Chapter 1

Research in Physics Education: The Early Years

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I was asked to talk a little bit about what it was like in the old days, and that invites personal reminiscences and anecdotes. I don't pretend to have made an investigation that can be characterized as legitimate history, so let an old man ramble. We'll come back first of all to the question that I asked at the end of the last session about all the projects we have worked on over the years. Many groups, complex projects, all over the place. The last one of those, the Introductory University Physics Project, under the acronym of IUPP, is reported on in a tendentious report in an *American Journal of Physics* issue earlier this year (Coleman, Holcomb & Rigden, 1998). I see very little in the way of impact and results despite its complexity. There were some comments around the table a little while ago about various projects reinventing the wheel. Now, if you stop and think about it, in the final analysis reinventing the wheel isn't all that bad. Actually the wheel works. What they keep doing is reinventing the flat tire, which doesn't work, and we need to learn more about how to avoid that, despite complex projects. Now I really ought to define my terms. I deliberately planted a term. I want to come back to the implications of it later—complex projects. You've been interpreting that word in one way, but in my own case, I have to be mathematically inclined and what I mean by complex projects are *the set for which costs are real and results imaginary* and we haven't really been talking to each other. I use a term in one way and you interpret it in another and this kind of thing is going on all over the place in physics instruction and it needs some research and attention which has not been given to it. I hope to be able to come back to this later.

Now it's a delight to me to be able to come to a session like this. To see those posters with good questions being asked and investigated and see the attendance at sessions that discuss student learning and understanding at the AAPT meetings over and beyond this and of course I can see the change. What was it like back then? Let me dwell—I can give you a couple of examples of what it was like in the way of personal experience.

After having spent the years of the second world war studying explosion phenomena and shock waves, I went back to academic work at my alma mater, Stevens Institute of Technology in Hoboken, New Jersey and I quickly began to see, (having an ego deflating experience which most of you probably share with me) to discover that my lucid lectures and demonstrations were depositing virtually nothing in the minds of the students. I began to discern this because I fortunately stumbled on how to ask test questions that brought some of this out and gradually grew more skillful in talking with students who came for help and listening to what they said, identifying some of the problems. I quickly discerned, for example, in one of the elements we had just dwelled on so much in the concept of force—Newton's

Third law—that the students couldn't comprehend that an inanimate object like a table could exert a force. This came out of office discussions—listening to the students—and so I began to make them verbalize, recognize when they didn't know or understand the definition of a term, define terms, write explanations on tests, interpretations of results, and not just make calculations. I began to see some at least marginal development in the directions I wanted to go.

After six years at Stevens I moved to Amherst College, where in those days they had a tightly organized core curriculum, one component of which was a freshman calculus physics course required of all students. Absorb that one if you will. It was required of all freshmen, regardless of majors, at a liberal arts college—calculus and physics. I had to direct that course and I was fortunate in having a superlative set of colleagues who followed along with the idea of not doing too much too fast, leading the students to define, talk, verbalize, interpret, connect with every day experiences. This was in the fifties and at some point I decided that maybe I ought to write a paper for *AJP*. I'd never had anything in *AJP* before, and since there was a lot of curiosity about this required course I thought I'd take the opportunity to describe it and to inject the idea of leading, of engaging the student mind through talking and reasoning about the concepts and ideas being developed. That was a major component of this paper, which I submitted to *AJP* somewhere in the mid-fifties. The editor was Tom Osgood then, at Michigan State, an acoustic physicist. The paper was very quickly rejected on the grounds that it was of marginal interest to the readers of the *American Journal of Physics* and as I say I hadn't any experience in this area at all. I simply put the paper and letter of rejection in my file and forgot about it. But a couple of years later, Nathenial Frank, who was then chairman of the department at MIT. (For the old-timers here that's the Frank of Slater and Frank and those very fine textbooks.) He came out to visit us, curious about what was going on. He wasn't just a visiting fireman. He spent more than a day, a day and a half, going to classes, listening to lecture, looking at tests, seeing what was going on. He came to me and asked me why I hadn't published about the course and I pulled out the paper and the letter of rejection and showed it to him. He asked me if he could take it with him and make some inquiries. Well, I was quite naive, politically and otherwise, at that time. Frank stirred up a ruckus at AIP for which I was later accused of being responsible. Anyway, Osgood's term as editor expired and Walter Michaels became editor. Big Red Mike was an entirely a different kind of character. He is the man who, incidentally, is responsible for that very fine Ph.D. program in physics at Bryn Mawr College. Anyway, Mike accepted my paper and it was finally published in AJP in 1959 (Arons, 1959). But there's an example of what it was like. Trying to get a paper along lines of this kind published is difficult enough now, I know, but was substantially more so then.

Another example of the kind of thing that was going on; I was elected in the early sixties to the commission on college physics, which was then active in catalyzing curriculum development at the college and university level. Zacharias and Friedman, two members of the committee, were the people responsible for PSSC physics. Zach in particular, over and over again in the commission meetings, said we ought to be doing research in physics education. But when people like that talked about research in those days, they didn't mean the kind of thing that you are engaged in at all. What they meant was, refining the delivery systems, the exposition, the text presentation, lecture presentation, the films and so forth, to the point that where they were so clear and so perfect that any passive student mind would assimilate them simply by having it drop in. That was what research was going to be—delivery—and there was no conception of listening to what the students said when you gave them the opportunity to reflect or talk about something.

I was very young then you know; take that into consideration. Sitting on the college commission were Zacharias and Ed Condon and Dick Crane and Bob Leighton and Matt Sands from Cal Tech, people of that variety. All senior to me. When I, on a couple of occasions, murmured that research might consist of finding out what the student learning problems were, the response that I got, in particular from one of the senior physicists on the commission, a man for who I had and still have tremendous respect, much senior to me, said, "Oh well, look, you're talking about gimmicks of your own creation and variety—that is not going to add anything to this enterprise." He, like the others, was thinking in terms of delivery systems. There is an example of what it was like when you tried to talk to some of the leading figures in the community.

One final example, one of the things that I learned early on in listening, asking students questions, listening, is in connection with interpretation of position-time diagrams in kinematics. I remember the episode quite vividly when I tumbled to something through what happened with a student. I drew a position-time diagram the conventional way and then the history, a horizontal line parallel to the t-axis and asked the student to interpret it and there was hemming and hawing and nothing happened and finally it occurred to me to say, "Look, the edge of the table here is a straight line, we're talking about straight line motion. Put your hand on the edge of the table and do with your hand what that diagram says." I watched the student, I saw the muscles twitch, and that's what gave me the cue. I saw the muscles twitch and then the grin. "It's standing still." Well, kinesthetic experience, connection with the abstract ideas, and I incorporated homework problems in that fashion in my text of 1965 and then later on in my text for elementary teachers in 1977. Back in 1965 I was laboring under the delusion that this was in effect publication, that people read textbooks. That's how naive I was. Here was the idea. You use this homework problem, you make the connection. Now we have the sonic range finder and all the wonderful things that go with it, and I love all of them but I can't help saying that you can still accomplish a lot with the hand along the edge of the table.

Anyway, at a writing conference in the mid-sixties—one of those complex projects that I was referring to—there was a session being held about presentation of kinematics. This was a writing conference for a more general audience than our graduate school bound student, and this particular session was about how to deal with kinematics in the introductory course. So I went to the board and tried to describe this episode with the student and how an effective connection might be made through kinesthetic experience. The chairman of the session cut me off abruptly. This was a waste of time. This was an Arons gimmick. “What we need to be doing is presenting kinematics in an effective way,” and I was simply cut off—I wasn’t allowed to continue. There’s an illustration of what it was like at the time. Things have changed, and boy do I welcome it.

Now toward the end of the sixties, into the seventies, things began to change slowly. I encountered Robert Karplus. We were both officers in AAPT. Incidentally, Bob and I got our Ph.D.s under the same thesis supervisor. You may or may not have heard of him, E. Bright Wilson Jr., the physical chemist at Harvard. Both my degree and his degree are in physical chemistry. We gravitated into physics. Renegades of one sort or another. Anyway, I encountered Bob, who got interested in elementary science because he had seven children in the schools and he brought in the Piagetian ideas and was running around administering tests, the Piagetian type tests, on control of variables and ratio reasoning, and showing the difficulties associated with those. But Bob was working mostly below college level. In 1971 John Renner from Oklahoma, with his graduate student Joe McKinnon (influenced by Karplus; they’d had contact with him) published a paper in *AJP* under the title “Are colleges concerned with intellectual development?” (McKinnon & Renner, 1971). They had administered the control of variables and ratio reasoning tests to a group of Oklahoma City University freshmen and found that only 25% could answer the questions correctly—25% they regarded as in transition, and 50% were entirely wrong. Now people didn’t believe this and there were a number of papers by various individuals spotted around the country, in *AJP*, reporting replication of the McKinnon and Renner results and all of them circling around about the same figures. College level students: roughly 1/3 being able to deal with those questions, 1/3 partly wrong and 1/3 completely off. Around that point I got in touch with Bob and asked whether he would join me in writing a letter *to The Physics Teacher*, *The Journal of Chemical Education*, and *The Journal of College Science Teaching*, a letter simply pointing to these statistical results and saying, “Here’s something that needs attention.” We wrote this short letter (Arons & Karplus, 1976). Sent it to all three journals. It was published by all three journals and the tsunami wave that it created was something like the result of dropping a pebble in Lake Superior—no attention whatsoever. However, gradually things began to move on a relatively small scale but in significant ways. Tony Lawson; he’s a biologist and many of you may not be acquainted with his work at all. He’s been very prolific. He’s at Tempe and has been working mostly below the college level but has done very insightful studies, heavily Piagetian influenced. Tony began to publish. Loren Resnick, out of the Pittsburgh psychology group, had a paper in *Science* saying essentially that although the kind of work on learning that is being done in psychology departments is all right in its way, we need to begin studying domain specific tasks. In other words, get at some subject matter. That was a significant paper. Again, it didn’t make a big wave.

The SESAME program at Berkeley got under way in the seventies and some of the theses began to appear, and reports in the journal. Mark St. John, Jill Larkin, Dick Ballard, came out of the SESAME program. Now that was a separate group, you see. It was a coalition of physics, chemistry, mathematics, biology—a number of departments, in a program separate from the subject matter departments, and they gave a degree for educational work in a subject area. At the University of Washington we were interested in doing a doctorate and at that time our administration was heavily influenced by an emissary from the Ford Foundation. They were propagating the introduction of a new doctor's degree, Doctor of Arts, in an effort to take some of this out of the hands of the highly professionally oriented subject matter departments and create an avenue for people to go into community college teaching and so on and so forth. Our department was not interested in allowing us to give a Ph.D. degree in physics in the education area but they accepted the idea of the Doctor of Arts, and we started that program. We gave one degree under it but then the higher education coordinating board came along and said, "No proliferation of degrees. This is proliferation." They wiped out the Doctor of Arts program. At that point our department, by default, allowed us to give a Ph.D. in physics. So you see it happened by having the bottom fall out of something else. Now, of course, under Lillian McDermott, the program speaks for itself and we don't have that kind of trouble. But that was the initiation.

So, this was the nature of that intervening period. The movement was getting under way but it was very small. Fortunately, it was taking place through reasonably respected people and reasonably influential institutions but at one point, it must have been the late sixties or early seventies, Bob and I tried to organize a session discussing student learning problems in the AAPT. Fortunately, we were assigned a very small room because about three or four people turned up. Now I see this difference and I assure you that I find it heart warming.

Now these are some of the tales and attitudes of the time. I want to spend a little time on some things that are dear to my heart and I consider unfinished business. One of these, a realization that I think is profoundly important, has not penetrated very deeply. It's something that I came across very early on, when I began to work with the elementary teachers going to the University of Washington. It's connected with those low percentages of success on the Piagetian test of Karplus and McKinnon and Renner. This is a theorem that I think stands up, although I haven't done research that would provide quantitative documentary proof. If you have not been through a particular abstract learning experience, concept formation, that might have been registered at the age of 10, 11, 7, whatever, you come to it de novo as an adult. The adult goes through the learning and understanding of that concept or idea, stumbling over the same hurdles, making the same mistakes, holding the same misconceptions and preconceptions as the 13 or 11 or 9 year old and if anything, the pace of learning is slower because of the overlay of impeding verbal garbage that has been accumulated in the meantime. Now this is a fact as far as I'm concerned. If you don't believe it, have a look at it but I submit that this is a profoundly important fact because it has to do with what is going on in the way of teacher education in our echelon in the colleges and universities. It is casually assumed that you can simply tell these adults these various things that they need to know in order to teach elementary curriculum and that as adults they will probe them and master them quickly and easily—different from the experience necessary for the child. This is simply not true, and until this is recognized and effectively utilized at college and university level, very little is going to happen. We're going to keep generating complex projects over and over again. They're unsuccessfully implemented so you've got to generate new complex projects. That's one item and I urge your attention. The question is not just establishing this fact, but once it's established, how do you convey it to our colleagues around us who are implementing the teacher education programs? I have no idea how to do that and I claim no success but that has to be done.

Another item is arithmetical reasoning, with ratios and division. Less than 5% of the undergraduates, when I encountered them at the University of Washington, could handle fifth and sixth grade word problems involving ratio reasoning and division. They didn't understand that if you took the number of grams and divided it by the number of cubic centimeters you got how many grams were in one cubic centimeter. They couldn't make that translation and therefore they couldn't do any of the subsequent reasoning. After encountering this in the undergraduate population I began working with in-service teachers and I found that less than 5% of them could handle word problems in fifth and sixth grade arithmetic. In other words, there was no distinction between the pre-service and the in-service teachers on this kind of thing, and that obtains to this day. If you don't realize that, I urge you to have a look at it and incorporate it into some of the research. What do you have to do to bring them along? Unless we achieve this with our pre-service teachers, we're going to be in the remediation business at the in-service level in perpetuity. That's the way things are going and you can't be in remediation in perpetuity. Nobody supports it. We've got to start turning out teachers who don't need remediation and that isn't being done.

Now the reason I hammer on this arithmetic and ratio reasoning business is—and this is a conjecture and I can't document it; it's anecdotally based, but I've seen it over and over again—when the learners, pre-service or in-service or whatever, make the breakthrough on arithmetical reasoning and division and begin to handle word problems, their confidence and sense of security increases in such a way that they seem to break through on all sorts of other stuff. It makes a profound difference in their stance, their attitude, and in what is going on. As I say, I can't give you quantitative documentation of that, but on extrapolating my own experience I believe this to be true and I'd urge you to have a look at it. But what goes on at college and university level is that you see these students and they don't like math. Now I never allowed these students to refer to this kind of quantitative reasoning as math. If they said math I didn't understand what they were talking about. "This is fifth and sixth grade arithmetic. You're going to be teaching." But what goes on is that we give courses at college and university level that ignore all this. We've got to track the students and get the loving evaluations and keep the enrollment and so forth and so we churn out teachers who need remediation the instant they graduate. Unless this is stopped, we're not going to make any progress regardless of all the talk about excellence and new curricula and heavens knows what else. Look at the existing decent curricula, K-12, that have been developed in the course of preceding years. They're not perfect, but if the existing decent curricula were competently implemented, we would be several orders of magnitude beyond where we are now and the university crowd wouldn't know what hit them.

Finally, one other item, coming back to my use of the term complex. You interpret it one way, I interpret it another. Linguistic aspects—I see very little attention being paid to those, but they arise all over the place. A couple of examples: you all know that the students have tremendous difficulty with the idea of the object—the ball at the top of its flight, the pendulum at the end of the swing—having non-zero acceleration. Well, let's look at the linguistic aspects behind this. Teachers and textbooks tell the students that the ball stops at the top of its flight and the pendulum stops at the end of its swing. What does the word stop mean to a student at that stage of the game? It means stand still for awhile, and if the object stands still for awhile it certainly has zero acceleration, so they're not wrong in their thinking, in terms of the words that are being used. "Oh! The object has zero velocity for an instant." What does the word instant mean to the student? If you inquire, you'll find that it means a very short duration, and if the object has zero velocity for a very short duration then it certainly has zero acceleration. The object has zero velocity at an instant for zero duration. Now the linguistic aspects are non-trivial and they're all over the place. One more example at a somewhat more sophisticated level. We dissipate work frictionally by pushing the object over the floor or boring a cannon. What happens to the work done? The energy that's dissipated? Teacher and textbook: "The work is converted into heat." Now I want you to think, how many of you say that? I won't call for a raising of hands. Work is converted into heat. Stop and think about that. To the student, the impression is conveyed that heat is transferred to that system. But frictional dissipation of work is an adiabatic process. There is no heat transfer. There is no interaction with a higher temperature body. What has transpired? The work has gone into changing the internal energy of the system in such a way as to raise its temperature. We could have produced the same change of state, the same change in temperature, by transferring heat. No heat was transferred in the actual process. But the student is given the impression that heat was transferred. What was it that Joule did? How do we know that we can treat heat as a form of energy, that over-arching idea for all of classical physics? If you double the amount of work you double the amount of heat that you would have to transfer in order to produce the same change of state. It's that linear relation that leads us to recognize that we can treat heat as a form of energy.

All right, words are full of this kind of thing. But I find I always like to deliver a message in a final end point like this. I urge that some attention in research be given, not just to the learning and understanding problems of the students, but to our problems of learning and understanding and the ways in which we impede student learning and understanding in the manner that I've been illustrating, and with that I wish you the very best in these endeavors.

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