Realism: The Bane of Science Education, and What Can Be Done About It

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For more than a century, the result of science instruction has been little or no change in student understanding of the phenomena studied. What most science students learn, instead, is that they are on the lower rung of a caste system in which they are dependent on a higher caste for declarations of the truth. An alternative approach to teaching science, which has been demonstrated to result in significant change in understanding, is ignored and resisted. This article examines the reasons for this sorry state of affairs and explains the alternative approach, mainly in the words of Dewey I. Dykstra, Jr., culled from articles that appeared in the highly commendable open-access e-journal *Constructivist Foundations* ↗.

1 The unreasonable ineffectiveness of education in the natural sciences (and elsewhere)

In *The Unschooled Mind: How children think and how school should teach*, psychologist Howard Gardner (1991) observed that during the first years of their lives, youngsters master a breathtaking array of competences with little formal tutelage. All normal children readily acquire the language spoken in their vicinity. If they happen to grow up in a polyglot environment, they can master several languages and know under which circumstances to invoke each tongue. They become proficient at singing songs, riding bikes, executing dances, and catching balls hurled under various conditions. They develop powerful theories of how the world works and how their own minds work, are able to deceive someone else in a game even as they can recognize when someone is trying to play a trick on them. They evolve a clear sense of truth and falsity, good and evil, beautiful and ugly. Yet these same children often experience the greatest difficulties upon their entry in school. Reading and writing may pose severe challenges; learning mathematical operations can prove vexing, and the higher reaches of mathematics may remain forbidding. Gardner contended that even when school appears to be successful, it typically fails to achieve its most important missions.

Evidence for this sorry state of affairs comes from a by now overwhelming body of educational research. These investigations document that even students who have been well trained and who exhibit all the overt signs of success typically do not display an adequate understanding of the materials and concepts with which they have been working. For example, researchers at Johns Hopkins, M.I.T., and other well-regarded universities inside and outside the Unites States have documented that

> students who receive honor grades in college-level physics courses are frequently unable to solve basic problems and questions encountered in a form slightly different from that on which they have been formally instructed and tested. . . When questioned about the phases of the moon, the reasons for the seasons, the trajectories of objects hurtling through space, or the motions of their own bodies, students fail to evince the understandings that science teaching is supposed to produce. Indeed, in dozens of studies of this sort, young adults trained in science continue to exhibit the very same misconceptions and misunderstandings that one encounters in primary school children. . . The evidence in the venerable subject of physics is perhaps the "smoking gun" but. . . essentially the same situation has been encountered in every scholastic domain in which inquiries have been conducted. . .
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> [W]hat an extensive research literature now documents, is that even an ordinary degree of understanding is routinely missing in many, perhaps most students. It is reasonable to expect a college student to be able to apply in a new context a law of physics, or a proof in geometry, or the concept in history of which she has just exhibited "acceptable mastery" in her class. If, when the circumstances of testing are slightly altered, the sought-after competence can no longer be documented, then understanding — in any reasonable sense of the term — has simply not been achieved. (Gardner, 1991, pp. 3–6)

Dewey I. Dykstra, Jr., puts it more bluntly. Pointing to a regularly updated bibliography (Duit, 2007) that at present (February 2008) includes about 7,700 entries documenting change in students' conceptions, he observes that these entries

> reveal that little or no change happens when students experience even the best of standard science instruction, not just physics. . . Entries in this bibliography now extend back to 1904. What can be called person-on-the- street (*pots*) conceptions of natural phenomena have been documented in student behavior and interviews over a full century. Instruction has changed little since well before that time — it still follows the standard *inform, verify, practice* model. It is difficult not to conclude that *in all science instruction for more than a century, the result has been little or no change in student understanding of the phenomena studied*. . . (Dykstra, 2005, original emphases)

2 Students' previous ideas

Why are students not mastering what they ought to be learning? Gardner believed that "until recently" (as of 1991) those involved in education "have not appreciated the strength of the initial conceptions, stereotypes, and 'scripts' that students bring to their school learning nor the difficulty of refashioning or eradicating them" (*ibid.*, p. 5).

The identification of students' previous ideas — ideas not transformed by teaching — is now a major research effort. In this context a project undertaken by a group of educators at the Universidad Nacional Autónoma de México deserves special mention: it involved locating, identifying, retrieving, analyzing, organizing, and categorizing students' previous ideas present in the research literature, as well as identifying successful pedagogical strategies that look for cognitive transformation. Their website http://ideasprevias.cinstrum.unam.mx:2048/ provides an extensive searchable database.

But the near general failure in education to take account of students' previous ideas, to work with them and to transform them, is only a symptom. We need to diagnose the disease.

3 Elitism and the failure of realist education

The vast majority of those who experience instruction in science leave the experience believing they are not good at science, physics in particular. "In fact," Dykstra (2005) writes, "our system is so effective at convincing people early of this characterization that few ever experience instruction on topics in physics by someone who specializes in teaching such topics."

> Apparently most students find the experience of physics instruction distasteful and discouraging. All of the students learn from these experiences that there are a very select few who can make sense of physics, but the vast majority cannot. (*ibid*.)

The outcome of standard instruction in physics is not only a spectacular failure but also has an appalling effect on society in general:

> We fail to teach what we intend. Instead, we manage to teach most people they are on the lower rung of a caste system in which they are dependent on a higher caste for declarations of the truth. (*ibid*.)

Is this why "[s]ince the late 1970's a number of very vocal members of the physics teaching community have openly dismissed the research results and alternative teaching practices showing vastly improved learning results" (*ibid*.)? Alternative approaches to teaching physics, which have been demonstrated to result in significant change in understanding, are ignored and resisted. Physics is still mostly taught as it was for centuries before 1980. This sorry state of affairs has led Dykstra to describe the teaching of physics as follows:

- Physics teaching is the presentation of the established canon by approved methods for the benefit of the deserving. (*ibid.*)

Embedded in this program is a realist notion of the nature of the knowledge that constitutes the canon:

> . . .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)

The notion that this knowledge can be presented, and hence transmitted, implies that it can exist in the symbols (words, sounds, gestures) that are used in the presentation. The notion that it can be experimentally verified further suggests that it also exists in nature, independent of teachers and students. To explain why not all can receive the transmitted knowledge effectively, the construct "deserving" is introduced:

> If one is deserving, then one can effectively receive the transmitted knowledge. To be deserving one must first have the mental capacity and then one must work diligently enough to be successful at "getting" what has been transmitted or can be seen in nature. In this program the teacher's responsibility is to present the established knowledge by approved methods. This is frequently put as to expose the students to the knowledge. At this point the teacher's job is essentially completed. Whether or not a student "gets" the knowledge is out of the teacher's hands. The student is either deserving or not. Maybe the teacher can influence students to be diligent or work hard, but the mental capacity part was set before the teacher comes in contact with the student.
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> It is important to notice that this program also implies a concept of the nature of people. A few people are deserving, but most are not. This is an elitist notion of people. Some people can "get" it but most cannot. (Dykstra, 2005)

After all, we can't all be physicists — or so those say who assume that everyone in the class has already decided to be a physicist and wants to be trained, not educated, in the subject. According to Dykstra, this elitist notion is a paradigm in the sense of T. S. Kuhn (1962). By defining which observations have sufficient status to be addressed and which do not, it explains all relevant observations. There is no need to ask why so few "get" the transmitted knowledge. To question the approved methods or not be driven to present the canon is heresy within the paradigm.

> Situations describable as realist paradigms are very possibly unique. The underlying beliefs and characterizations of the world in such paradigms are considered statements of "objective truth." Hence, the whole system of such paradigms is not considered a construct by the true believers. Instead, it is the truth. Such paradigms are not ideologies according to their practitioners, because the elements that constitute the system are statements of truth. As truth, once established, it is not to be questioned. . . Some more conscientious of the practitioners of the paradigm may tweak the methods and take very small liberties with what portions of the canon are presented to see if a few more of the deserving can be uncovered. This experimentation is limited. One who goes too far runs the risk of being accused of heresy. Such pressure is always carried out in the name of objectivity, since the ideology of the paradigm is that there is no ideology to the paradigm.
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> To prepare a physics teacher in this paradigm, we must first make sure that person is in possession of the canon. Without this, what would be presented is false, corrupt or incomplete. In the U. S. we expect the potential teacher to take as many as possible of the physics courses a "real" physics major takes. Then, we spend a semester teaching this person approved methods of presentation. This is called a "methods" course. We give them a little practice and a chance to show they can execute the methods that have been taught. This is called "student teaching" in the U.S. When teacher candidates can repeat back the canon including the proscribed skills and execute the methods of presentation, then we certify them to be teachers of physics. We have an approved practitioner of the paradigm.
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> From within the paradigm just described, using T. S. Kuhn's terms, the normal science is that this is the way things are. We cannot, but continue to refine our present understanding as we approach ever more closely the truth. We are closer now than we were a decade past. Things are just this way.

> We can judge this paradigm by its effect on society. Its system fails students. Students leave instruction with the same understanding of the phenomena as they began the instruction. Most of the students learn that they are not among the deserving. It fails society in that it promotes elitism, creating an artificial caste system, and renders most members of society intellectually stunted or handicapped. (*ibid.*)

4 A successful alternative

That the attempt to transmit knowledge is such a spectacular failure in science education suggests a substantial failure of the realist program. Fortunately a remarkably successful alternative exists. (Unfortunately, it is still largely ignored.) Dykstra explains:

> The Swiss Genetic Epistemologist, Jean Piaget, and his colleagues studied the thinking of children and students for more than 60 years. This work focused not on what happens in school, but on what appears to be happening in the minds of young human beings. Piaget and his co-workers developed an explanatory model for the developmental processes they observed in many students (Piaget 1985). Human beings establish and maintain equilibrium between their conceptions of their world and their experiences in their world. When they perceive disequilibration, they move to re-establish equilibrium. This can happen in either of two ways. The offending experience can be ignored or avoided, swept under the carpet, so to speak. On the other hand, conceptions of the world can be changed such that the offending experience no longer offends.
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> In this model, human beings are constantly experiencing their world. There is a constant, not always conscious, checking of these experiences against expectations based on existing explanatory schemes. As long as experiences are consistent with existing explanatory conceptions, these experiences reinforce those conceptions. It should be noted that a significant part of this process is the selective ignoring of certain differences that in the applicable conception are deemed unimportant. This processing of experience that matches or fits existing explanatory conceptions is called by Piaget "assimilation." Under these conditions, existing explanations account for experience, hence there is neither need nor motivation to revise or devise new explanatory conceptions. There is equilibrium between experience and existing explanation.
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> When experience is encountered that is perceived not to fit existing explanation and this mismatch cannot be ignored, a state of disequilibration between explanation and experience is experienced. Once avoidance is not an option, then a process of self-regulation is initiated and existing explanation is modified and tested until the new or modified explanation fits these new experiences. An accommodation is developed. The disequilibration can be minor or monumental. Either way the new explanation fits experience better than the previously existing explanatory conceptions.
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> If one wishes to engage someone in developing new understanding, disequilibration is key. This is central for any teacher who wishes students to leave the instructional setting with new understanding. The teacher needs to understand the students' thinking about a phenomenon. With this understanding in mind, the teacher needs to search for examples of experience with the phenomenon that do not fit the students' thinking. Having picked an example, to maximize the chances that students disequilibrate, the teacher will engage the students in making and explaining predictions about the example. This engages commitment to the explanation by the students and makes explicit features of

> their explanatory conceptions. The prediction sets up a test of their explanations. If the teacher has developed a sufficient understanding of the students' understandings, then when they experience the example experience, they will not be able to assimilate it. Disequilibration is the result. (Dykstra, 2007)

As documented by Dykstra (2005), non-engineering majors exposed to this alternative teaching practice consistently and routinely change their understanding by an amount several times larger than science and engineering majors in standard physics instruction. The change in understanding achieved by standard physics instruction, on the other hand, is so minute as to afford no justification for this instruction.

> On established diagnostics of students' conceptions, course averages for non-science majors routinely change by four or five times the amount the class averages change for science and engineering majors that experience conventional instruction on the same topics. The large change in understanding is not just achieved by a few special students, but essentially by all who are willing to participate in the process. The instruction described is pursued with the goal of engaging students in examining and testing their own sense of the phenomena. This is in contrast to typical instruction in which the activity has the exclusive goal of transmitting the knowledge to the students by telling and showing them. The structure of the canonical knowledge does not drive this instruction. Instead, the students' understanding and the experiences it can be applied to drive the instruction. It is not a focus on the phenomena, nor is it an attempt to guess what scientists figured out in the past. It is a focus by the students on their own understanding and testing it carefully against experience with the phenomena. (Dykstra, 2007)

> Two reasons can be imagined to explain that standard instruction is so entrenched and so widespread, but with such little actually learned. The first comes out of the broader explanatory scheme used here. The standard elitist-realist paradigm, as is a characteristic of paradigms, has developed an explanation for everything it deems relevant. . . Very few really are "deserving," so we spread a wide net to catch the few "good" people. Add to this an assessment scheme which consists of (1) checking to see if the catechism can be recited (assessment of the students) and (2) looking to see if everyone is complacent and satisfied (assessment of the teachers) and one hardly needs any more explanation. The second, not completely independent of the first, is that the system we have works out really well for those considered deserving. To perpetuate this caste system, a system is needed to convince people, even the undeserving, that this is just the way things are. In that way, the deserving do not have to defend their special status, all of society will do this for them. Hence, the preservation of inflated egos of the "deserving" can be seen to be a factor in preserving this *status quo* in physics instruction. (Dykstra, 2005)

> Having the students read a standard text or the teacher present the canon, not only is a waste of time; it stifles the process of developing new understanding. In standard instruction there is a text to be read and relied upon and most class time is taken up by instructor lectures, yet we see no useful change in understanding. . . Instead, most of the class time needs to be occupied with students explaining to each other their conceptions, discussing how well the various conceptions fit the experiences with the phenomena, planning with each other what adjustments might be called for when the fit to experience is found lacking, and discussing the results of tests of these accommodations against further experience with the phenomena.

> In order to see the development of physical theories in students' minds, the teacher must

> have access to copious amounts of student explanations and predictions concerning the phenomena being studied. The teacher needs to be familiar with ways of thinking about the phenomena the students are likely to have. A teacher candidate can begin developing this familiarity by studying the efforts of others who have examined students' conceptions. The bibliography (Duit 2004) is a major source in such study. Ultimately, it is necessary to listen to and watch many students as they demonstrate their understanding of the phenomena and as they evolve their understanding. This has to happen in the classroom. (Dykstra, 2005)

This alternative method of teaching can be described as follows:

- Physics teaching is the process of engaging students in developing new understanding of physics phenomena. (*ibid.*)

As the traditional elitist paradigm is committed to — and sustained by — a realist epistemology, the alternative method follows naturally from the epistemology of "radical constructivism" (RC).[1]

> In a RC paradigm, teaching cannot be about the teacher confronting the misconceptions of students and correcting them. This is the typical, very logical response of those in the elitist-realist paradigm who deign to look at the student conceptions research in the bibliography. In RC a student's conception is not a misconception. It fits the student's experience sufficiently that the student perceives equilibrium between the conception and experience. It is the student's perception of equilibrium or disequilibrium that plays the central role. The teacher cannot give the students new conceptions because the teacher cannot transmit meaning. Only the student can change his or her own conception. This only happens when the student perceives some disequilibration, lack of fit, between personal conceptions and personal experience. All a teacher can do is to set up conditions in which students are more likely to make changes.
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> In order to influence whether or not the students make any changes to their conceptions, the teacher needs to engage the students in a series of processes:
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> 1. *Elicitation*: First, the students need to be engaged in examining their own beliefs about the phenomenon at hand. Each student needs to make these explicit to her or himself by writing and then talking about them. This process is often called the elicitation of initial conceptions. Normally it is not necessary in everyday life to make such things explicit to oneself, nor is it called for in normal schooling; hence it is not a practice most are comfortable with or skilled at. In fact, in typical schooling students learn at a very early age that it is not wise to express one's own ideas, but to focus on guessing what the teacher wants someone to say.
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> To accomplish elicitation in the face of these challenges, students can be engaged in making a prediction. They are greeted with an actual example of the phenomenon and asked what they think would happen if a certain change were made. In addition to the prediction, an explanation that makes sense to them is asked for. Students are asked, first, to write this down without discussion. Then, they are asked to share their ideas with a small group of other students. In this sharing discussion, they are asked to interact and try to understand any new ideas or new nuances of ideas they encounter and

1 See the article "Radical Constructivism — Childhood's End" in this issue.

make notes about these. The point here is not whether the prediction is accurate, but that the students make explicit to themselves and each other the nature of their conceptions.

2. *Comparison*: Until this point they are generally restrained from actually trying to see what will happen. The central object of manipulation here is neither the apparatus nor the phenomenon itself. Instead, it is the students' understanding, their explanatory conceptions, of the phenomenon. To try things first generally drives these conceptions deeper making them more difficult to elicit and explicitly examine. This latter is the function and purpose of putting the elicitation phase first. Once the elicitation is completed and all understand the explanations deemed reasonable, it is time to check to see if experience fits any of these explanations. The students are asked to carefully observe and faithfully record what is observed with respect to the particular prediction at hand. They need to make note of what fits the predictions and what does not fit the predictions. In the case of the latter they are asked to make specific notes about the nature of mismatch between the experience and the predictions.

It should be noted that since the teacher is trying to establish conditions in which conceptual change would occur, the teacher should select specific examples in which what the students will predict does not match the experience they will have. This requires the teacher to have constructed a sufficiently reliable mental model of the students' mental models in order to make such selections. It also requires that the teacher have a broad knowledge of the details of experiences possible with the phenomena to be studied. Note that the canon of physics has not been mentioned here. It is very difficult for teachers to have these skills unless teachers have explicitly participated in the same sorts of processes to accomplish change in understanding themselves.

3. *Resolution*: When the anticipated disequilibrated state has been achieved by the students, given an intellectually safe environment, many begin to critically analyze their initial explanatory knowledge and the nature of the misfit between it and their new experience. The students are encouraged to construct possible modifications to those initial conceptions or whole alternatives. To achieve an accommodation, it is necessary to test these modifications or alternatives. Such tests are carried out by first working out predicted outcomes based on the proposed changes and then checking to see what happens. Iterations are continued until most students report satisfactory equilibration.

4. *Application*: The testing of possible accommodations constitutes a nesting of additional phases (1) & (2) repeated within the third phase. Alternatively it can be seen as a kind of 4th phase, one of application in which not only the testing of potential modifications to explanation is conducted, but the phenomenon is further explored, using apparently successful explanatory schemes. In effect then the phenomenon is seen through the new perspective made possible by the new explanation. In the process how well and broadly this scheme applies to the phenomenon is determined. Often, new aspects of the phenomenon are discovered and deeper understanding of the explanatory scheme is realized. (Dykstra, 2005)

5 Closing words

The failures of instruction in the elitist-realist paradigm warrant the conclusion that this paradigm

> fails on the grounds of outcomes and logical integrity. It should be either abandoned or substantially modified, if such is possible. Until and unless a satisfactory modification is demonstrated, it should not be allowed to drive what it calls education. What it calls "education" is not education. At best, it is training and indoctrination in a rationally and ethically unsupportable paradigm. At worst, it is ideological indoctrination and is a destructive institution in our society. It has no place in the education of our society. (Dykstra, 2005)

The failure of the realist paradigm in education amounts to the failure of realist epistemologies. The success of the RC paradigm in education, on the other hand, demonstrates the strength of RC epistemology. This epistemology is free of ontological commitments — as free as epistemology can possibly be. It is a fallback epistemology that does not seek to replace the realist ontology enshrined in traditional science education by any alternative ontology. On the other hand, RC opens the door to alternative ontologies that are not only *more* consistent with data that science has at its disposal but also consistent with data that science does *not* have at its disposal, such as the abundance of mystical, spiritual, and supraphysical experiences that have been recorded across continents and through the ages.

The oxymoron "more consistent" is used advisedly, in the sense of "not only consistent with experiences sanctioned by the dominant paradigm but also consistent with experiences the dominant paradigm sweeps under the rug" — such as an abundance of well-documented "paranormal" phenomena (Kelly, *et al.*, 2006).

One of the corollaries of RC is that knowledge can be neither transmitted not shared.

> Language usually creates the illusion of transmitting thoughts, ideas, knowledge, and feelings from one person to another. One person speaks or writes and the other listens or reads, and in this way gains insight into how the other person thinks and feels. This, however, is an illusion. In order to see this clearly, you need to look more closely at what takes place in a verbal exchange. If I say something, I produce noises, if I write, I produce visible signs. Insomuch as they are familiar with my language, those people who hear these sounds or see these signs will recognize them as words. In the course of their lives, they have ascribed meanings to these words, i.e., notions of objects, situations, processes, experiences and feelings. These are their own associations which they have made for themselves. As everyone creates meanings for words from his own subjective experience, they vary from person to person. By this I mean that my words produce meanings and notions in other people which are not mine but theirs. . . As soon as you begin to talk about less mundane matters — philosophy for example — individual differences in the terms come to light very quickly. Although we all experience this quite frequently, the illusion that language is a means of transportation persists. If you say something and the other person does not understand it, you say it louder. (von Glasersfeld, 2006)

> Knowledge cannot be simply transmitted: i.e., imprinted on the learner, to be retrieved in identical form for inspection later. The question is then: "What is the meaning of "shareable knowledge," if we cannot check whether it is really shared? The answer. . . is that knowledge may be considered to be shared between two persons only insofar as *they can agree that they share it*. In other words: they share it until something happens that lets them discover that they do not! . . . Loosely speaking, then, we share, to the extent

> that we think we do! (Quale, 2007)

These fairly recent insights were anticipated by Sri Aurobindo in an essay first published in 1910:

> The first principle of true teaching is that nothing can be taught. The teacher is not an instructor or taskmaster, he is a helper and guide. His business is to suggest and not to impose. He does not actually train the pupil's mind, he only shows him how to perfect his instruments of knowledge and helps and encourages him in the process. He does not impart knowledge to him, he shows him how to acquire knowledge for himself. He does not call forth the knowledge that is within; he only shows him where it lies and how it can be habituated to rise to the surface. The distinction that reserves this principle for the teaching of adolescent and adult minds and denies its application to the child, is a conservative and unintelligent doctrine. Child or man, boy or girl, there is only one sound principle of good teaching. Difference of age only serves to diminish or increase the amount of help and guidance necessary; it does not change its nature. (Sri Aurobindo, 2003, p. 384)

Sri Aurobindo transgresses into ontology when he refers to "the knowledge that is within" and states that "it can be habituated to rise to the surface." RC lacks the insight that "[n]othing can be taught to the mind which is not already concealed as potential knowledge in the unfolding soul of the creature" (Sri Aurobindo, 1999, p 54). Here we come face to face with the fact that epistemology — in particular the question of how knowledge is acquired — is ultimately inseparable from ontology. Several observations point to a fundamental identity of the two, suggesting that, as Sri Aurobindo (2005, p. 129) puts it, the "source of Reason is identical with the Knowledge that acts as Law in the world." But this takes us beyond the scope of the present article.

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