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BOOK REVIEW

Shifting the Focus of Undergraduate Physics and Engineering Courses

Calvin S. Kalman (2017). Successful Science and Engineering Teaching in Colleges and Universities (2nd Ed). Information Age Publishing, Inc., Charlotte, NC. ISBN: 978-1-68123-957-6. 175 pages. US $49.00 (Paperback)

Roland M. Schulz[1]

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1 Physics Education Research and its Problems

With Kalman's 2017 book *Successful Science and Engineering Teaching in Colleges and Universities*, Physics Education Research (PER) has slowly but surely come into its own. By the time of Lillian McDermott's 1984 paper (*Research on conceptual understanding in mechanics*) reviewing the research on the topic, the field was already about a decade old, where pioneering studies were undertaken by Clement and Driver, Champagne and Klopfer, Gunstone and White, McCloskey, and others. A decade on, studies looking at students' misconceptions and the difficulties of learning physics concepts whether in high schools or in large lecture halls during first-year undergraduate courses had considerably multiplied. By 1989, Harvard physics professor Eric Mazur was shocked to discover that a diagnostic test had shown a majority of his undergraduates had not learned Newtonian mechanics to the level he thought they should have once the course ended—that in fact too many 'Aristotelian' conceptions survived. To address the dilemmas, the early 1990s saw the 'Force Concept Inventory' test being introduced (Hestenes, Wells, and Swackhammer, 1992), which proved so revealing and became so popular that it is now considered a classic, and is still in use by instructors today at high schools and colleges.

While the force inventory was intended to probe students' preconceptions of mechanics as they enter the course, their "Mechanics baseline test" (Hestenes and Wells, 1992) was created to probe for levels of understanding of Newtonian mechanics post course—to help the teacher assess what had actually been learned, to what depth, and if preconceptions had indeed been overcome. The results are often still shocking to behold for instructors today when using the diagnostic tests. Both 'tests' are seen as complementary—for as any successful teacher knows,

✉ Roland M. Schulz
rmschulz@shaw.ca

[1] Centre for Imagination in Research, Culture and Education (CIRCE), Simon Fraser University, Vancouver, BC, Canada

there exist large gaps between the intended curriculum, the implemented curriculum, and the learned curriculum (McDermott, 1991, Millikan lecture 1990: What we teach and what is learned—Closing the gap). A major concern of PER has been to identify the causes and to close the pedagogical 'gap'.

By the end of the 1990s, PER overviews had begun to appear in the *American Journal of Physics*, summarizing what had been produced in the field to that point: it was impressive. McDermott and Redish (1999 *Resource letter*: *PER-1*: *physics education research*) referenced 224 papers on the teaching and learning of physics concerned with several central topics: from mechanics to electricity and magnetism, optics, fluids, waves, etc., and to a lesser extent, modern physics. Also cited were studies on student problem-solving behaviour, their attitudes and beliefs, epistemology, learner reasoning, effectiveness of laboratory, and lecture instruction, and even cognitive studies related to concept development, conceptual change, and mental modelling. This remarkable record and the merit of accumulating research had led Redish to conclude it was time to "build a science of teaching physics" (1999, *Millikan lecture 1998*: *Building a science of teaching physics*) through the creation of university-wide new PER groups. Hestenes (1998, *Who needs physics education research*?), however, had already warned that too many physics faculties and instructors at that time still downplayed the significance of educational research, especially the worth of creating and funding a physics education research sub-department within the hallowed faculty itself.

Some universities acknowledged the concerns earlier, some much later than others, regarding the crisis of how undergraduates were being taught—about the how and why they were learning physics so poorly—one study in fact showing students left courses with a more anti-scientific mind-set than when they entered. Too many were slow to accept that "traditional lecture-based instruction demonstrates that a reasonably good understanding of science can be taught to a select 5% of the population" (Redish, 1999, p. 565). By the 2000s, attitudes had changed: Heron and Meltzer (2005, *Guest Editorial*: *The future of physics education research*: *Intellectual challenges and practical concerns*) noted that a considerable number of physicists had "converted" from traditional areas of research to PER, along with increasing numbers of PhDs awarded in the new sub-field. The University of British Columbia in Vancouver, Canada, for example, was a relative latecomer in acknowledging the need for PER but eventually hired the Nobel prize winner Carl Wieman (also the founder and director of the well-known PhET at the University of Colorado) in 2007 to establish a PER group there, once the pedagogical problems could no longer be ignored.

2 Shifting the Focus

One physicist who was not a latecomer but has been an active member for many, many years of the now thriving PER community in physics and education faculties has been the author of the present book under discussion, Calvin S. Kalman. He is professor of physics and principal of Science College at Concordia University in Montreal, Canada. He has been the chair of the Division of Physics Education of the Canadian Association of Physicists. Among his earliest papers was one on computer-assisted learning in the undergraduate physics laboratory in 1987, at a time when computers were just beginning their debut for educational purposes. An author of 75 papers on high energy physics, these are complemented with additional 58 papers on science educational research—among the newest is one focusing on using a combination of interventions to change students' epistemological beliefs (Kalman et al. 2015, *Combinations of* *interventions can change students' epistemological beliefs*). His book *Successful Science and Engineering Teaching* (2017) hence brings to the fore his ideas and implemented successful strategies of physics teaching cumulated after many decades of reflecting on his teaching and practice while instructing and assessing student learning.

The book is intended as a useful guide for instructors who are concerned with improved, deeper understanding of physics and engineering concepts for their undergraduate students, including overcoming preconceptions and helping them better their grades through enhanced reading and thinking skills when approaching their technical textbooks or attending lectures. As an author who is fully versed in the PER literature, his 'textbook' is intended to provide authentic solutions to overcoming those serious problems identified with teaching and learning of physics over the decades—since mounds of research not applied to real classrooms in order to attain resolution has sadly wasted its potential—which too much educational research suffers from.

Kalman along with many like-minded PER colleagues is concerned to shift the still prevailing teacher-centred culture, with the dominating lecture format of first year undergraduate courses, to a more student-centred learning culture. Here the book is extraordinarily timely and valuable, and probably many physics and engineering instructors will wonder why someone had not managed to publish a practical book of this kind earlier, given the recognized need (barring the first edition). One can think of it as a sort of instructor 'self-help manual', notably for its informal writing style, the numerous examples it provides, including honest student self-reflections, and ready-to-use suggestions with regard to how to run successful small collaborative groups. And these are only some of the named handy strategies presented in the book, which contains many helpful ideas and includes actual physics problem-sets with solving strategies based on students' cognitive struggles (Ch. 9).

Although the book is surprisingly short, about 162 pages with 11 chapters, each chapter is itself comprised of only 10 to 15 pages in a tight easy-to-read format, and each concludes with a short summary. This makes the text very approachable, especially the many graphic illustrations intended to clarify the various issues being raised, which include flow charts, Venn diagrams, concept mapping, and a reflective writing rubric.

Kalman is clear that he does not oppose lecturing or direct instruction per se, rather seeks to replace the traditional lecture time slot (with at best question-answer format at the end), with shortened, broken up lecture segments interspersed with student-centred activities such as reflective-think-pair-share, peer instruction (with 'clickers') and collaborative groups. These latter three strategies are not in themselves new to PER, of course (though they could very well be new ideas for novice instructors!), however, what is new and effective is the way that Kalman combines them with his understanding of learning theory and the way language functions in the educative process.

Any competent physics/engineering instructor will want their students to go beyond mere skills of algorithmic problem-solving and memorization, and attain rather a fuller understanding of the concepts involved as well as improve their critical thinking skills. Kalman sees the last two as the primary goals to be achieved from courses. But that requires of the instructor the ability to recognize that learning from textbooks and lectures presents serious obstacles for students in their own right—even for the brightest—as so much of the research attests. Since oral and written language is the medium for both communication and interpretation, students usually tend to misread and misinterpret what both the textbook and the teacher present. Technical textbooks demand time and effort to read correctly, and most students ignore them until required for locating problem exemplars or for numerical problem-solving; they certainly do not read them for pleasure. Textbooks in fact present a scientific world to the student written from the view of the expert, relying on technical vocabulary and abstract language (compounded by mathematical symbols) that can seem just as strange as learning a foreign language, which tends to alienate instead of encouraging engagement (Lemke 1990, *Talking science. Language*, *learning*, *values*).

3 Reflective Writing Strategies, Hermeneutics, and Learning Theory

To overcome the obstacles and attain the two main goals the important tool of reflective writing (and its various versions like free-write, writing-to-learn, course dossier method) is stressed. He clearly distinguishes reflective writing from student's own summative writing (when reviewing their notes and textbook) and elucidates how it can play a substantial role in student learning if used properly throughout the course to address different learning issues. This writing tool has come to gain more importance in PER, one key idea being that students first treat the text as an interpretive problem before the class starts, helping to sort out their own ideas while tackling concepts before any numerical problem-solving. It focuses their attention on the importance of concepts themselves, which students too often underrate for problem-solving. It helps connect current and previous class material; it clarifies concepts, adds to preparation, and better attention span while listening to teacher talk and, ideally, improves their critical thinking through metacognition—by raising their awareness about how and what they think and what attitudes they harbour about the course topics and their abilities (math anxiety?); in effect: learning how to learn.

Kalman embeds both his notion and use of the tool of reflective writing in his hermeneutic understanding of language. This conception is diametrically opposed to a view of language performing like a lucid sender–receiver message, a kind of unfiltered Morse code type delivery system—the so-called transmission model of language—that too many instructors naively assume and unconsciously employ. With remarkable brevity Kalman clarifies how Gadamer's hermeneutic circle method can lead students through an interpretive act to more meaningful learning, based upon a student's self-dialogue with a textual extract as an example, while wisely avoiding a diversion discussing language theory and the philosophical hermeneutics of Heidegger and Gadamer. As an aside, the study of hermeneutics and its relevance for science learning has been at the margin of concern for researchers in science education although socio-linguistic based studies has been in the ascendency for over a decade—all the more noteworthy that Kalman has pioneered its worth, of all things, for improved post-secondary physics and engineering education. (Here he purposely builds upon the astute previous work of the physicist and philosopher Martin Eger 1993 a, b, *Hermeneutics as an approach to science Parts I*, *II*).

Hermeneutic learning theory and reflective writing aim to achieve the goal of metacognition when students become confronted by the situation where their everyday preconceptions (or 'intuitive ideas') conflict with canonical scientific concepts when trying to understand the textbook or listening to an instructor—resulting in cognitive dissonance. Kalman commits two entire chapters, as he must, to the important and heavily researched topics of how students construct knowledge, misconceptions, and their cognitive development, and how to develop a scientific mind-set by changing their epistemologies. He even briefly discusses the debate in the scientific community, and the lack of consensus about whether students enter classes with isolated structures of knowledge, as disorganized ideas (the 'knowledge-in-pieces' view), or harbour more elaborate ‘theories’ (the ‘alternate framework’ view). He does not choose sides but gives the reader just enough research insight to show the issue is complex, and there exists some truth on both sides. The point is twofold, to give novice instructors awareness that students are not blank slates, including identifying for them where the background research stands, and more of issue, allow students the ability through reflective writing to explicitly surface their own individual predispositions, possibly which of the two standpoints may unreflectively impact their way of thinking.

The aim is to ‘help students to evaluate their conceptual framework so that they realize that they compartmentalized their knowledge into templates for every situation. Only then can they adopt a holistic approach and get to appreciate the conceptual framework of the course’ (p. 55), which better corresponds with the expert’s viewpoint. One need not hold to Piaget’s view of cognitive development, as Kalman does to reinforce his conceptual change theory, to appreciate the effort and ability of switching stubbornly held non-Newtonian ideas and changing epistemologies.

4 Integrating History and Philosophy of Science: the Problem with Textbooks and Nature of Science

His classroom-focused and classroom-tried examples do weigh heavily towards the application of the once quite popular conceptual conflict nature of learning model, based as it (originally) was on philosophy of science. He utilizes Kuhn’s and Feyerabend’s idea of incommensurability and relies heavily on Feyerabend’s epistemological (and quasi-historical) viewpoint (‘principle of counterinduction’ p. 70) that frameworks in science can be switched only when a viable alternative (theory) is available. In one interesting study he cites, performed with his own research team and conducted in an introductory calculus-based mechanics course, he sought to compare which method of teaching for deeper conceptual understanding was more successful, the frequently used ‘peer instruction and clicker’ strategy (of Mazur) or the ‘collaborative groups activity’ strategy using conceptual conflict (targeting 4 key concepts). The data he presents shows that although the peer group performed well when it came to kinematics concepts, the collaborative group method received a statistically significant higher score when it came to dynamics. Building on this, another research-based classroom study they performed showed that there was an improvement when students perform critiques in conjunction with conflict group activities than if they solely do conceptual conflict group exercises.

For Kalman textbooks are not sacrosanct either, he is aware how they themselves often distort the nature of science (both its epistemology and historical development), and create in students’ minds fundamental misconceptions of the scientific enterprise itself—another extensive topic of previous studies— and there are many insightful and useful nuggets in the book which teachers can mine, explore, and implement in their teaching. His use of history of science episodes combined with how philosophers of science have viewed the nature of science, for example, help students better construe how science actually functions and proceeds. He mentions one teaching strategy where he has separate groups each study one of four philosophers throughout the course (Kuhn, Popper, Lakatos, Feyerabend), and using a compare and contrast technique help sharpen their critical thinking (example ‘Discuss the Michelson-Morely experiment from the point of view of your philosopher’ p. 90). In another example, he again uses Feyerabend’s counterinduction idea while implementing a group activity (directly modelling this epistemologically based learning theory) using the contrasting alternative frameworks of pre-Galilean physics conflicting with Newtonian physics. Here students' intuitive ideas are quite often actively opposed. It probably goes without saying that these 'Arts-type' features (or 'additions') of first year courses are not typical for what most people have come to view as conventional introductory physics classes, but it would certainly enrich them, and Kalman illustrates how it can be done.

The use of history and philosophy of science in such a fashion may very well strain the pedagogical capacities and abilities of some instructors given the fact that most are not very conversant with these two fields—serving as academic background as they should to their respective specialist science(s)—and their own more narrow-focused academic science training. Nonetheless, the physicist Arons (1988 *Historical and philosophical perspectives attainable in introductory physics courses*) clarified what could be achieved here, already over three decades ago. But it shows just how far some facets of PER and instruction have come.

5 Conclusion

Finally, two aspects about the title of the book are misleading. For one, the 'science' in the title is a misnomer and should rather be identified with the subject of physics alone, since this specific science is exclusively dealt with in the text. For another, I found the accessibility and informal approach, especially the numerous examples and instructional strategies presented therein (like reflective writing and peer group inquiry and the link with conceptual change learning theory) just as helpful for high school science teachers who teach physics (or for that matter useful ideas for chemistry instruction) at the upper grades. There is no need to unduly restrict it to postsecondary courses—though I acknowledge this level as his principal area of interest and research.

Calvin S. Kalman has provided an invaluable instructor's manual for all those people genuinely concerned with changing the culture of traditional physics and engineering education for the betterment of their students and enjoyment of their subject. One can only hope that many instructors will profit by it.

Compliance with ethical standards

Conflict of interest The author acknowledges the there was no conflict of interest involved in the writing of the book review.