe on page 257 of the April 2016 issue is convincing. I also appreciated the study of supercooling of water samples of varying degrees of purity on page 293 of the same issue.

- Article 015022 in the January 2016 issue of the *European Journal of Physics* gives an introductory derivation of the wave and beam equations starting from discrete ball-and-spring or accordion-like bending-slab models, respectively. Article 025301 in the March 2016 issue discusses how Snell's law fails to describe the propagation of light in a medium where the surfaces of constant refractive index are not a set of parallel planes. Also, article 035602 in the May 2016 issue considers the idea (first mentioned by Feynman) that, because of gravitational time dilation, the center of the earth is a few years younger than its surface. Article 015005 in the January 2016 issue of *Physics Education* asks whether the 8-minute propagation time for light from the sun to reach the earth implies that the sun will already be 2° below the horizon when you see it on the horizon at sunset? Article 015010 in the same issue presents a simple approximate derivation of the temperature of a black hole. Both journals can be accessed at http://iopscience.iop.org/journals.

- Page 213 of the March 2016 issue of *Resonance* has a well-written review of the theory and detection of gravitational waves. Another interesting review is of the physics of "singing" sand dunes on page 339 of the April 2016 issue. These articles can be freely accessed at http://www.ias.ac.in/listing/issues/reso.

- An article on page 2094 of the December 2015 issue of the *Journal of Chemical Education* explains why combustion always yields about 418 kJ per mole of oxygen gas. A commentary on page 583 of the April 2016 issue proposes modifying the vague term "amount" of a substance with the adjective "stoichiometric" to make it clear one is referring to number of moles and not to mass or volume. The journal archives are at http://pubs.acs.org/loi/jceda8.

- Article 010128 in *Physical Review Physics Education Research* at https://journals.aps.org/prper/pdf/10.1103/PhysRevPhysEducRes.12.010128 recommends that Faraday's law be taught by presenting (via worksheets or clicker questions) to students contrasting cases so that they discover the key features of a situation required to obtain a nonzero induced voltage or current.

Web Watch

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- A 2D simulation of the dynamics of simple atoms and molecules at http://physics.weber.edu/schroeder/md/InteractiveMD.html lets users explore phases, pattern emergence, and equipartition.
- Check out STEMblog at http://blog.stemconnector.org/. Also see the web page devoted to STEM opportunities for women and minorities at http://www.onlinecolleges.net/for-students/women-and-minorities-stem/.
- If you browse College Factual's list of top 10 colleges for a physics major at http://college.usatoday.com/2015/03/14/top-ten-u-s-colleges-for-a-major-in-physics/, you will see why I am listing it. Also see the blog page and reader comments about choosing an undergraduate college at http://www.preposterousuniverse.com/blog/2006/10/16/unsolicited-advice-part-three-choosing-an-undergraduate-school/.
- RedOrbit has interesting postings related to science, technology, and health at http://www.redorbit.com/. Another great site is ScienceAlert at http://www.sciencealert.com/.
- NOVA Next starts from the conventional textbook ideas of friction and applies them to a handful of atoms in an optical lattice at http://www.pbs.org/wgbh/nova/next/physics/friction/.
- Read the Science post at http://www.sciencemag.org/news/2015/10/machine-produces-largest-humanmade-waves-world about a flume in the Netherlands that produces the largest manmade waves in the world.
- A set of K–12 curricula relating science and math to engineering is online at https://www.teachengineering.org/curriculum/browse. Also see the list of simple machines in elevators at http://www.elevators.com/simple-machines-used-in-elevators/.
- JPL has a beautiful website devoted to Mars science at http://mars.nasa.gov/msl/.
- A short conceptual overview of some of the implications of Maxwell's equations is at https://www.theguardian.com/science/life-and-physics/2015/nov/22/maxwells-equations-150-years-of-light.
- Why does the pitch of a banged mug of hot water change as you stir hot cocoa into it? See http://www.physicscentral.com/experiment/physicsathome/hot-cocoa-effect.cfm?utm_source=thank%20you&utm_medium=email&utm_campaign=Year%20End%202015. Also read about the physics of champagne at http://physicsworld.com/cws/article/indepth/2015/dec/01/six-secrets-of-champagne.
- BBC presents a layman's webpage on the import of general relativity at http://www.bbc.co.uk/guides/zs7d2p3.
- Boston's Museum of Science has a web presence at http://www.mos.org/museum-online.
- The periodic table at http://apod.nasa.gov/apod/ap160125.html shows the astronomical origin of each element. Also see the TED-Ed periodic table of videos at http://ed.ted.com/periodic-videos.
- XKCD has an illuminating (sorry!) discussion of why you cannot start a fire using a magnifying glass to focus the light from a full moon at http://what-if.xkcd.com/145/.
- Annenberg has collected together some useful teaching resources about mathematics at http://www.learner.org/resources/discipline-math.html.
- A free online page will optimize images for web pages, email transmittal, or disk storage at http://www.imageoptimizer.net/Home.aspx. Another useful resource at http://www.printwhatyoulike.com/ will you let select which parts of a web page to print and which to skip. Finally, the page at https://readability-score.com/ will measure the readability of your writing.
- YouTube has a set of videos of nifty science experiments using simple equipment at https://www.youtube.com/user/SteveSpanglerScience.
- This Week in Chemistry at http://www.compoundchem.com/category/this-week-in-chemistry/ chooses 5 features per week, many of them of interest to materials physicists.
- An ornate website surveying the history of air and space flight is at http://theageofaerospace.com/discovery.

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