European J of Physics Education ISSN 7202-1309 Vol3. Iss. 4 2012 Dykstra

New Themes in Physics Teaching: A personal retrospective

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(Received 20.06.2012; Accepted 15.08.2012)

Abstract
For a little over 40 years, what we label now, physics education research, has been conducted. As a result, new themes in the research in physics learning and in physics education have emerged. Some of these themes are cognitivism, qualitative research, learning as construction of knowledge, epistemological underpinnings that are not realist, student understanding-driven pedagogies, and scholarship in fields outside physics. These themes have arisen in minds of our colleagues, who focus their attention on students' understandings of physical phenomena, instead of how well the students do on conventional tests. Physics education research shows that alternative pedagogies result in a wider range of students making much greater changes in their understanding of the phenomena than the conventional pedagogies, far beyond mere statistical significance. Yet, these themes are still just themes and not major changes in physics teaching as a whole enterprise. Since we know these pedagogies are better for our students and thereby for our culture, the challenge becomes one of how to overcome the hegemonic pressures pushing back toward the *status quo*.

Keywords: physics education, student conceptions, radical constructivism, Piaget.

Introduction[1]

The modern era of physics education research (PER) began with the work of Robert Karplus, John Renner and others, such as Fred Reif, in the late 1960's and early 1970's. (Karplus, 2002; Heller & Reif, 1984; Reif, 2008) Probably the most significant of the contributions in the early days was from Robert Karplus. He introduced Piaget's ideas and works to the physics teaching community and played a role, along with Jack Renner, in introducing Piaget's work to the broader science education community. (Fuller, *et al.*, 2009)

Piaget's theory of cognitive equilibration involves a non-realist view of the nature and origins of human knowledge.[2] As such, to understand the theory and how it works one must be able to step out of the prevailing realist paradigm and at least temporarily be able to think in this non-realist stance. To use the theory in order to develop pedagogy consistent with it, one must let go of conventional or folk theories of teaching and knowledge.[3]

The field of research in physics education has been growing for all this time and is still advancing. Several Physics Departments in the U.S. now give Ph.D.'s in Physics for research in physics education, including the University of Washington at Seattle, University of Maryland, University of Maine-Orono, The Ohio State University, and Kansas State University, among others in North America. The number of papers involving PER at American Association of Physics Teachers

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[1] At the outset, it should be pointed out that this is the retrospective of someone from North America, whose professional work has only very occasionally involved collaboration with colleagues from Europe. Reading the works of European colleagues does not include experiencing the sequence of events and people who are part of the development of PER and physics education in Europe. Hence, the task remains for European colleagues to tell the PER story from their perspective.

[2] In Piaget's theory, knowledge refers to the understandings or conceptions we form in our minds in order to explain our experiences and predict future events. We have experiences, but when we think about or report them, the very words involved are conception-laden products of mental construction.

[3] See the section below titled: Teacher-Centered to Student Understanding-Centered, for a description of the folk theory of teaching.

(AAPT) has gone from a single session of 4 or 5 papers to more sessions involving PER (in one way or another) than all other topics. Yet, a very large percentage of the students' classroom experiences show little, if any, evidence that findings from PER have been employed in their classrooms. The evidence indicates change is necessary.

Change that does not threaten the *status quo* generally meets with little resistance. Change that involves thinking and operating outside the *status quo* meets very powerful resistance. Sometimes the resistance is openly conspiratorial, but usually it is the social and professional responses of members in the prevailing paradigm that result in strong pressures back toward the *status quo*. These pressures are hegemonic — pressures from the members of the majority paradigm. As yet, the hegemony of the *status quo* in physics teaching is alive and thriving. Its defense mechanisms are functioning effectively.

Themes in Physics Education & PER

In the sweep of the last 40 years or so, a number of new themes have come to light in the PER literature. It is hard to call any one of these new themes a trend in physics education, because the term, trend, suggests an on-going, substantial, increase in the prevalence of the new theme being employed in physics classrooms. Such an on-going increase in deployment of any one of these themes is very unclear to non-existent at a level significant in terms of the total number of hours students spend in classrooms where physics topics are a part of the class.

What follows is a list of themes in physics education and PER. The list is in no particular order and each item in the list is not totally independent of other's in the list. The themes are listed in pairs to bring out the differences between them and the *status quo*. The first member of each pair is an element of the *status quo*. The second member of each pair is an element that has become a competing theme from PER.

Behaviorism to Cognitivism

During the 1960's thinking in science education *among English speakers* began to include cognitivism against the background of behaviorism. The behaviorist stance is that we cannot know what people's thoughts are, *i.e.*, what others are actually thinking, therefore as scientists we should ignore all such un-shareable evidence.[4] In other words, the mind is to be treated as simply an impenetrable black box. This position is a part of the paradigm of behaviorism. The idea of teaching then is simple; find the right stimulus (from the teacher or text) to get the response desired by teacher and standards authors.

A problem with this conclusion, that the mind be treated as a black box, is human beings do exhibit patterns in their observable behavior. With such patterns we can construct possible explanations for the patterns and test them for fit to the behavior of human beings. This is the process of science applied to a specified set of experiential evidence. It is important to keep in mind the reference to experiential evidence is to the experiences of the researcher or teacher while observing and interacting with students. In this line of reasoning, the construct, human mind, has a status equivalent to the construct, atom. Both are parts of explanatory systems constructed to explain specified sets of experiences we have.

In contrast to behaviorism the cognitivist stance is: We don't have direct access to the thoughts of others, but we can observe what they say and do. We can also interact and observe their responses. From this evidence we can construct useful, working models of how students might be thinking and we

[4] To do science, the evidence must be reproducible (same result every time) and shareable (others must be able to reproduce the results).

can construct theories about how, why and under what circumstances they appear to change their understandings.

Piaget, who early in his career worked on developing an I.Q. test for children[5] before they can read or write, worked from a necessarily cognitivist position. For Piaget this cognitive orientation started early in his career and lasted until he passed away (approximately 1920 – 1980). (Chapman, 1988) Piaget published in French, which enabled English speakers to remain unaware of it until the shift from behaviorism to cognitivism opened their range of attention. On the other hand, one might argue that the work of Piaget and his colleagues, introduced by those such as Robert Karplus, helped drive a shift from behaviorism to cognitivism amongst English speakers in physics/science education, at least in the U.S.

Quantitative to Qualitative Research

Up into the 1970's in many science education research journals, research was not "real" research unless methods of statistical analysis could be applied to the data collected.[6] One can see this in journals such as *Science Education* and the *Journal of Research in Science Teaching*. Sample the articles and Tables of Contents in these journals from the 1960's through the 1980's. In the sample the shift in emphasis will be observed. With few exceptions anything that could not be expressed in numbers was considered unacceptable in such journals in the early part of this time period.

There is a famous quotation from a Physicist to the effect that one's knowledge of something is very meager if one cannot measure it.

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind…" Wm. Thompson, Lord Kelvin (1883)

In Thompson's defense he said these words in a lecture on units of measure in electricity. It is unclear from this quotation whether he believed the same to be appropriate in general. But, the sentiment has been repeated in other fields to justify limiting analysis only to things that can be reported as numbers.[7] It is still repeated proudly by certain elements in physics education. The problem with this policy is that things that can have a quantitative number assigned to them are often the least important in development of reasoning and conceptual change.

As the nascent PER community began to study the work of Jean Piaget and his colleagues, they saw excerpts from transcripts of interviews with and observations of children from a few months old to the age of 16 or so. The interviews are a reification of the assumption that the development of the cognition of children can be discerned from their responses, what they say and do. In order to reveal this cognition a different approach to interviewing had to be developed.[8]

Piaget and his colleagues were looking for evidence of the genesis and development of reasoning about the world. The interviews were often about physical phenomena. Interested physicists noticed that interview transcript excerpts in the publications also shed light on how students are thinking about the physical phenomena, which were the subjects of the interviews. This launched a major and on-going still, program using this Piaget-inspired interview method to reveal evidence of students' conceptions about physical phenomena.

[5] He was developing an IQ test for children, in Benet's lab in Paris.
[6] This has changed since, but it was in full force in the 1970's.
[7] Note the comments on certain articles by certain Editors published in the pages of *Science Education* during the 1960's and 70's.
[8] See the section below titled: "Final Remarks: Piagetian Interviews"

The interview evidence is not quantitative, but qualitative. Typically several subjects are interviewed over the same example of a phenomenon. Constructing a potential working model of student thinking is a qualitative process. In PER the interview process is often iterative. What comes out in the first round of interviews has an effect on the nature of the interviews in the second round and so forth in any subsequent rounds. Piaget and his colleagues at the Center for Genetic Epistemology used this same iterative process.

In PER, once distinct patterns of responses are observed from the interviews, then a "mass" administered interview or diagnostic can be developed, often in multiple-choice format. These diagnostics attempt to give students choices, based on what has been found in the interviews. The choices are from students, the interviewees, like themselves. A good diagnostic shows evidence that a very large percentage of those responding to them find at least one of the available choices makes sense to them—very few students fail to find an appropriate choice. Numbers of students will exhibit the same pattern of choices, consistent with a particular, possible conception of the phenomenon. The result is that with such student understanding-driven diagnostics we can see the extent to which the conceptual schemes we see in the individual interviews occur in large groups. With such well-developed tools assessing the effects of curriculum materials and pedagogies on student understanding becomes possible. (Thornton & Sokoloff, 1998)

Teacher-Centered to Student Understanding-Centered

The conventional notion of teaching is that t*eaching is the presentation of the established canon by approved methods for the benefit of the deserving*.[9] This is a folk theory because it is rarely, if ever, challenged. For most this is thought of as a description of the way things are. It is just what teaching is. In the U.S. teacher preparation programs are designed with the folk theory of teaching as the guiding principle: "give" the teacher-candidates the canon (via lecture and text), show them approved methods of presentation, and then have them practice presenting the canon to students. Once the teacher-candidate has been assessed as having the canon and judged to be capable of presenting it, a teaching license is issued. Teachers are evaluated on how well they conduct their teaching in conformance with this folk theory.

The work by physicists using Piagetian interview techniques and diagnostics derived from them reveals that very little change in student conceptions is the standard result of folk theory-inspired teaching in physics. This realization has moved some to question the folk theory of teaching. (Dykstra, 2005)

When one sets the goal in teaching as change in student understanding, instead of presenting the canon, the pedagogy shifts from teacher centered to student centered. The result is the development of very different pedagogies, shown to have much more effect on the students' conceptions and reasoning in physics in results from PER (Duit, 2009). These findings reveal that these differences in the effects of the pedagogies are well beyond mere statistical significance. (Dykstra, 2005)

Knowledge: Accumulation to Construction

In the folk theory of teaching, knowledge is a transmittable commodity, which can be accumulated resulting in an increased state of being educated. In this paradigm, teaching is often referred to as transmitting the accumulated wisdom of the ages to the students. It makes one proud to be part of this time-honored process.

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[9] "I can still remember a time, however, when the conventional wisdom was that some students have what it takes to develop a mastery of a difficult subject such as physics, while others simply did not, even after expending considerable effort." (Erlich, 2002) It is these latter students who are among the undeserving in the folk theory.

But, we know from the work in PER that change in understanding is not the result of folk theory instruction. Piaget and his colleagues explain the origin and development of reasoning and knowledge as a process of mental construction. Human beings prefer a kind of equilibrium between their conceptions of the world and their experiences with the world. When one notices an inconsistency between one's conceptions and a new experience, a dis-equilibration, there are two basic possibilities of response: (1) Ignore the offending experience and hope it does not happen again. (2) Draw close to the experience, try it again to be convinced it happens and then try to work out a better explanation than the previous one, which did not account for the novel experience. New possible explanations are tested against experience until a satisfactory one is found—a new equilibrium is thus established between one's revised conceptions and one's experiences. Cognitive development and the construction of ever more effective understanding can be seen as a series of equilibria, each new equilibrium established by constructing new or modified conceptions explaining an expanding world of experience.[10]

Realism vs. Radical Constructivism

There are two philosophies of the nature of knowledge, which underpin the themes listed above. One is realism. The other is radical constructivism (RC).

In realism our knowledge depicts an external reality that is independent of the mind. One example of this position is the following:

"…we postulate the objective existence of physical reality that can be known to our minds…with an ever growing precision by the subtle play of theory and experiment." (de la Torre & Zamorano, 2001)

What distinguishes RC from realism is for RC, knowledge, while it fits our experiences, it does not depict or match an external reality independent of mind. In RC our knowledge is constructed in the mind and, as such, does not really exist "out in the world."[11]

One might ask, from the realist point of view, what good is RC, if we cannot know what physical reality is? The response from RC is that all we have is explanation that fits the evidence of experience and this enables us to make successful predictions about a phenomenon. Knowing physical reality itself is inaccessible and unnecessary. In RC a skeptical position is taken, manifest in the question: How can we know that a particular explanation is true when the explanation cannot be directly compared with reality and all we can do to check for fit with our experiences?[12]

One might be tempted to argue that there is a kind of continuum between these to philosophies. On this possible continuum would be various forms of realism and of constructivism. But, candidates for positions in a claimed continuum either are compatible with the initial assumptions of realism or they are compatible with the initial assumptions of RC. They cannot logically be based on both sets of mutually exclusive assumptions.[13] The problem is that realism and RC are not on one continuum.

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[10] To have an effective explanation is to have an explanation that fits the totality of the available experiential evidence and which enables successful predictions.

[11] In contrast to the realism expressed by de la Torre and Zamarano, consider this RC-like position of Max Planck: *"Now there are two theorems that form together the cardinal hinge on which the whole structure of physical science turns. These theorems are: (1) THERE IS A REAL OUTER WORLD WHICH EXISTS INDEPENDENTLY OF OUR ACT OF KNOWING and (2) THE REAL OUTER WORLD ARE NOT DIRECTLY KNOWABLE." (EMPHASIS in the original)* (Planck, 1932)

[12] This question is basically that of the Skeptics from early Greek times.

[13] In realism we can know or approach knowing the true nature of physical reality. In RC since we have no other way of knowing physical reality than our experiences, the best we can do is construct explanations that fit the evidence. This fit to evidence does not convey the status of truth to the explanations. In realism and RC we have two mutually exclusive paradigms.

Realism is on a continuum, the other end of which is solipsism or nihilism.[14] RC does not exist on this continuum.

Faddism vs. Scholarship

One of the challenges to change in the themes discussed above is a tendency to treat explanatory systems describing learning as if they are just new ways to describe what we have always thought about what happens in the classroom. We see this in the tendency to use new terms to convince other people one is "with" the new trend. The instant a new set of terms arises, people shift to the new jargon. As all of this is happening, the evidence is the new terms have been appropriated without changing underlying thinking or observable actions as a consequence.

In this way the *status quo* is not threatened and no explicit hegemonic pressure is needed because there is no threat. But, the members of the hegemony, the dominant paradigm, by their lack of scholarly approach to the "latest thing" in science education, are enforcing the hegemony individually. This is, in part, a natural tendency to first see something new in terms of how one already "knows" the world. This is reinforced by the status of the folk theory of teaching as, in effect, beyond question. This latter is the contribution of the hegemony. The point of scholarship is to be able to be independent of these natural tendencies and put in the place of these tendencies rational responses to evidence.

We see this faddism highlighted in our educational efforts. Piaget was "in" for a while, but we have "moved on." We began hearing about Vygotsky, how he came along after Piaget and picked up where Piaget left off. Piaget is dropped and Vygotsky becomes in vogue.[15]

When Piaget's work was being introduced, many saw it as a theory of stages in the development of reasoning. Since many students had not yet reached the ultimate stage of reasoning, including such things as proportional reasoning, this delayed development of reasoning was considered the reason why students could not "get" what was being presented to them in physics classes. These students under the folk theory of teaching were not, or not as yet, among the deserving—those who have the requisite mental abilities to "get" the canon being presented to them. In this way the folk theory was not questioned, but reinforced.

A little scholarship on Piaget's work reveals that the stage description in the development of reasoning serves as a way of organizing the very large quantity of evidence collected by Piaget and his colleagues over 60 years. This description of the evidence is based in a developmental point of view. If summarized from a different point of view, the organization of the data would have been different. Piaget's theory is not one of stages in the development of reasoning. Piaget's theory concerns how and why this development happens. It is a theory of cognitive equilibration. As described above this theory entails a non-realist view of the nature of knowledge. As such, it is indeed a threat to the *status quo* triggering a push back from the hegemony, if it were to gain ground in the physics education community.

With Piaget as a fad interpreted as consistent with the folk theory of teaching, the community is free to move on to the next fad. One of the subsequent fads was Vygotsky and his work. Because they were exposed to Vygotsky after their exposure to Piaget, people began to say and write that Vygotsky came along after Piaget and continued his work. They are both called constructivists without acknowledging the realist/non-realist distinction that separates them. (Pass, 2004)

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[14] It is the case that from the realists' narrow point of view the only thing other than realism that exists is solipsism. When realists first encounter RC, they often jump to the conclusion that RC is just solipsism because it is certainly not realism. (Dykstra, 2007)

[15] It is important to keep in mind, while the majority seems to have treated Piaget and Vygotsky as fads; there are others who are serious scholars of Piaget and Vygotsky.

Just a little scholarship reveals that they were both born in the same year, 1896. Vygotsky passed away in 1934. Piaget worked on until his death another 46 years after Vygotsky died. How could Vygotsky have "carried on" with Piaget's work after Piaget?

In Vygotsky's major book, there is a chapter essentially on how Piaget was wrong. Looking closely at this chapter, it becomes clear that Vygotsky was a realist. How could Vygotsky have continued with Piaget's work when their theoretical underpinnings were mutually exclusive positions on the nature of knowledge?

All of this is not to claim that no one has been scholarly in their efforts to understand the works of Piaget and Vygotsky. But, it is evident that few have been scholarly.

It does not leave one comfortable to realize how the evidence of scholarship in our physics differs from the evidence of our scholarship in physics education. The ray of hope here is that the second member of each pair of themes in the list is indeed a theme in physics education and PER. As such, these themes are still available to be studied, tested and adopted in physics education, which could eventually elevate them to the level of trends.

Conclusions

Forty years of PER have resulted in qualitatively new themes in physics education. Work in PER has demonstrated that employing these new schemes to develop new pedagogies results in substantial change in student understanding of the physical phenomena studied in physics classes. PER also shows that the pedagogy based in the previously existing themes results in remarkably little change in student understanding of the same phenomena. Yet, no change is observed in the experiences of nearly all students in the vast majority of physics classes because folk theory pedagogy still prevails.

One possible way to explain the apparent failure of the physics teaching enterprise to respond to the evidence is to belittle our colleagues by calling them lazy, lacking in sufficient empathy for the students, unprofessional, and otherwise confronting them about the error of their ways.[16] There are several things wrong with this strategy to get change to happen. (1) This approach tends to result in the so labeled people to resist anything suggested as alternative. (2) It fails to acknowledge the intelligence of our colleagues, while we promote the intelligence of our students. (3) It fails to attend to the dynamics of change in social structures such as the one we wish would change.

One way to think about the challenge in a more systemic way is to think in terms of hegemony, the influence of a dominant view or paradigm. An established paradigm includes responses, hegemonic pressures, which tend to push any departures from the norm back toward the norm. These range from responses by individuals in the paradigm to responses by decision makers in the paradigm. Some of these responses are the enforcement of paradigm-based standards. The end result is a smoothly running system, a stable hegemony, the results of which are explainable within the paradigm. Change in such a system requires either substantial modification of the paradigm or abandonment of the paradigm for a new one.

An argument can be made that the folk theory of teaching is part of this behaviorist paradigm. In this folk theory in terms of behaviorism, teaching becomes finding just the right way of telling or showing students aspects of the established canon of knowledge, so that the students respond in the desired way on exams. The fact that not all students are successful is explained by the belief that not all students are capable of such hard subjects as physics or the sciences. In this paradigm, as with all well-developed paradigms, there are no loose ends. This is because a paradigm defines what is worthy of inclusion, as well as, what is not worthy. For example in behaviorism, the inner workings of the mind are excluded as pointed out above.

[16] Doesn't this sound like some of our colleagues advocating confronting students over their misconceptions?

To even begin to be motivated to look for an alternative requires a degree of dis-equilibration in the members of a paradigm, *i.e.*, the recognition that the existing paradigm does not account for certain experiences in some way deemed important by them. This is accomplished in a similar fashion to our pedagogies, which engage the students in examining their own conceptions and how well they fit the evidence. We know from the work in PER that just telling them will fail spectacularly to evoke any change, just as telling students Newton's laws of motion fails to evoke change in student conceptions.

What should we do? Certainly, we should keep on with the research in physics learning and the development of effective pedagogy. Publishing our work will benefit the PER community, but to the member of the dominant paradigm, this is like telling them they are wrong and threatening their egos. We should not expect our publications in general to have any more effect on our colleagues than do the text books result in a change in understanding of the nature of force in our students, for example. Instead, as with students, we need to engage colleagues in examining their conceptions about physics learning and teaching and comparing these with the evidence.

It takes serious, on-going interaction between students to construct an understanding of the conceptual basis for Newton's laws. It is, then, not surprising that serious interaction between and with our colleagues over the discrepancies they find between their conceptions about physics, learning and teaching, and the evidence is necessary. Hegemony works against such discussion. In a smoothly running system, everyone has learned their place and function and they know how the paradigm explains the results deemed necessary to explain. No such discussions are necessary within the system. Many members of the paradigm avoid such discussion as an idle waste of time and attention. These are the challenges.

Final Remarks: Piagetian Interviews

Most interviews before the advent of the influence of Piaget's work were very strictly structured. In the behaviorist paradigm, specific set of questions was to be asked in exactly the same manner with exactly the same words with the responses recorded. There were no digressions or explorations driven by something a particular interview subject may have said or done. The general effect is to limit the data or evidence to the pre-determined expectations of the researcher. In other words, the data collected reflects only the world-view of the researcher, which as we now know from PER can differ substantially from that of the students. This pre-Piagetian style interview corresponds to the typical physics exam, which endeavors to determine whether the student "got" the information presented and the skills practiced. With both conventional interviews and exams, one can work out a scheme for scoring before the interviews or exams are conducted — not so true for the results of Piaget-style interviews.

The conventional interview approach fundamentally differs from the effort to construct a model of how the students think about the world of physical phenomena. Since at the start one does not know with any certainty what the students' conceptions are, a much more flexible strategy is required. Typically there is a specific phenomenon in physics to be explored that sets the stage for the interview.

In a Piaget-style interview conversation generally starts with a question from the interviewer often about an example of the phenomenon present with the interviewer and the student. This first question is the same for all of the interviews. There may be a small number of other questions the interviewer is going to ask in each interview. But, the interviewer needs to be able to ask additional questions driven by the attempt to understand the students' understandings. Hence, no two interviews are exactly alike. A scheme for scoring the students' responses cannot really be determined other than in retrospect.[17]

[17] Even the idea of "scoring," is misleading because of its use in folk-theory teaching. In these Piagetian-style interviews, after they have been analyzed to construct possible descriptions of students' conceptions, one can classify them by the conceptions indicated in the students' responses. Scoring in the typical sense is neither useful nor possible.

Instead of scoring the interview, all words and actions need to be recorded and considered. One can see this in the publications by Piaget and his colleagues. Multiple sample excerpts from transcripts of the interviews accompany every description of students' thinking. What is being reported by Piaget and his co-workers does not simply render into numbers and tables.

In the most careful work, an initial round of interviews is studied in order to refine or refocus the second round of interviews. One reason for this is to check if a particular conception description, derived from the first round of interviews, is supported in the subsequent round of interviews.

The interviewer's mental models of the students' conceptions are rational constructions *by the interviewer* developed to explain the *interviewer's* experiences with the interviewee. This renders debates over whether or not a student "has," or is using, a particular conception technically moot in RC. The only debate possible is whether or not a particular description of a conception fits experience with the interviewee.

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