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Against Realist Instruction: Superficial Success Masking Catastrophic Failure and an Alternative

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Purpose: Often radical constructivists are confronted with arguments why radical constructivism is wrong. The present work presents a radical constructivist alternative to such arguments: a comparison of the results of two instructional practices, the standard, realist-based instruction and a radical constructivist-based instruction, both in physics courses.

Design: Evidence from many studies of student conceptions in standard instruction (Duit 2004) is taken into account. In addition, diagnostic data, pre and post instruction, were collected from over 1,000 students in multiple institutions across the U. S. over a period of about 15 years via an established diagnostic of conceptual understanding of motion and force. **Findings:** Evidence from many studies of student conceptions in standard instruction (Duit, 2004) is that little or no change in student conceptions happens in standard instruction. About half the students in the particular study reported, all science and engineering majors, experienced standard, realist-based instruction and show an average effect size of 0.6 standard deviations and an average normalized gain of 15%. The other half of the students, none of whom were science and engineering majors, experienced radical constructivist-based instruction and show an average effect size over 2.5 standard deviations and an average normalized gain over 60%. Diagnostic pre scores were nearly the same for both groups. **Practical implications:** The outcome, that students, neither science nor engineering majors, made changes in understanding foundational topics in physics far greater than science and engineering students, poses (1) an ethical challenge to the continued adherence to standard, realist-based instructional practices and (2) an intellectual challenge to the usefulness and appropriateness of the elitist-realist paradigm on which such standard instruction is based. **Conclusions:** This radical constructivist argument uses the effect of paradigms to judge their pragmatic value, not their truth-value. Based on pragmatic value, radical constructivism results in superior outcomes when applied to physics instruction. The approach to instruction can be applied generally in education.

Key words: elitism, physics, paradigm, realism.

Prologue

In Radical Constructivism (RC) (Glaserfeld 1991) we judge our understanding by what can be accomplished using that understanding. Realists do not understand the notion that RC is not about “truth,” but about fit to experience. In this article, we look at evidence in educational settings. While the evidence will be mostly from physics education, what is being described is not unique to the results of physics instruction. Education as we know it today is based in realism. How do the results of this education as we know it compare with results of education based in RC?

Introduction

In the Fall of 1969 a young man started teaching high school physics. He believed that the students should leave an instructional experience understanding the phenomena studied differently than they began the instructional experience. As it turns out, this was naïve, but for him it was the point of teaching and education. He quickly realized it was not happening in his own classroom and, as we shall see, later he and others found it does not happen in most classrooms. As a new teacher, he had mentors who tried to help. Because at the time he could not articulate what the problem was

and because the development of understanding is not central to education as we know it, his mentors, though sincere, were unable to assist him in some way that would settle his dissatisfaction.

Understanding

When students can repeat something verbatim, it is obvious that they have learned it. Whether they have understood it, is a question these tests avoid. (Ernst von Glasersfeld 2001)

What might be meant by understanding? Von Glasersfeld suggests that understanding is avoided in typical test results. Gardner makes a kind of operational definition.

“...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.

“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.” (Howard Gardner 1991), pp. 3 and 6)

The orientation to the meaning of understanding in the present work is focused on the nature of a person’s understanding, not on the nature of what might be claimed to be independent of that person. Hence, if one observes another to act in a certain way in some context, one can formulate an explanation, a constructed understanding, under which the other person seems to be operating by a process known as abduction. (Peirce 1955) If, later in another context, one’s explanation of the other fits the other’s understanding, then it is reasonable to be able to predict the behavior of

the other. If the other person does indeed behave in the fashion predicted, then one can make the claim that it is as if the constructed understanding is present in the other. If the observed behavior differs from the prediction, then one can make the claim that the constructed understanding does not appear to be present in the other. These constructed mental models of the understanding of others are the closest we can come to knowing the understanding of others. Descriptions of such understandings that can be seen to be explanations of the behaviors of others in the case of force and motion are given later in this article.

On the prevalence of change in understanding in physics instruction

Early work

By 1980, this same young man had taught high school for 4 years, completed graduate work in Physics and taken a position in a university Physics Department. At about the same time he earned his doctorate, articles were beginning to appear in journals describing students' understanding of topics in physics. In some of these articles the following observations were expressed:

Kinematics-velocity. "Our research also has provided evidence that for some students certain preconceptions may be remarkably persistent. As mentioned above, even on post-course interviews, when difficulties occurred they could be traced to the same confusion between speed and position that had been demonstrated during pre-course interviews. The belief that a position criterion may be used to compare relative velocities seemed to remain intact in some students even after several weeks of instruction." (Trowbridge & McDermott 1980)

Kinematics-acceleration. The conceptual difficulties with acceleration that were encountered by the students in our study appeared to be very persistent. Often, as illustrated by the pairs of interview excerpts on Acceleration Comparison Task 1, the procedures used by a particular student were the same before and after instruction. ... A significant number of

students from a wide variety of courses confused the concepts of velocity and acceleration. ... At the completion of instruction, fewer than half of the students demonstrated sufficient qualitative understanding of acceleration as a ratio to be able to apply this concept in a real situation. Even with assistance in making the necessary observations, these students were unable to combine this information in a manner that permitted successful comparison of two accelerations." (Trowbridge & McDermott 1981)

Electric circuits. "We have examined students' explanations of an extremely simple electric circuit, one that involved only three major components. We found that many students were unable to interpret the circuit correctly. ... One suspects, therefore, that a significant proportion of students in physics courses will have this type of difficulty. Even more disturbing is the fact that the misconception persisted in some students who had been through a calculus-based course in electricity which included five experiments on electric circuits." (Fredette & Clement 1981)

Real image formation. "It was clear from the interviews with the post-students that it is probably not uncommon to emerge from an introductory physics course without understanding the essential role of a converging lens or a concave mirror in the formation of a real image... There is often a tacit assumption that students who have performed satisfactorily in the geometrical optics portion of an introductory physics course can respond correctly to the basic questions presented at the beginning of this paper. The discussion above demonstrates that, although they might have been able to give correct verbal responses to these questions, the students who participated in our study were frequently unable to relate their knowledge to simple, but real, optical systems." (Goldberg & McDermott 1987)

Scope of findings

By 1990 many such articles had been published in many journals and books were being written on the topic of students' conceptions in science. Several groups had been maintaining bibliographies of these works in the middle 1980's including our young man, now older. These efforts were combined and can be found in a regularly updated bibliography

now including more than 6,400 entries (Duit 2004). All of the entries that document change in students' conceptions reveal that little or no change happens when students experience even the best of standard science instruction, not just physics. The items in the bibliography come from a variety of countries, in both hemispheres.

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.

An insidious change in understanding – the affective side

While standard physics teaching seems to be leaving students' conceptions of the physical world unchanged, *it is not leaving students unchanged in other important respects.* Only a tiny percentage leaves such instruction with positive beliefs about either themselves or the field of physics.

"On est frappés par la récurrence des mots qui désignent l'expérience des mathématiques et ses souvenirs: dictature, répulsion, terrorisme, couperet, cauchemar, mathophobie; et en même temps: inintérêt, application mécanique de règles, ennui profond. Il en va largement de même pour les sciences, en particulier pour la physique, que toutes les enquêtes désignent comme la discipline ayant laissé les plus mauvais souvenirs et provoquant après coup le plus de réactions hostiles, voire agressives."

"One is struck by the prevalence of particular words which describe the experience of mathematics and memories of it: dictatorial, repulsion, terror, nightmare, math-phobia and at the same time: disinterest, mechanical application of rules, profound boredom. It is largely the same in the case of the sciences, in particular with physics, which all the interviewees describe as the discipline that gives the worst memories and provokes the most hostile, even aggressive, reactions." (Astolfi 1997, translation by the author)

Very successful students, as judged by their high school physics teachers, speaking near the end of their high school physics course:

"I used to love math and science. ... Now I just want to get through. I am always being told what to do, what to think. There's no outlet. I am supposed to absorb someone else's information and then I realized it's not for me.

"I listen all week, then when we do the lab, there are really no surprises. ... It took me a real long time to get into physics. It almost seems that in physics you can figure out the lab without actually doing it, which isn't very motivating. It just seems like, maybe it's the way it's set up, but I pay attention all week and I have a general idea of what's going on. The lab is on a Thursday, toward the end of the week, so...we build up to the lab. ... We, my group, we use what we learned in our notes, the equations and stuff, to fix up our lab results. Most of the time we read the lab backwards. I don't know if that's cheating but he [the teacher] sets himself up that way." (McDonnell 2005, p. 584).

College students responding about their experience in introductory physics and chemistry courses at the university level:

"I think the students around me are having the same sort of thought-provoking questions about the material that I put into my journal, but under time pressure they don't pursue them, [and] eventually they learn to disregard "extraneous" thoughts and to stick only to the details of what they'll need to know for the exam. Since the only feedback we get is on the homework assignments, the students cannot help but conclude that their ability to solve problems is the only important goal of this class.

"[Another criticizes] ...a course design that assumes that everyone in the class has already decided to be a physicist and wants to be trained, not educated, in the subject..." (Tobias 1990, pp. 37 and 41)

The last four of these comments were collected in studies involving students with credentials typical of students who would do well in the science and engineering. Clearly they left their experience with a less than positive attitude about physics as a field of study.

Sadly, 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 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. Just on the order of 25% of high school graduates take physics in U.S. high schools. As evidenced in the above comments, even taking physics from such a specialist may only make the result worse. What is of fundamental importance here is not the flow of people into the profession of physics, but the negative, elitist lesson nearly all of the students conclude about themselves—a lesson as we shall see is questionable at best.

A closer look at the cognitive aspect

During the 1990's several diagnostics of student conceptions concerning various topics in physics were developed. One of these was used before and after science and engineering students studied motion and force in introductory physics courses from institutions across the U. S. over a period of a dozen years. Most of the institutions from which the data was received are large state supported universities of the sort producing the bulk of the engineering and science graduates in the U. S.

Pre and post data were provided from both of two different levels of introductory physics at the university level. One level of course is one involving only algebra and trigonometry and is typically taken by majors in biology, geology, kinesiology, construction management, and pre-health professions, such as pre-medical. The other level of introductory physics course involves the calculus and is taken by majors in physics, chemistry, geophysics, and engineering. The same topics are treated and similar laboratory exercises and homework problems are carried out. The significant difference between these two courses is the level of mathematics. The teaching practices in the courses are essentially the same. Students are expected to attend lecture and read a textbook by which they are *informed* about the

physical world. They are expected to carry out laboratory activities in which what they have been informed is supposed to be *verified*. They are expected to solve homework problems or exercises in which they are to *practice* what they have learned.

1. *The diagnostic.* The diagnostic, the Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokolof 1998), is a set of multiple-choice questions in which the questions and the sets of choices have been crafted to reveal students' conceptions about force and its relationship to motion and their conceptions about motion. The diagnostic has the purpose of discerning the nature of the student's conceptions of force and motion, not whether a student knows the "right" answers according to a physicist. The process of development, involving several thousand students, included collecting free-form responses to questions. Individual interviews were conducted with students concerning their under-

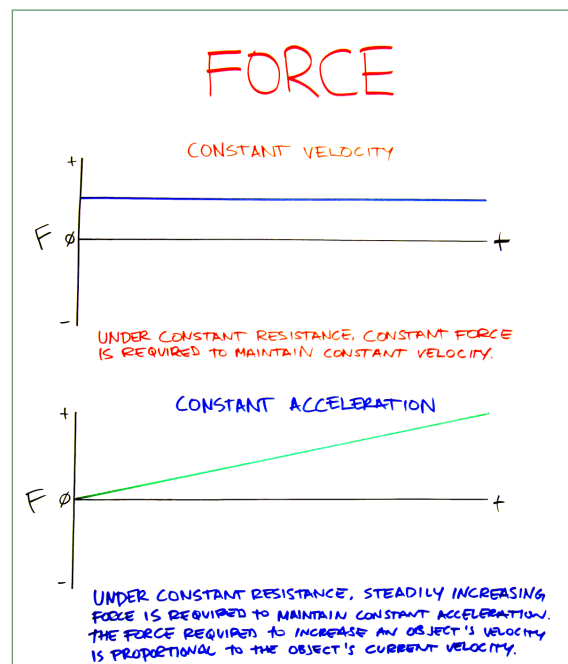


Figure 1: This is a poster made by students at the very beginning of their study of the nature of force. Most students regardless of the introductory course, whether they are in secondary school or college make very similar posters in that they express the person-on-the-street (pots) view of the nature of force.

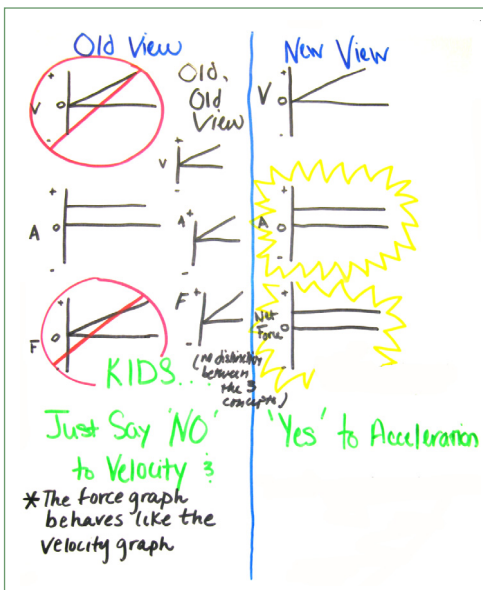


Figure 2: This poster was made by non-science/non-engineering students in a conceptual physics course at the end of their study of the nature of force in an alternative approach to physics teaching. It reveals that these students appear to understand the Newtonian-like (*New*) view of the nature of force and are aware of the distinction between it and the *pots* view. Typical science or engineering students at the end of standard physics instruction on the nature of force are not likely to depict a *New* view, nor be aware of the distinctions between the views demonstrated by the students who made this poster.

standing of the questions and reasons for the choices they selected. The FMCE has questions concerning velocity, acceleration, and what physicists would refer to as Newton's first and second laws of motion, Newton's third law of motion, and mechanical energy. On each topic there are at least 5 questions and several have in excess of 10 questions. There is a mix of questions involving graphs of either force or motion and questions that do not involve graphs.

Of the 21 questions on Newton's first and second laws, 17 were used to formulate two 15-point scales. One of these corresponds to the choices made by the student consistent with the typical person-on-the-street (*pots*) view of force and motion. The other 15-point scale corresponding to the choices made by

the student consistent with a Newtonian-like (*New*) view of force and motion.

2. *Two views of force and motion.* These two conceptions of force and its relationship to motion can be briefly described in the following ways. In the *pots* view, force is the explanation of motion or velocity. In this view there is always a force in the direction of motion and the magnitude of the velocity varies as the magnitude of this force. Figure 1 is from a poster made by a group of four students at the beginning of their study of the nature of force. In the *New* view, net force is the explanation of acceleration. The term, net force, refers to the aggregate effect of all the forces that happen to be acting on an object at any point in time. In this view the acceleration is always in the direction of the net force and, as the magnitude of the net force varies, so does the magnitude of the acceleration. Figure 2 is from a poster made by non-science/non-engineering students at the end of their study of the nature of force. It suggests that an understanding of these two views of thinking about force and how these two views contrast is present in the group of four students who made the poster.

view do not generally make much conceptual distinction between motion and changing motion; that is, between velocity and acceleration. Acceleration for them is a kind of special case of motion: velocity in which the magnitude of the velocity is increasing. In this view deceleration is a special case of velocity in which the magnitude of the velocity is decreasing. When the velocity is zero or constant, there can be neither acceleration nor deceleration, hence both have magnitudes of zero.

Persons who appear to use the *New* view parse motion differently. For them all changes in motion, that is, changes in velocity, are in some sense equivalent and distinct from the motion or velocity itself. This is much like the distinction between a function and its derivative in the calculus, but familiarity with the calculus is unnecessary to form this distinction about motion.

The two views are conceptually fundamentally different from each other in that the

New view rests on this distinction between velocity and this particular notion of acceleration as any change in velocity. In the *pots* view such a distinction does not exist. The nature of force in the two views is very different because what is being explained by the two views of force, the velocity in one and the acceleration in the other, is profoundly different. In the actions of a person holding the *pots* view of force, the notion of acceleration used in the *New* view of force does not appear to exist. Trowbridge and McDermott (1981) refer to this in the quotation from their paper about student conceptions of acceleration given earlier in this article.

3. *Evidence of change in science and engineering majors in standard physics instruction.* Table 1 gives some results from this study. Only data from students for whom there was both pre and post data was included. The table indicates the type of physics course, the general location of the institution, the year in which the data was collected and the number of students in each course.

It is clear that the initial (pre) person-on-the-street (*pots*) view average score is relatively high (about 10 out of 15) and the initial (pre) Newtonian-like (*New*) view average score is very low (0.6–2.6 out of 15). Scores in these ranges might reasonably be expected in the pre diagnostic, if there had been no previous instruction. But, one should keep in mind that these students experienced the typical curriculum in the U. S. They experienced one or more instructional sequences on forces: first, in elementary school (grades 1–6, ages about 6–12), another in 8th or 9th grade (ages about 14–16) and at least 25% of them received instruction on these topics in high school physics (normally 12th grade, age about 18). Because the students in this part of the study are all science or engineering majors, it is probable that more than 25% of them took a physics course in high school.

The changes from pre to post scores are not particularly large. The *pots* view scores drop from 9 or 10 down to 7 or 8 out of 15. The *New* view scores rise from 1 or 2 up to 3 or 5 out of 15. This final outcome does not convince one that any significant number of the students in these courses leave with an understanding of the *New* view concepts explicitly taught by Ph. D. physicists and their graduate students. These students still appar-

ently think about the world in terms of the *pots* view.

Effect size refers to the size of the difference in the class average diagnostic scores, post minus pre, in units of the standard deviation of the scores. An effect size of 0.6, the average here, is often considered in the moderate range for educational research. Given the actual final performance of the students, such an effect size can hardly be called laudable, especially in the *New* view score.

Normalized gain and loss are measures of the fraction of the possible gain or loss that could occur in the scores. In Table 1 the normalized loss is calculated on the *pots* view scores. Typically for a whole class average in these examples of standard physics instruction, the *pots* view score drops. The normalized loss is calculated to give a negative result when the *pots* view score drops. The normalized gain is calculated on the *New* view scores. A typical normalized gain of 0.15, the average seen here, or about 15% might be acceptable, if the pre *New* view score were high. Since this is not the case, a normalized gain in *New* view score of 15% is wholly unacceptable. We need to be seeing effect sizes and normalized gains that are many times larger, if the standard deviations remain similar.

These results are consistent with reports in the bibliography. They appear to be reproduced routinely every semester in most locations, in the U. S. and in many other locations around the world. What is taught in standard physics instruction is not understood by an overwhelming majority of the students. It is important to remember the changes seen here are the third or fourth attempt to teach these ideas to students considered to be, as science and engineering majors, among those capable of learning this material. 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.

The outcome of standard instruction in physics is a spectacular failure and 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.

Whole class scores			Average Scores				Effect Size		Normalized	
Year	Term	N	Pre (0–15)		Post (0–15)		(st dev)		Loss <L>	Gain <g>
			pots	New	pots	New	pots	New		
Algebra–Trig Level Intro Physics										
<i>West Coast Public Univ. A</i>										
1990		99	10.1	1.5	8.5	3.3	–0.47	0.59	–0.16	0.13
<i>“Prairie State” Public Univ.</i>										
2002	SP	112	10.3	0.9	9	2.7	–0.40	0.66	–0.13	0.13
Calculus Level Intro Physics										
<i>North East State Public Univ.</i>										
1998		72	9.6	1.7	8.5	3.5	–0.30	0.47	–0.11	0.14
<i>West Coast Public Univ. B</i>										
1999	Wint.	87	9.3	2.6	6.5	5.4	–0.62	0.60	–0.30	0.26
1999	SP	73	9.1	2.3	7.6	4.0	–0.36	0.38	–0.17	0.13
2000	SP	115	9.2	2.4	7.2	4.8	–0.50	0.59	–0.21	0.19
<i>West Coast Private Univ.</i>										
2000	SP	38	9.8	0.6	9.6	1.7	–0.08	0.54	–0.03	0.09

Table 1: Pre–Post Data, Measures of change in normal instruction, science and engineering majors. pots: person-on-the-street view of force and motion; New: Newtonian-like view of force and motion; N refers to the number of matched pairs of data from each class. Effect size is the post score minus the pre score, the quantity divided by the pooled standard deviation. Normalized loss is the post pots score minus the pre pots score, the quantity divided by the maximum the pots score could go down (to zero). Normalized gain is post New score minus the pre New score, the quantity divided by the maximum the New score could go up (15 minus the pre New score).

Realism in instruction

Evidence calling for explanation

The tacit assumption and sometimes explicit characterization of physics teaching seems to be that we present content so that students can receive it with the idea that they hold on to it. The drive is to present the content to the students so that they can have it. The implications being that (1) they must be presented the content in order to have it and (2) that the content can be presented in such a way that it is possible for the students to receive it.

One could characterize physics teaching in this view as *content*-driven. But, if this really is the case, why is it that so many students have failed to get it for so long with nothing being done about it? Instead of asking what is the

intent, maybe we should look at what is happening:

- Very little change in understanding of physical phenomena occurs as a result of physics teaching.
- Most people we subject to this instruction leave with an unrealistic view of the enterprise of physics, that it is all mathematics and completely determined by measurements.
- Most leave the instruction believing they are not capable of understanding physical phenomena. They must rely on those who are capable of such understanding for knowledge of the truth about the phenomena.
- Typical classroom activities and exams in physics do not reveal the presence or absence of changed understanding of the phenomena.

- Since around 1980, what is now referred to as the physics education research (PER) community has been bringing to our attention the finding that most students leave physics instruction not understanding what has been taught. In addition to the sources already cited, one can find papers and sessions presented at meetings of the American Association of Physics Teachers, the American Educational Research Association and the National Association for Research in Science Teaching since the late 1970's on this issue.
- As a consequence of physics teaching having been the same, *inform, verify, practice* method for numerous generations, change in understanding in physics courses has been lacking possibly for centuries.
- In that time many sincere, diligent, very intelligent people have taught physics, yet standard classroom activity and exams in physics have been crafted which do not reveal whether or not change in understanding has occurred. None of these people seem to have noticed the general lack of change in understanding of the phenomena about which they teach.
- Since 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, for example Geilker (1997), Erlich (2002), Cromer (1997) and Aldridge (1995).
- Alternative approaches to teaching physics demonstrated to result in significant change in understanding are ignored and resisted. Physics is still mostly taught as it was for centuries before 1980.

An explanation

It seems in spite of the stated intent, what is actually happening is better described in another way. A better description would be to describe the teaching of physics as:

Physics teaching is the presentation of the established canon by approved methods for the benefit of the deserving.

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." (Torre & Zamorano 2001, p. 103)

That this knowledge can be transmitted is clear in that it is to be presented. Apparently approved methods have passed the criterion of being effective transmissions of knowledge. In this program such knowledge apparently can exist in the symbols (words, sounds, gestures) used in the presentation. It also apparently exists in nature independent of the student since what is presented is to be verified in laboratory experiments or exercises.

It is acknowledged that not all can receive the transmitted knowledge effectively. To account for this the construct, deserving, is applied. 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.

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 – but that's okay, we can't all be physicists (*sic*).

This program is an expression of teaching within a realist, elitist paradigm. Being a paradigm in the Kuhnian sense, it explains all relevant observations. The paradigm defines what observations have sufficient status to be addressed in the paradigm and what observations do not. It is a complete system within itself. There is no need to ask why so few "get" the transmitted knowledge. Von Glasersfeld's question: "...but do they really understand?" is irrelevant and *non sequitur*. To question the approved methods or not be driven to present the canon is heresy within the paradigm. This paradigm construct explains the observations listed above.

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.

We see then that the meaning of *content-driven* as applied to this description of physics teaching is the drive to *present* the content. One must cover the subject. *It is not about students "getting" the content.* 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.

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.

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.

An alternative paradigm

As it turns out, the young physics teacher, now older, started out, without realizing it, on the outside of the established paradigm. He mistakenly thought the point of teaching was that students develop new understanding as a result of their experience in the classroom. For him the typical outcomes of conventional teaching were disturbing. Without yet being able to articulate the nature of this anxiety, he searched for an answer. He found it when the work of the Genetic Epistemologist, Jean Piaget, was described so that he could see it as a theory base from which to operate in the classroom. (Fuller, Karplus & Lawson 1977) In a sense this theory base would enable him to do science as he taught with the goal of empowering his students to develop new understanding.

A different teaching practice

Fortunately in addition to being able to study Piaget's ideas, the young man benefited from close mentoring contact with a number of colleagues. As of this point in time one result is an alternative practice of physics teaching that can be called *student understanding-driven*. This teaching practice can be described as:

Physics teaching is the process of engaging students in developing new understanding of physical phenomena

The focus here, the central object of manipulation, is neither the canon, nor the phenomena, nor the apparatus. It is the students' explanatory schemes, their conceptions concerning the phenomena, their understanding of the phenomena. The experiences, for which these explanatory schemes are developed, play the important role of checks on the explanations for fit, but it is the explanatory conceptions that are the main focus of attention. These conceptions constitute a student's understanding, hence the practice is *student understanding-driven*.

Whole class scores			Scatter Plot Averages				Effect Size		Normalized	
Year	Term	N	Pre (0–15)		Post (0–15)		(st dev)		Loss <L>	Gain <g>
			pots	New	pots	New	pots	New		
Conceptual Physics, College Level										
<i>Intermountain State University</i>										
2000	FL	90	9.3	0.8	2.5	9.2	-2.20	2.50	-0.66	0.59
2001	SP	87	9.8	0.8	2.2	9.6	-2.40	2.40	-0.74	0.62
2002	FL	66	9.4	0.8	2.2	8.8	-2.19	2.26	-0.72	0.57
2004	SP	69	7.9	2.2	1.8	10.8	-1.85	2.31	-0.78	0.67
2005	SP	53	9.9	0.8	1.5	11.1	-3.08	3.38	-0.85	0.73
High School Level										
<i>North Central State High School</i>										
2001	FLa	23	11.3	0.6	0.6	13.3	-5.4	6.3	-0.95	0.89
2001	FLb	24	10.6	0.9	0.8	13.1	-3.7	6.1	-0.93	0.86

Table 2: Pre–Post Data, Measures of change in alternative instruction, non-science, non-engineering majors.

A radical constructivist paradigm

This alternative teaching practice is embedded in a radical constructivist (RC) paradigm. (Glaserfeld 1991) In this paradigm the nature of knowledge is incommensurate with that of the realist-elitist paradigm described above. In this RC paradigm, knowledge can be divided into two types. One is experience, experiential knowledge, and the other is explanation, explanatory knowledge. (Jammer 1999) This explanatory knowledge cannot be judged any other way than for fit to experience. The degree of fit does not convey in any way the status of true description of an independent reality or of being closer to such truth. Such truth for explanatory knowledge has neither existence nor status in this RC paradigm. This is one of the fundamental points of incommensurability between radical constructivist and realist paradigms.

Experiential knowledge is the experience itself, hence experiential knowledge cannot be transmitted via language. Students must have their own experiences. Without these experiences there is nothing to explain, no need for explanatory knowledge.

The explanatory knowledge is not declarative statements but the meaning of such statements, the understanding from which the statements are generated, the conceptions

that give such declarative statements meaning to the maker of such statements. This explanatory knowledge exists only in the mind of each individual as a constructed mental entity. As such, this knowledge cannot be transmitted. It is a consequence of the condition that meaning exists nowhere but in the mind of the individual, that for the meaning to arise in the individual, the individual must construct it. Hence, the label, constructivism, describes the consequence of the fundamental nature of knowledge employed in radical constructivism.

For a realist, everything breaks down at this point, if it has not already. We are all isolated and incapable of communicating with each other, if meaning cannot be transmitted. For the radical constructivist, nothing could be further from the case, but in RC communication has an entirely different explanation. For the realist, the transmission of realist-type knowledge cannot be dissociated from communication. For the radical constructivist, communication is the individual construction of meanings to be associated with symbols and combinations of symbols from someone else. At an early age, one constructs the notion of "other" based on patterns of regularity of experience. Later, one modifies the construct "other" to endow it with cognizing

capacities one is aware of in one's own consciousness. By experience, trial and error, and reasoning, one is continually building and modifying a kind of look-up table that connects the symbols of language with meanings that appear to fit experience (Glaserfeld in press). Through copious interaction with "others," we develop look-up tables that work sufficiently well that we can take our own look-up table as shared with "others." This taken-as-shared communication process enables us to interact enough to decide certain experiences can be taken-as-shared and that explanations can be taken-as-shared.

The ability to make these mental constructions is considered a capacity of all human beings. Elitism plays no role in this paradigm, either in the teaching practice or in explaining the outcomes of the teaching.

Piaget describes a mechanism that drives this process of meaning construction. What drives meaning construction is the need or desire for equilibration between one's explanatory mental constructs and one's experiences. (Piaget 1985) One moves to modify or construct new explanation when one perceives one's existing mental constructs do not fit experience, i.e., when one disequilibrates. Because the resolution of the disequilibration is new mental constructs that do fit experience, the resulting accommodation is always one that fits a greater range of experience, hence, a kind of pragmatic progress. In a nutshell, for change in understanding to occur, the teacher first needs to engage the students' attentions in comparing their existing conceptions with some behavior of the phenomenon that likely does not fit those conceptions.

Some results of this alternative teaching practice

Using the same diagnostic, the FMCE, described previously in this work, conceptual change on force and motion was studied in a course for non-science/non-engineering majors. The teaching practice used is the one described above from within a radical constructivist paradigm. Fewer of these students are likely to have had physics in high school. Most college science faculty imagine these students to be in the category: less deserving. As such the learning results would be expected to be inferior to that of the science and engineering majors.

A high school teacher trying out the alternative teaching practice for the first time also used the FMCE diagnostic. The only modes of communication between this teacher and the author were electronic mail and telephone. The teacher was conducting a project as part of the requirements for a master's degree in science education. Table 2 displays data collected in these two different classroom settings.

A comparison between Table 1 and Table 2 shows a marked difference in conceptual change on the diagnostic scores. The initial average scores for each view in Table 2 are not particularly different than those in Table 1. This is because these students experienced similar standard instruction in elementary school and in the 8th or 9th grades to that experienced by the science and engineering majors in Table 1. The magnitudes of the changes in table 2 are much larger. The effect sizes are larger and the normalized changes are larger. The effect sizes easily meet Bloom's challenge of a change of two-sigma over the results of normal instruction. (Bloom 1984)

Clearly, non-science, non-engineering majors in this alternative teaching practice, guided by radical constructivism, consistently and routinely change their understanding of these phenomena by an amount several times larger than science and engineering majors in standard physics instruction guided by an elitist realism. This is far beyond statistical significance. Typical statistical significance in educational research is claimed for the kind of changes (0.5 standard deviations) seen in Table 1. Yet, we see that the level of understanding actually accomplished in Table 1 post-scores is so small as to be impractical as a justification for the instruction.

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. Such outcomes as seen in Table 1 are just the way things are. 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 every-

one 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.

Teaching within a radical constructivist paradigm

In this alternative program of physics teaching, the teacher plays a fundamentally different role.

"...a physics major has to be trained to use today's physics whereas a physics teacher has to be trained to see a development of physical theories in ... students' minds." (Niedderer 1992), p. 151)

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 in Table 1. 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.

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 disequilibrium, 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.

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:

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.

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 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 disequilibrium 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 experi-

ence. 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.

Superficial success:
Training and indoctrination of scientists in the elitist-realist paradigm is accomplished
It takes 3–5 or more cycles of standard instruction for understanding to be accomplished
Spectacular failure:
For nearly all of society there is no change in understanding concerning the phenomena studied
In any science
In any country
For the last century or more
Students, including those who become scientists, learn
Only a few special people can “understand” science.
We must rely on “scientists” for “scientific truth.”

Table 3: Outcomes of elitist–realist science instruction. Not unique to science instruction

Student understanding-driven, not canon or content-driven

The established canon does not drive the ordering or development of the predictions that are used. It could be allowed to do so, but the learning results suffer when this is done. Before the semesters of the college level conceptual physics course shown in Table 2. The series of predictions the students were asked to engage in was still partially canon driven. Equal time in the study of motion, kinematics, was given to position, to velocity and to acceleration. The standard paradigm holds that one cannot really know velocity until one really knows position and so forth for acceleration. It was noticed from the diagnostic data that whether or not a student demonstrated understanding of velocity was not a predictor of change in understanding with respect to force.

Under this canon-dictated, equal-time-for-all-three-topics design, the typical effect sizes were slightly under 2 standard deviations and the normalized gain was slightly less than 0.5. When all but two of the ten activities on position and velocity were dropped and the time gained was used to examine acceleration more deeply, results changed. The result of abandoning the canon and allowing one's understanding of the students' understandings drive the process can be seen in Table 2. There was an additional 0.5 standard deviation effect size and about 0.15 normalized gain. This departure from the canon results in an additional change essentially equal to that of the standard instruction *in total*.

Conclusions

Standard physics instruction is effectively described as *the presentation of the established canon by approved methods for the benefit of the deserving*. It runs on an *inform, verify, practice* cycle. Teaching practices based in this description result in almost no practical change in understanding of the phenomena studied on the part of the students. On the other hand, there is change in understanding as a result of this instruction. Unfortunately, the change is that students learn a caste system based on who can "understand" the phenomena in standard instruction and who cannot. Since most of them leave the instruction not understanding, most decide they are not in

the caste of those who can understand. It is those in the caste who can "get" the canon who are considered the deserving. Furthermore, all learn that this is just the way things are—the ideology-less ideology of objectivity in realism. This program of teaching and the elitist-realist paradigm on which it is based can be seen to explain the spectacular, widespread, and long-term failure of standard physics instruction and its destructive influence in society.

If there were no examples of effective alternatives, this state of affairs could be argued as truth. An alternative approach to teaching based on a radical constructivist paradigm is shown to be one such alternative. This teach-

ing practice runs on an *elicit, compare, resolve, apply* cycle. Students considered less deserving, less capable in the other paradigm, but taught in this alternative practice, are shown repeatedly to be capable of making far greater change in understanding than science and engineering majors taught in the elitist-realist paradigm of standard instruction. This result demolishes the "objectivity" of the deserving/less deserving explanation for the fact that so few students "get it" in standard science instruction. As a result the "objectivity" of the whole elitist-realist paradigm fails.

In RC one cannot claim radical constructivism to be "The True paradigm." One can only show that RC is the basis for a paradigm

FUTURE WORK

Regardless whether one agrees or disagrees with the above line of reasoning, one still faces a moral, ethical dilemma in terms of social justice in education. The outcomes of standard instruction are unsatisfactory and destructive. At least one alternative with good outcomes has been demonstrated.

In the name of social justice in education, are we not obligated to respond in a careful, but serious, reasoned way, that rises above sectarian bickering?

Are we not obligated to end, with all possible haste, the negative outcomes of standard instruction? Are we not obligated to end, with all possible haste, the training of teachers to inflict such intellectual and social damage by thoroughly revising their training to equip teacher candidates not to inflict such damage? Unless we accomplish paradigm change from the elitist-realist paradigm, that paradigm will remain hegemonic and the destruction will continue. *Got change for a paradigm?*

Paradigm change occurs when people become dissatisfied with things as they are. One can reasonably argue that our young man started outside the prevailing paradigm. What drove him to develop an alternative practice of teaching and to consciously define for himself his paradigm was his disequilibrium over the discrepancy between his expectations about the outcomes of teaching and his observations of the outcomes when he began teaching. Can teacher candidates be engaged in the same discrepancy? This may be what Niedderer (1992) was referring to when he wrote: "... a physics teacher has to be trained to see a development of physical theories in ... students' minds."

It is possible to imagine a RC-based course of study for teacher candidates in any subject. This course of study would have as its central focus; the evidence of a person's understanding in whatever subject is to be taught. Surrounding this central focus should be the examination of how, why and under what circumstances understanding appears to change and methods of facilitating this change process in the students. The presentation of the established canon of the subject and approved methods would cease to determine anything in the course of study for teacher candidates, though the established canon might remain a presence at the periphery in the course of study for teachers.

Students who learn in this radical constructivist paradigm not only develop significant, deeper understanding of the phenomena studied, but also develop a different self-image. This self-image is positive and empowering. Students come to see the value in understanding the point of view of others and develop skills for working with others to create better common understanding of issues they face. Every student in every classroom can do this. Wouldn't the world they create be far better than the one we have now? When do we start changing how we teach? *If not us, who? If not now, when?*

that yields far more favorable results in instruction. On the other hand, the failures of instruction in the elitist-realist paradigm and its failure to fit experience, in terms of who can and who cannot “get” instruction in physics, do enable us to draw the conclusion that the elitist-realist 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 unsupported 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.

The line of reasoning presented is about the relative usefulness of realism vs. radical constructivism. Radical constructivism leads to outcomes much more desirable than elitist realism in the context examined. While one

can see direct application to physics teaching, the conclusion and applications apply much more generally. This is justification for trying to understand radical constructivism instead of trying to prove it wrong.

Epilogue

Presently our young physics teacher, now much older, is accomplishing his goal of engaging students in developing new understanding of physical phenomena. His still developing understanding of the work of Piaget and of Radical Constructivism play significant roles in the on-going development of this successful teaching practice. The results for college students in Table 2 reveal that his students make changes in their understanding of the phenomena in quantity far superior to that of students experiencing standard instruction. He continually works at engaging the unengaged in his classrooms in order that even more achieve the results of the rest of the class.

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Dewey Dykstra grew up in Maryland, USA. In junior high and high school he entered and won prizes at Science Fairs. He graduated with a B.S. in Physics from Case Institute of Technology in 1969 and began teaching high school in the inner city of Cleveland, OH that same year. After three years he moved back to Maryland and taught 9th grade physical science and 12th grade physics for a year. He entered graduate school at The University of Texas at Austin and earned a Ph.D. in condensed matter Physics in 1978. He has been on the Physics faculty at Oklahoma State University and Boise State University. He is privileged to have had as mentors: Robert Fuller, James Minstrell and Ernst von Glasersfeld, among others. – “In addition to teaching and research in physics, I have conducted projects investigating the nature of learning in physics problem solving and developing physics instructional materials with guidance from evidence collected concerning students' conceptions of physical phenomena. Over the years I have held several positions in the American Association of Physics Teachers, both elected and appointed and is a regular contributor to meetings of this organization. I enjoy travel and have been pleased to share my work or taught physics in Canada, Germany, India, Italy, Mexico, Scotland and Trinidad. In India I had the privilege of engaging Tibetan Buddhist scholar monks in inquiry concerning physical phenomena. When I get a chance, I enjoy visiting archaeological sites, playing bagpipes, and cooking.”

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