The Arons-Advocated Method *§

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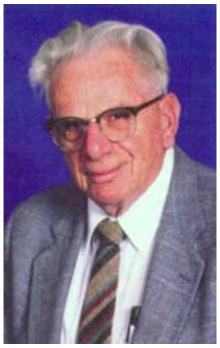

Arnold Boris Arons (1916-2001)[§]

Structured Abstract[†]

Background: Arnold Arons, along with Robert Karplus, can fairly be called one of the founding fathers of U.S. Physics Education Research, a field that has emerged as a viable sub-discipline of physics in the last two decades. The instructional methods advocated by Arons were influenced by the work of Socrates, Plato, Montaigne, Rousseau, Dewey, Whitehead, and Piaget, but are primarily derived from Arons' epic half-century effort to improve introductory science teaching by *shuting up and listening carefully* to students' responses to probing Socratic questions on physics, science, and ways of thinking.

(Continued on page 2)

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< http://www.physics.indiana.edu/~hake >, or download directly as a 144 kB pdf by clicking on
< http://www.physics.indiana.edu/~hake/AronsAdvMeth-8.pdf >. I welcome comments and suggestions directed to <rrhake@earthlink.net>.

‡ Partially supported by NSF Grant DUE/MDR-9253965.

§ For Arons' obituaries see Haskell (2001), Matthews (2001), McDermott et al. (2001), & WHOI (2001). For further bibliographic information and a fascinating interview see Minstrell (1981).

† Mosteller, F.,B. Nave, & E.J. Miech. 2004. "Why We Need a Structured Abstract in Education Research," *Educational Researcher* **33**(1): 29-34; online at < http://www.aera.net/pubs/er/toc/er3301.htm >.

(Continuation of Structured Abstract from page 1.)

Purpose: To summarize and explain the eleven salient features of the *Arons-Advocated Method* (AAM).

Intervention: AAM emphasizes: (1) conceptual understanding, (2) *operative* knowledge, (3) interactive engagement, (4) Socratic dialogue, (5) attention to cognitive development, (6) attention to preconceptions of beginning students, (7) *operational* definitions, (8) reduction of volume and pace of standard introductory courses, (9) idea first, name afterward, (10) importance of a course "story line," (11) science as a liberal art.

Research Design: Analytic essay.

Conclusions: Arons' ethnographic diagnosis of, and prescription for, the current moribund state of undergraduate science instruction are generally consistent with the results of other qualitative and quantitative education research stimulated in part by his work. Resuscitation along lines advised by Arons appears especially crucial for upgrading K-12 education in the U.S., since prospective K-12 teachers derive little conceptual understanding from traditional introductory science courses and then tend to teach as they were taught with similar negative results. Such enhancement might serve to raise the appallingly low level of science literacy among the general population and thus increase our chances of solving the monumental science-intensive problems (political, economic, social, and environmental) that beset us.

I. INTRODUCTION

In 1980, after a disastrous attempt to explain Newtonian mechanics to prospective elementary teachers, I sought advice on efficacious physics pedagogy by telephoning around the country. I had little success until science-education pioneer Robert Karplus [see Fuller (2002)] at Berkeley advised me to call "the only person in the country who understands the problem," Arnold Arons at the University of Washington. In a watershed 30-minute telephone conversation, Arons, speaking from 12 years of hard-won experience with elementary education majors (Arons 1977), recommended that *I abandon the traditional passive-student lecture*. He patiently explained his physics education method: hands-on laboratory experience with concrete physical systems, repeated interactive engagement at increasingly sophisticated levels, emphasis on operational definitions, and Socratic Dialogue.

Seeking to learn more about this unorthodox approach, I studied some of Arons' insightful articles [e.g., Arons (1972, 1974, 1976)] and was deeply impressed. I tried to construct several laboratory write ups in an Arons mode, and found that such "Socratic-Dialogue-Inducing" (SDI) labs were relatively effective in advancing the conceptual understanding of physics not only among elementary education majors [Hake (1991a)], but also among premeds and science majors [Hake (1987; 1991b; 1992; 1998a,b; 2002a,b,c; 2003b,c)], and even non-physical-science professors [Tobias & Hake (1988)]. [For a more detailed account of my conversion to the *Arons Method* of physics instruction see Hake (1991a).]

In the 1980's I attempted to spread the word regarding the efficacy of the *Arons Method* by traveling about the country giving talks with that title. However, I later changed the title to the *Arons-Advocated Method* when Arons insisted that he had done nothing original, and that most of what he advocated was from Socrates, Plato, Montaigne, Rousseau, Dewey, Whitehead, and Piaget. Arons was doubtless influenced by those educators, and his method may well be *consistent* with their work. But, judging from Arons' own words (see below), his method is better described as ***empirically*** derived by *shutting up and listening carefully* to students' responses to probing Socratic questions on physics, science, and ways of thinking. Arons (1974) wrote:

> If a teacher disciplines himself to conduct such Socratic Dialogues . . .[see Sec. II, #4 below]. . .he begins to see the difficulties, misconceptions, verbal pitfalls, and conceptual problems encountered by the learner. . . . In my own case, *I have acquired in this empirical fashion virtually everything I know about the learning difficulties encountered by students.* [My *italics*.] I have never been bright enough or clairvoyant enough to see the more subtle and significant learning hurdles *a priori*.

In my opinion, the *Arons-Advocated Method*, with its basis in the astute probing and analysis of student minds by a discerning research physicist deserves greater attention. I would extend Randall Knight's (1995) recommendation that "every teacher of introductory physics, from high school through the calculus-based course, should have a copy of this book . . .[Arons (1990, 1997a)]. . . within easy reach," to include every science teacher, education researcher, and cognitive scientist. Judging from psychologist Robert Grossman's (2004)] use of Arons' work to elucidate "knowledge transformations," even non-physical science professors can benefit.

Arons (1984b) ends his *Physics Teacher* trilogy [Arons (1983b; 1984a,b)] on "Student Patterns of Thinking and Reasoning" with the anticipation that cognitive research will bring a rationale and an order to his abundant empirical insights:

> I fully anticipate that future advances in cognitive research will analyze, reconstruct, merge, separate, and reassemble in various more orderly ways, the insights I have attempted to describe. For the time being *I simply present what I have been able to discern through the still surrounding haze*. [My *italics*.]

In the ensuing two decades, cognitive science [see e.g., Bransford et al. (1999)] and physics education research [see e.g., McDermott & Redish (1999), Hake (2002c), UMPERG (2004)] have, in my opinion, shown that Arons' ethnographic [Howe & Eisenhart (1990), Howe (2001)] insights are generally consistent with the results of other *scientific* [Shavelson & Towne (2002)] qualitative and quantitative research. In my opinion, that work, even though the crucial pre/post test component [Halloun & Hestenes (1985a,b); Hake (2004b)] has been ignored by the NRC (1997, 1999, 2000, 2003a,b), has convincingly demonstrated the validity of Arons' diagnosis of, and prescriptions for, the current moribund state of undergraduate science instruction [see e.g. Handlesman et al. (2004)].

What are the salient features of the *Arons-Advocated Method*? Herewith is my own selection of eleven major components, as culled from my reading of Arons' thoughtful articles and books, listening to his provocative talks, and exchanging opinions on matters of pedagogy and physics. The items included are *not*: (a) exhaustive – they omit some facets of Arons' strategies, (b) independent – they overlap one another in mutually reinforcing ways, or (c) unique – other physicists and educators might choose to emphasize other components of the Arons method.

II. THE *ARONS-ADVOCATED METHOD* – EMPHASIS ON:

1. *Conceptual Understanding*. In " 'Critical Thinking' and the Baccalaureate Curriculum," Arons (1985) wrote

> . . .scientific concepts are not objects "discovered" by an explorer but are the abstractions deliberately created or invented by acts of human intelligence . . . . this approach allows a clear introduction to the notion of operational definitions . . . [see "7" below].

And again in "Achieving Wider Scientific Literacy," Arons (1983a) gave, as numbers 1, 2, and 7 of his "hallmarks of science literacy":

> 1. Recognize that scientific concepts . . . . are invented (or created) by acts of human intelligence and are not tangible objects or substances accidentally discovered, like a fossil, or a new plant or mineral.
>
> 2. Recognize that to be understood and correctly used such term require careful *operational* definition . . . . [see #7 below]. . . , rooted in shared experience and in simpler words previously defined; to comprehend, in other words, that a scientific concept involves an idea *first* and a name *afterwards*, and that *understanding does not reside in the technical terms themselves*.
>
> 7. Understand, again through specific examples, the sense in which scientific concepts and theories are mutable and provisional rather than final and unalterable, and to perceive the way in which such structures are continually refined and sharpened by processes of successive approximation.

2. ***Operative Knowledge.*** Arons (1983a) in "Achieving Wider Scientific Literacy" wrote (my *italics*):

> Researchers in cognitive development describe two principal classes of knowledge: figurative declarative) and operative (or procedural) [Anderson (1980); Lawson (1982)]. *Declarative knowledge consists of knowing* "facts"; for example, that the moon shines by reflected sunlight, that the earth and planets revolve around the sun . . . . *Operative knowledge, on the other hand, involves understanding the source of such declarative knowledge* (How do we know the moon shines by reflected sunlight? Why do we believe the earth and planets revolve around the sun when appearances suggest that everything revolves around the earth? . . . .) and the capacity to use, apply, transform, or recognize the relevance of the declarative knowledge to new or unfamiliar situations. *To develop the genuine understanding of concepts and theories that underlies operative knowledge, the college student, no less than the elementary school child, must engage in deductive and inductive mental activity coupled with interpretation of personal observation and experience.* Unfortunately, such activity is rarely induced in passive listeners, but it can be nurtured, developed, and enhanced in the majority of students providing it is experientially rooted and not too rapidly paced, and providing the mind of the learner is actively engaged.

And in a similar thread in " 'Critical Thinking' and the Baccalaureate Curriculum," Arons (1985) quoted Alfred North Whitehead (1929):

> *Above all things we must be aware of what I will call "inert ideas" – that is to say, ideas that are merely received into the mind without being utilized, or tested, or thrown into fresh combinations*.

3. ***Interactive Engagement*** rather than didactic exposition (stream of words) . . . . [quantization of this stream has been theorized by Hestenes (1994)]. . . for difficult concepts including (a) hands-on and minds-on experience with concrete physical systems, (b) repeated engagement at increasingly sophisticated levels. I think Arons would agree that an *operational definition* [see #7 below] of "interactive engagement methods" could be phrased as "those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" [Hake (1998a)]. Regarding "repeated engagement at increasingly sophisticated levels," Arons wrote (1983b) [*italics* indicate emphasis in the original, <u>underlines</u> indicate my emphasis]:

> Experience with learning difficulties encountered by students in introductory science courses suggests the existence of a number of basic patterns (or processes) of thinking and reasoning. . .[see below]. . . which underlie almost all learning and understanding. It is my conviction that helping students become explicitly conscious of those patterns, and giving them *repeated* opportunity to practice and exercise such modes of thought in successive, *different* contexts of subject matter, greatly enhances their grasp of concepts and principles as indicated by gradually improving ability to analyze physical phenomena and to make predictions in new and altered situations. In other words, helping students cultivate reasoning processes such as those to be

> described in this paper increases their capacity to learn still more. . . .It must be emphasized, however, that *repetition* is an absolutely essential feature of such instruction – repetition *not* with the same exercises or in the same context but in continually altered and enriched context. . . Experience with the modes of reasoning I will be illustrating . . . [see below] . . . must be spread out over weeks and months and must be returned to in new contexts after the germination made possible by elapsed time. Starting with only a few students being successful, each repetition or re-cycling sees an additional percentage of the class achieving success, usually a leveling off somewhat below 100% of the total after approximately five cycles. . . . [According to Jim Minstrell (private comunication), Arons calls his 5-cycle rule the "rule of hand," rather than the "rule of thumb."]. . . (These are empirical facts which I have observed but for which I have no explanation.)

In his tour-de-force *Physics Teacher* trilogy, Arons (1983b, 1984a,b) enumerated the following basic patterns of thinking and reasoning, giving concrete examples of each:

1. Verbal interpretation of the ratio of two numbers.
2. Arithmetical reasoning involving division.
3. Coupling arithmetical reasoning to graphical representation.
4. Scaling and functional reasoning.
5. Idea first and name afterward.
6. Translating symbols into words.
7. Describing phenomena in words.
8. Reversing a line of thought.
9. Making decisions.
10. Recognizing inapplicability of formulas.
11. Recognizing the importance of what is *not* the case.
12. Comparison and serial ordering.
13. Estimating and dealing with orders of magnitude.
14. Non-uniform change without calculus.
15. Discriminating between observation and inference.
16. How do we know . . . .? Why do we believe . . . .?
17. Recognizing lack of needed information.
18. What would happen if . . . . . ?
19. Asking one's own questions.

Jerome Epstein (1997-98) and George Kolodiy, were heavily influenced by Arons' articles to develop an evidently successful program to bring students' understanding and utilization of some of the above patterns of thinking and reasoning up to speed *prior* to enrollment in standard science courses. This program, dating from the early 1980's, was explicitly designed to enhance students' ascension to Piaget's "formal reasoning" level, primarily by Socratic Dialogue, hands-on activity, and writing. Unfortunately, the Epstein/Kolodiy effort has had no more lasting effect than other meritorious and innovative educational programs, e.g., Arons' (1959) ground-breaking science-as-a-liberal art course at Amherst, and Benezet's (1935/36) pioneering demonstration of the cognitive advantage of delaying algorithmic arithmetic drill until the sixth grade.

4. ***Socratic Dialogue*****.** Arons (1985) described what he *does* with Socratic dialogue (my *italics*):

> One must learn to ask simple, sequential questions, leading students in a deliberate Socratic fashion. After each question, *one must shut up and listen carefully to the response*. [It is the tendency of most inexperienced questioners to provide an answer, or to change the question, if a response is not forthcoming within one second.] One must learn to wait as long as four of five seconds, and one then finds that the students, having been given a chance to think, will respond in sentences and truly reveal their lines of thought. *As students respond to such careful questioning, one can begin to discern the errors, misconceptions, and missteps in logic that are prevalent.* One learns nothing by giving students "right answers" or "lucid explanations." As a matter of fact, students do not benefit from such answers or explanations; they simply memorize them. Students are much more significantly helped when they are led to confront contradictions and inconsistencies in what they say and then spontaneously alter their statements as a result of such contradiction.

In his addendum to "Toward Wider Public Understanding of Science," Arons (1974) had this to say regarding the benefit of Socratic Dialogue to the teacher and to education (my *italics)*:

> I am deeply convinced that a statistically significant improvement would occur if more of us learned to listen to our students . . . *By listening to what they say in answer to carefully phrased, leading questions, we can begin to understand what does and does not happen in their minds, anticipate the hurdles they encounter, and provide the kind of help needed to master a concept or line of reasoning without simply 'telling them the answer.'*. . . .Nothing is more ineffectually arrogant than the widely found teacher attitude that "all you have to do is say it my way, and no one within hearing can fail to understand it.". . . . Were more of us willing to relearn our physics by the dialogue and listening process I have described, we would see a discontinuous upward shift in the quality of physics teaching. I am satisfied that this is fully within the competence of our colleagues; the question is one of humility and desire.

Arons' description of what he *does* with the Socratic method fits that of the *historical* Socrates as researched by the late Gregory Vlastos (1990, 1991, 1994), *not* that of Plato's alter ego as depicted in Plato's *Meno*. Philosophers Phillips & Soltis (1998) on pp. 9-12 treat the *Meno* as strictly a reflection of Plato's philosophy. For a discussion of the *historical* Socrates and his widespread misidentification as Plato [by e.g., Morse (1994), Swartz (1994, 2000), and Redish (2003)] see e.g., footnote 39 of Hake (1998b) and also Hake (2002b).

5. ***Attention to Cognitive Development***. [See e.g., Arons & Karplus (1976), Arons (1979; 1981; 1983a,b; 1984a,b,c; 1985; 1986; 1990, p. 305; 1995; 1997a, p. 365]. Arons & Karplus (1976) wrote:

> If our suggested inference is correct [that only that 1/3 of college freshman have arrived at what Piaget. . . [see, e.g. Inhelder & Piaget (1958), Inhelder et al. (1987),]. . . called the "formal operational" level], it seems to us that *explicit awareness of the problem and measures to attack it, must begin in the colleges and universities. These institutions educate the teachers for the educational system with which we are concerned.* (My *italics*.) They must provide leadership in converting it from a passive one that merely allows *sui generis* development of a small fraction to one that actively assists the intellectual development of the far larger proportion of the population that we have every reason to believe is fully capable of abstract logical reasoning.

In one of his later papers, Arons (1995) set forth the following tentative conjecture that he considered to be of potentially great importance (I agree):

> Many of those students who initially have great difficulty with elementary ratio reasoning and with word problems utilizing division, simultaneously have great difficulty with most other modes of abstract logical reasoning. (In the Piagetian lexicon they would be described as "concrete operational.") When these students finally break through to mastery of arithmetical reasoning with division (after the frustrating struggle with as many as five or more episodes in altered context), they almost simultaneously also break through on other modes of reasoning such as control of variables, dealing with abstract concepts such as velocity and acceleration, and, especially, acquiring improved capacity for hypothetico-deductive reasoning.

For recent research on ways to improve student's effective use of the control of variables strategy see Klahr & Nigam (2004) and comments on that work by Hake (2004a). For a good discussion of hypothetico-deductive reasoning see Lawson (1995).

6. ***Attention to Preconceptions of Beginning Students***. Arons (1997a, p. 56; 1990, p. 49) writes:

> Most of our students come to us imbued with intuitive rules or notions that we are strongly tempted to call, pejoratively, "misconceptions." These intuitive notions are, however, neither perverse nor idiosyncratic; they are rooted in everyday experience, and they were initially held by all our predecessors. Our pedagogical orientation becomes sounder and more reasonable when we characterize these notions as understandable "preconceptions" to be altered through concrete experience, rather than as ignorant "misconceptions" to be removed instantaneously through verbal inculcation and a few demonstrations in which the student does not participate. [See also Arons (1986).]

For a bibliography of the vast misconceptions literature see Duit (2004).

7. *Operational Definitions* .

An operational definition of “X” simply gives the operations for *measuring* “X”. Operational definitions are therefore crucial in science and in critical thinking, even despite the protestations of the “anti-positivist vigilantes” (Phillips 2000). For a good discussion of operational definitions see, e.g., Holton & Brush (2001). The latter authors quote Poincaré:

> When we say force is the cause of motion we talk metaphysics, and this definition, if we were content with it, would be absolutely sterile. For a definition to be of any use, it must teach us to *measure* force; moreover, that suffices; it is not at all necessary that it teach us what force is *in itself*, nor whether it is the cause or the effect of motion.

8. *Reduction of Volume and Pace of Standard Introductory Courses*. Arons (1983a) writes:

> . . .we must cut back on the volume and pace of coverage that have escalated in *all* our courses. Students must have time to form concepts, think, reason, and perceive relationships. They must discuss ideas, and they must write about them.

Then Arons (1986) wrote:

> The relativistic model of instruction is based on the premise that, if one starts with an E – N – O – R – M – O – U – S [my emphasis] 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.

For a cartoon representation of the “relativistic model of instruction” that characterizes most introductory physics courses see Hake (2000a).

9. *Idea First, Name Afterward*. For examples of pedagogy emphasizing this issue see the 15 pages indicated in the index of Arons (1997a) or the 9 pages indicated in Arons (1990) for “idea first, name afterward.” To give one example, on page 82 of Arons (1997a) [pages 69-70 of Arons (1990)] Arons writes:

> . . .students must be made aware that the name does nothing more than conceal ignorance – that to this day, despite the power of the Newtonian synthesis and the beauty of the general theory of relativity, we have no mechanism for the interaction and no idea of how it “works.” It is interesting to note what Galileo had to say about this matter. In the *Dialogue Concerning the Two Chief World Systems* one finds the following exchange:
>
>> SIMPLICO: The cause of this effect [what it is that moves things downward] is well known; everybody is aware that it is gravity.
>>
>> SALVIATI: You are wrong, Simplico; what you ought to say is that everyone knows that it is called “gravity.” What I am asking you for is not the name of the thing, but its essence, of which essence you know not a bit more than know about the essence of whatever moves the stars about. I accept the name which has been attached to it and which has been made a familiar household word by the continual experience we have of it daily. But we do not really understand what principle or what force it is that moves stones downward. . . .
>
> It seems that the appropriate form of this dialogue has not changed very much over the interval of almost four hundred years.

10. *Importance of a Course “Story Line.”* Arons (1983a) writes:

> Examples of reduced coverage and selection of reasonable story lines do exist in our textbook literature, although the examples are relatively few in number. To illustrate what I mean . . . *The Project Physics Course*. . . [Rutherford et. al (1970) is]. . . an example of how to weave a story line that brings one to the beginnings of modern atomic and subatomic physics, leaving out unnecessary subjects along the way and introducing many of the intellectual perspectives advocated in this essay. . .

Arons modestly omits mention of his classic *Development of Concepts of Physics* [Arons (1965)] – see below.

11. Science as a Liberal Art . Arons (1983a) writes:

> I know at first hand. . . [Arons (1959)]. . . that students can and do respond to the demand both for thorough understanding of the science and for penetration of the intellectual perspectives. It is futile, however, to exhort the students regarding the importance of a liberal education and to give them nothing but ringing platitudes. We must be sufficiently knowledgeable and concerned to bring before them compelling instances of intellectual, moral, or esthetic experience.

Arons practiced what he preached. In presenting him with the Oersted Medal for 1972, in honor of his notable achievements in physics teaching, Bailey Donnally (1973) said:

> While at Amherst College he was widely know as a skilled teacher and was featured in a cover story on education in *Time* magazine. The content of the course for which he was cited and the instructional philosophy on which it was based are exemplified in his text, *Development of Concepts of Physics*, ...[Arons (1965)]. . . The very careful attention of a logical sequencing of ideas, the deep concern for a careful development of concepts in the minds of students, and the steady attention to the cultural basis of Western science so evident in that book have been his hallmarks.

Did the Amherst students of the 50's appreciate Arons? In an interview with Arons, his ex-doctoral student Jim Mistrell (1981) asks him "What has been the highlight of your teaching career?" Arons answers:

> I suppose it was what happened during my first year at Amherst, where I moved from Stevens in the Fall of 1952 . . . . In the last lecture, instead of a passive review or the addition of more subject matter, I stood back and talked about the meaning of education, about the whole intellectual experience we had tried to make available, about thinking, learning, and the development of their own minds. I pointed out some of the insights they should now have into science as a human endeavor requiring intellect and imagination, a two-edge blade with powers for both good and evil, encumbered with profound limitations. As I ended the lecture, closed my notebook, and was about to leave the room, the class burst into a standing ovation. This was completely unanticipated; I had never had it happen before; it came completely out of the blue. I just gasped, and I can recall a bit of moisture in my eye.

In regard to the liberal side of science/math education, I once asked Arons for his opinion of the virtually forgotten *Benezet Method* [Benezet (1935/36), Mahajan & Hake (2000)] of delaying drill on arithmetic algorithms until the sixth grade in favor of reading; inventing; discussing stories and problems; estimated lengths, heights, and areas; and finding and interpreting numbers relevant to their lives. Arons (2000) responded (my *italics*):

> *I have looked at the Benezet papers, and I find the story congenial*. The importance of cultivating the use of English cannot be exaggerated. I have been pointing to this myself since the '50's, and am delighted to find such explicit agreement. I can only point out that my own advocacy has had no more lasting effect than Benezet's. [You will find some of my views of this aspect in (Arons 1959)]] . . . . Benezet taught excellent arithmetic from the very beginning just as it should be taught. What he removed was useless drill on memorized algorithms that had no connection to experience and verbal interpretation. . . . This, of course, brings us back to the same old problem: *Whence do we get the teachers with the background, understanding, and security to implement such instruction. They will certainly not emerge from the present production mills.*

III. SUMMARY & CONCLUSIONS

The above eleven aspects of the *Arons-Advocated Method* are trenchantly summarized in the abstract of "Toward wider public understanding of science" [Arons (1972)]:

> Wider understanding of science will be achieved only by giving students a chance to synthesize experience and thought into knowledge and understanding. Such a chance is not available in the deluge of unintelligible names and jargon precipitated at unmanageable pace and volume in so large a proportion of our college courses, and it is not available in the absence of humanistic, historical, or philosophical perspectives within those courses. Neither will salvation be found in topical courses on currently "popular" matters such as the energy crisis, environmental problems, or societal impact – so long as these problems are plunged into without any genuine prior understanding of the underlying scientific ideas. Some deeply valuable lessons about the learning process, as it occurs in all individuals, are to be learned from among the best of the elementary science curricula that are now available in the schools. These lessons are transferable to college level and might help us simultaneously develop a new generation of teachers who would begin to disseminate a wider public understanding of science through competent teaching of science in elementary schools.

The above abstract also underscores Arons' concern with the recent history (1950 – 2000) of physics education in the U.S. [Arons (1993, 1997b, 1998); Hake (2003a)], and his conviction that enhancing science understanding of the general population requires drastic upgrading of elementary-school education, as can only occur if, among other things, prospective teachers are far better educated in the universities of America [Goodlad (1990, 1994), Goodlad & Keating, eds. (1994), NSF (1996), Hake (2003a, 2004a)]. An answer to Arons' (2000) key question:

> Whence do we get the teachers with the background, understanding, and security to implement such instruction?

is crucial to the large-scale K-12 implementation of the *Benezet Method* [Benezet (1935/36), Mahajan & Hake (2000)], *Physics First* [Lederman (2001)], and K-12 reform methods of science/math instruction generally [NRC (1996, 2000); Hake (2004a)]. The highest priority of the seven suggested steps [Hake (2002d)] to alleviate the current shortage of *effective* science/math teachers is to motivate universities to discharge their obligation to adequately educate prospective K-12 teachers.

According to an NSF advisory panel headed by Melvin George [NSF (1996)]

> Many faculty in SME&T. . . . (Science, Math, Engineering, and Technology) . . . . at the post-secondary level continue to blame the schools for sending underprepared students to them. But, increasingly, the higher education community has come to recognize the fact that teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which *SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers*." (My *italics*.)

Thus the improvement of SMET education at the *undergraduate* level along lines advised by Arons appears especially crucial to increasing the number of effective K-12 teachers, since prospective teachers derive little conceptual understanding from traditional introductory science courses and then tend to teach as they were taught with similar negative results. The upgrading of K-12 education might serve to raise the appallingly low level of science literacy among the general population [Hake (2000b)] and thus increase our chances of solving the monumental science-intensive problems (political, economic, social, and environmental) that beset us.

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> That such a trend. . . .[upgrading of grade 7-16 education due to implementation of the exemplary K-6 reform science curricula of the 50‘s and 60’s] . . . is not sweepingly underway is *not*, to my mind, so much a result of intrinsic weakness in the materials as it is a reflection of fact that *the education we provide our elementary school teachers leaves the great majority without adequate understanding of the most basic scientific subject matter and hence without the competence and security necessary to implement these materials effectively*.

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> The epitome of the Socratic method is described in Plato's *Meno*. . . .[This statement appears to be in direct contradiction to the work of classics scholar Gregory Vlastos (1990, 1991, 1994), the opinion of philosophers Phillips & Soltis (1998), and Swartz's (1993) own approval of Socratic Dialogue Inducing (SDI) labs.] . . . . We ran this account. . . .[Swartz (1994)]. . . word for (translated) word, figuring that it was its own parody. It's hard to do a parody of a parody, so we'll say no more about the matter here. If you really want to understand the method, better look it up in *TPT* or in the original Greek. Suffice it to say that Socrates tried it with only one slave boy. If you have more than one in your class, better forget it. (For research purposes, of course, it's a useful tool to find out what a particular student understands.)

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