Innovation and Change in Professional Education 16

Calvin S. Kalman

Successful Science and Engineering Teaching

Theoretical and Learning Perspectives

Second Edition

Springer

Innovation and Change in Professional Education

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This second edition is dedicated to my wife Marilyn, my children Ben and Sam, and my grandchildren Josh Lily and Max, and as I have indicated in the acknowledgment section, this work would never have come to fruition if it were not for the inspiration and ideas from my late wife Judy Kalman (February 23, 1946–June 29, 2006) in addition to her unflagging support and encouragement. She was a truly great teacher and a model for my own teaching.

Preface to the First Edition

The intent of this book is to describe how a professor can provide a learning environment that assists students to come to grips with the nature of science and engineering, to understand science and engineering concepts, and to solve problems in science and engineering courses. As such, this book is intended to be useful to any science or engineering professor, who wants to change their course to include more effective teaching methods; to instructors at postsecondary institutions, who are beginning their careers; and as a handbook for TAs. Since the book is based upon articles that I have had published in *Science Educational Research* and which are grounded in educational research that I have performed (both quantitative and qualitative) over many years, it will also be of interest to anyone engaged in research into teaching science and engineering at the postsecondary level. I have also tried to include enough background so that the book could be used as a textbook for a course in educational practice in science and engineering.

The book has two main axes of development. Firstly, how do we get students to change their epistemology so that their outlook on the course material is not that it consists of a tool kit of assorted practices, classified according to problem type, but rather that the subject comprises a connected structure of concepts? Secondly, helping students to have a deeper understanding of science and engineering.

In Part I, "How Students Learn Science," I develop some basic background on current understanding of how students try to deal with courses in science and engineering. Perhaps this part would have had a better title as "How Do Students Fail to Understand Science Subjects in Spite of the Best Efforts of Well-Intentioned Instructors." The capstone of this section, Chap. 3, deals with the fact that students have perceptions of the subject of our courses that are very different than the conceptual framework found in our courses and that it is very hard to get students to rid themselves of these notions. Those faculty who are already familiar with the literature on conceptual change theory can skip this part and proceed directly to Part II.

Part II, "Changing Students' Epistemologies," is the heart of the book. It develops the kind of scaffolding needed to assist the student to achieve a deeper understanding of the subject such as reflective writing and conceptual conflict activities based upon methodologies involving the use of collaborative groups and various forms of writing activities. It also develops the modern notion that simple conceptual change programs are not efficient since they try and attack the symptoms that prevent students' success in science courses rather than the root causes that underlie this problem. Thus this part of the book examines the whole problem of helping students to become critical thinkers and helping them to change their epistemologies.

The final part of the book looks into two successive chapters: firstly, at the special problems of courses for nonscience students and, secondly, at using the computer to tutor students.

Montreal, QC, Canada Calvin S. Kalman

Preface to the Second Edition

Many advances in research in science education have occurred since the appearance of the first edition of this book over 9 years ago. For example, much more is now understood about how reflective writing benefits students. It is now seen that reflective writing relates to Gadamer's (1975/1960) hermeneutical approach. Thus, Sect. 4.2 of the previous edition has been discarded and replaced with an entirely new material. Much better instructions are available for students on how to use reflective writing. Also a rubric has been constructed that simplifies the marking of reflective writing. Section 3.2, "A Theory of Conceptual Change," was based particularly on the work of G. Posner, K. Strike, P. Hewson, and W. Gertzog. Since then there has been a debate in the science education community between those who believe that students come in to the classroom with a theory about the subject which is different from that described by the teacher and found in their textbooks and those who feel that students' knowledge consists of isolated structures called phenomenological primitives (p-prims). This debate and the light thrown on it by M. J. Lattery's *Deep Learning in Introductory Physics: Exploratory Studies of Modeling-Based Reasoning* (Information Age Publishing 2016) is now considered in detail. In Sect. 9.3 of the first edition, the course dossier method was described – no research had been carried out on the subject. This lack has been remedied by the appearance of "Implementation and Evaluation of the Course Dossier Methodology," by Wahidun N. Khanam and Calvin S. Kalman (2017), in *The Canadian Journal for the Scholarship of Teaching and Learning: Vol. 7*. In the previous edition, Part II was labeled "Changing Student's Epistemology," which is also the title of the last chapter in the section. Nonetheless there was a glaring lack of discussion of the stages in epistemic development in students. Consequently in this edition, most of the material in Chap. 8 has been moved to Chap. 9 "Changing How Students Learn," and a new Chap. 8 "Constructing an Epistemology" begins with the Perry model and continues through later developments. In this edition, we have now included a discussion of how an instructor can enable the student to resolve cognitive dissonance in the difficulties students have in transcending their misconceptions toward target ideas. Cognitive dissonance theory (Festinger 1957) continues to develop and inspire new research; for reviews, see Harmon-Jones and Harmon-Jones (2007) and

Cooper (2007). Having relevant and inconsistent cognitions creates psychological discomfort or dissonance. Linenberger and Bretz (2012) found that the cognitive dissonance generated in the interviews provided important insights into students' understanding of enzyme-substrate interactions. Perhaps students have dropped out of courses not necessarily because of a lack of ability but rather because their epistemology (their view about the nature of knowledge and learning) is not suitable for them to succeed. In this edition, we go beyond the question of whether or not a pedagogical technique is effective, toward more of a focus on answering the question of why a particular technique or class of techniques is effective. In attempting to answer these why questions, we look into established psychological and developmental concepts, theories, and models (e.g., cognitive dissonance and epistemic development) to both provide structure to our studies and support the analysis and interpretation of the results. In particular it is shown that students' epistemological beliefs could become more expert-like with a combination of appropriate instructional activities.

It was also rightly pointed out that there was no discussion of peer instruction in the first edition. Since then research has been done comparing peer instruction with the conceptual conflict collaborative group activity that had been described in the first edition.

Finally I have had experience using the first edition as a textbook for a course of 13 2-h presentations to 37 professors at Tra Vinh University in Vietnam. Ten were from the education faculty and the rest came from all science disciplines. Springer kindly permitted the translation of the first edition gratis for this group of teachers. The course was very successful. It was very much of a participant-oriented course with participants using and experiencing all of the activities throughout the course. The new second edition should be of great use to all as a resource or as a textbook.

Montreal, QC, Canada Calvin S. Kalman

Acknowledgments

Firstly, I credit my first wife, Judy Kalman (February 23, 1946–June 29, 2006), who had many successes in teaching writing at Concordia University and Dawson College, with inspiring much of my effort to bring writing into the science classroom. She also convinced me to set aside my initial skepticism of writing methods such as journaling to attend an intensive 2-day workshop at the University of Vermont that impressed me enough to try some new techniques myself (the course dossier). She and Marjorie McKinnon were instrumental in convincing me to use collaborative groups in my teaching. At the time, Marjorie was associate director of the Concordia University Centre for Faculty Development. My first efforts in innovative teaching based upon computer-assisted instruction would never have come to fruition without the help of Ron Smith and David Kaufman. Craig Nelson, whom I have never met, inspired my idea to follow conceptual conflict collaborative group exercises with a writing activity. Without the support and many discussions provided by Mark Aulls, I would never have come to my understanding of how reflective writing works that is demonstrated in Chap. 3. I am particularly grateful to Wim Gijselaers, editor of the book series *Innovation and Change in Professional Education*. He went far beyond the duties of an editor in helping me make major changes to the draft of the first edition of this book to bring it to the present form.

I would like to thank Igal Galili for the permission to include a long excerpt of one of his papers that appears in *Science & Education*. I also would like to thank John Wiley & Sons, Inc., for the permission to include passages from an article by Dykstra et al. that appeared in *Science Education* and Encyclopædia Britannica, Inc., for the permission to reproduce an excerpt from the first edition of the encyclopedia. The short papers in Chap. 10 were originally intended as a chapter on constellation courses that I had edited as my part of a book on *Science & Society*. Funding never materialized and thus the book never appeared. I would like to thank Joseph L. Spradley, Arlen R. Zander, Martin A. Ludington, Alan J. Friedman, Lawrence S. Lerner, and Judith Eger (widow of Martin Eger), who kindly agreed to have these articles published here. It may have been serendipity as, to my mind, they are an essential part of this book. Some parts of this book have appeared in articles I wrote for *Physical Review Physics Education Research*, the *American Journal of Physics*, *Science & Education*, *Academic Exchange Quarterly*, the *Journal of College Science Teaching*, and *The Canadian Journal for the Scholarship of Teaching and Learning*.

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Part II Theoretical and Learning Perspectives

Part I
How Students Learn Science

Chapter 1
Introduction

1.1 The Beginnings of Physics Educational Research

Arnold B. Arons caused a paradigm shift in the way science education is performed at the postsecondary level. He realized that his "lucid lectures and demonstrations were depositing virtually nothing in the minds of the students." This important point will be met with skepticism by most science and engineering professors. Indeed, when Arnold Arons first pointed this out, it was almost uniformly disbelieved. That Arnold Arons is right is illustrated in the following anecdote: Many years ago I attended a workshop given by Graham Gibbs, a noted expert on study skills. He related the following experience.

Gibbs had been asked by a noted historian to help his class with note taking. Consequently, he attended a class to observe and then during the last 5 min of class speak about note taking. The professor was speaking about voyages to North America. The professor was such an engaging speaker that Graham Gibbs forgot why he was at the class. He seemed to even smell the salt water carried by the wind. With a start, he remembered why he was there and looked around the class. Surprisingly, at even the most interesting parts, students were staring out the window! This revelation led him to tear up his notes. At the end of the class, he handed the professor a transparency. "Write down the three most important points that you wanted students to take away from this class," he instructed the professor. Then he asked the students to write down the three most important points that they had derived from the class. After the professor displayed the transparency, Gibbs asked how many students had written down all of the points that the professor had written on the transparency. Not a single student raised a hand. Gibbs then asked how many students had written down two of the points that the professor considered to be the most important points that students should have derived from the class. Not a single student raised their hand. When students were asked if they had written down one of the three points that the professor wanted them to take away from the class, a few students near the front timidly raised a hand.

C.S. Kalman, *Successful Science and Engineering Teaching*, Innovation and Change in Professional Education 16, https://doi.org/10.1007/978-3-319-66140-7_1

Another difficulty with our science courses is that many students have great difficulty solving the assigned problems. Until midway through high school, students can be successful at solving problems in courses by memorizing templates for every situation encountered on an examination. That is, apply different templates to different knowledge subsets. Many students lack the ability to apply principles garnered from a problem to an apparently different problem. Other students can dismiss the conceptual basis of the problems, because their epistemology is formula driven and they accept calculated answers as a goal in itself.

Arons wanted to find out what student learning problems were at a time when talks on teaching sponsored by the American Association of Physics Teachers had concentrated on presentation of material (Arons 1998). Arons became convinced that if the mode of teaching was changed, many more students could understand science. Many students were failing science courses not because they lacked the ability to understand the courses, but because the courses were not meeting their needs. At the time it was difficult to get anyone to examine the root causes as to why students were having problems with the courses. Arons noted that scientists felt that research on educational methods for college and university science/engineering students should consist of "refining the delivery systems, the exposition, the text presentation, lecture presentation, the films and so forth, to the point that where they were so clear and so perfect that any passive student mind would assimilate them simply by having it drop in. That was what research was going to be—delivery—and there was no conception of listening to what the students said when you gave them the opportunity to reflect or talk about something."

Arnold Arons was joined in his efforts to look at the reasons why students in the introductory college and university physics courses had difficulties understanding the material presented to them in the late 1960s by Robert Karplus of the University of California at Berkeley. This led ultimately to a workshop on intellectual development (based on Piaget's theory) on February 1, 1975, that I along 134 other members of the American Association of Physics Teachers (AAPT) attended in Anaheim, California. The day before, I had given a talk as part of a joint symposium of the AAPT and the American Physical Society on courses in physics and society. After that meeting, Roger Dittman, the chair of the symposium, I, and some others decided to publish the proceedings. In the end, this did not happen. My part was to be on constellation courses (such courses attempt to relate physics and its developments to history, philosophy, religion, literature, the social sciences, and other natural sciences) and is mostly published here as the short papers in Chap. 10.

My first incursion into scientific educational research occurred in 1971. I decided to implement a computer-assisted (CAI) instruction program to help students who were having conceptual difficulties with the introductory course. Careful testing of questions is necessary. We introduced our CAI calculus dialogues during a summer session. We tried the dialogues on a few students at a time and immediately interviewed the students with respect to the reasons why they chose their answer to each question. The answers provided us with additional keywords, alterations in the language of the questions, and the need for logic changes in the programs. We would then change the dialogues before the next few students made their attempt. We also discovered that the original dialogue was too long and needed to be split in two parts. By the end of the summer session, we had confidence in our dialogues (Kalman et al. 1974). Dave Kaufman used the work as the main thrust for what must be one of the first Ph.D.s in physics educational research at the postsecondary level (1973). His Ph.D. work was presented at a meeting of the American Educational Research Association (Kaufman et al. 1975). See Chap. 9 for details on computer-assisted instruction.

1.2 The First Graduate Programs in Physics Educational Research

There had been Ph.D.s awarded in Europe in the study of preuniversity students' conceptual understanding. The first one was awarded to Agnes Banholzer in 1936 on "The conception of physical facts in the school." Arnold Arons was probably the first person to examine the conceptual understanding of postsecondary students. Around the time that Arons began discussions with Karplus, in 1968, Arnold Arons moved to the University of Washington. There he began a collaboration with Lillian C. McDermott. This collaboration led to the formation of the Physics Education Group at the University of Washington. This was the formal beginning of a new field of scholarly inquiry for physicists: physics education research. In the 1970s, Arnold Arons supervised the dissertation of a student who received a Doctor of Arts in physics at the University of Washington. Only this one student graduated in this program, which did not have the same requirements as a Ph.D. before the program was canceled. In 1979, the physics department at the University of Washington awarded their first Ph.D. in physics (David Trowbridge) for research in physics education to a student supervised by Lillian C. McDermott, director of the physics education group. Appendix D of the proceedings of the 1998 physics educational research conference lists a dozen such Ph.D. programs and four multidisciplinary programs that include physics education research in the United States. The importance of the University of Washington group was that it was not in a faculty of education. Professors were not solely trying to apply education and educational psychology principles to the study of science but were "investigating difficulties students encounter in the study of physics and developing curriculum to overcome these difficulties" (Prospectus for new graduate students issued by The Physics Education Group 1987).

1.3 Educational Research in Other Science/Engineering Disciplines

Discipline-based educational research in mathematics began around 1988. Dubinsky at Georgia State University began his research by extending Piaget's work. He works on exploring the subconcepts students need to grasp before they can understand key mathematics concepts. He has designed activities, to help students acquire these subconcepts. Schoenfeld at the University of California applies cognitive psychology in mathematics education. There are also many faculty members in astronomy, biology, chemistry, engineering, and geology, who are trying to apply the principles developed in physics and mathematics education, but there are no discipline-based educational groups.

In biology, there is the BioQUEST Curriculum Consortium (Beloit College). This project was founded in 1986 by John Jungck, editor of The BioQUEST Library.

BioQUEST is a group of educators and researchers committed to providing students with biology research and research-like experiences. The Consortium began with an initiative of the Commission on Undergraduate Education in the Biological Sciences, established by liberal arts college biologists in the 1960s. The Consortium currently has "a current resource of high-caliber Doctors/Ph.D.s/MBAs/Pharmacists/Engineers/Designers/Animators/IT professionals/Clinical researchers/Biostatisticians across divisions." BioQUEST emphasizes the acquisition of scientific literacy through the collaborative intellectual activities of problem posing, problem solving, and persuasion of peers. A major project has been the development of computer simulations that help students understand fundamental biological concepts. For example, students studying genetics can breed fruit flies and observe the inheritance of characteristics such as eye color. They can then augment their laboratory experience with software that simulates the breeding of thousands of virtual fruit flies, leading the student to discover the laws of genetics. The Consortium also conducts faculty-development workshops and distributes a free newsletter, BioQUEST Science and Mathematics Teaching Notes, three times a year to interested members of the education community.

In chemistry, the ChemLinks project was initiated by Brock Spencer of Beloit College and developed with members of the Midstates Science and Mathematics Consortium. Over 100 faculties from more than 42-year colleges, 4-year colleges, and universities have developed and tested modules dealing with chemistry, the environment, technology, and life processes. ChemLinks modules have been developed under the direction of the ChemLinks Coalition, headed by Beloit College, and the ModularChem Consortium, headed by the University of California at Berkeley. They cover topics relevant to contemporary issues and take 3–5 weeks to complete. Students are guided to develop the chemistry knowledge needed to deal with these complicated issues. Modules incorporate collaborative activities and inquiry-based laboratory projects that replace traditional lectures, exams, and laboratories.

In 1980, a consortium consisting of eight universities and the Center for Applications of Psychological Type was formed to study the role of personality type in engineering education. In engineering education of particular note is Richard Felder the Hoechst Celanese Professor Emeritus of Chemical Engineering at North Carolina State University. Felder has been particularly active in educational research in engineering. Of note is Felder and Hadgraft (2013), "Educational Practice and Educational Research in Engineering: Partners, Antagonists, or Ships Passing in the Night?". A proposition has been made that the movement toward increasing "rigor" in engineering education research has been driving a wedge between the engineering education research community and the broader community of engineering education practitioners and that the movement may rest on unvalidated assumptions. See http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Education_Papers-Chronological.html. (See also Singer and Smith (2013). Discipline-based education research: Understanding and improving learning in undergraduate science and engineering.)

1.4 North American Educational System

Almost all of the research discussed in this book was conducted at institutions in the United States and Canada. Most institutions in these countries and all of the institutions discussed in this book have courses based upon a semester system. The academic year is based upon two semesters which together usually take place during September through June. In the United States, semesters usually consist of 15 weeks and in Canada 13 weeks. Each semester is followed by a period set aside for examinations. Many students enter junior colleges before entering university. Junior colleges provide 2 years of courses, whereas other postsecondary institutions usually provide 3 years of courses. Students often choose junior colleges because the tuition is lower than at other postsecondary institutions and they are often located closer to where their parents live. Quebec Province in Canada where I teach has a unique compulsory junior college system called CEGEPs. Students enter CEGEPs after completing grade 11 in high school, and graduating students may then enter 3-year programs at Quebec universities to complete their Bachelor's degree. Quebec universities offer 3-year Bachelor programs for CEGEP graduates and 4-year Bachelor programs for out-of-province students.

Marks in courses in Canada and the United States are usually assigned using letters where A would be the highest mark and F the lowest mark.

Grade point average (GPA) is an important factor used in most North American universities. Grades for courses are assigned as letters (generally A through F). Then a number is assigned to the letter grade. The scale runs from 0 to 4 or 5. All grades are then averaged to create a grade point average (GPA). A *cumulative grade point average* is a calculation of the average of all of a student's total earned points divided by the possible amount of points: $\text{GPA} = \dfrac{\Sigma(\text{course credit} \times \text{grade points})}{\Sigma(\text{GPA course credits})}$

1.5 Research Questions in Science Educational Research

There has been a debate in the science and engineering education community between those who believe that students come in to the classroom with a theory about the subject which is different from that described by the teacher and found in their textbooks and those who feel that students' knowledge consists of isolated structures called *phenomenological primitives* (p-prims). The former was the accepted paradigm on student conceptions in science from the 1970s to 1990s. For example, in mechanics it was thought that students enter the physics classroom with stable and coherent conceptions about the natural world, similar to those held by ancient philosophers and scientists (Wandersee et al. 1994). However, diSessa published a chapter in Gentner and Stevens (1983) that strongly challenged this view. He argued that "spontaneously acquired" student knowledge consists of isolated structures called *phenomenological primitives* (p-prims). The dependence of scientific knowledge on p-prims is not generally recognized because "the work being done by p-prims is covert" (p. 16).

What is at stake in this debate? If student knowledge is a hopelessly disorganized jumble of ideas, instruction should build scientific concepts from the most productive and familiar "pieces," an approach taken with the *bridging* technique (Clement and Rea-Ramirez 2008). However, if this knowledge is more or less coherent, instruction should confront student ideas with logical arguments and experimental evidence, a tactic taken by the *elicit-and-challenge approach* developed in the seminal work of Posner et al. (1982); also see Ohlsson (2011).

No book can hope to cover all of science educational research. This book in addition to examining the issue discussed above attempts to explore the following major questions relating to basic issues that impede student learning:

1. What is the stage of the students' intellectual development? McKinnon and Renner (1971) state the hypothesis: "The majority of entering college freshmen do not come to college with adequate skills to argue logically about the importance of a given principle when the context in which it is used is slightly altered" (Chap. 2).
2. How can the instructor enable the student to resolve cognitive dissonance in the difficulties students have in transcending their misconceptions toward target ideas? Festinger (1962) wrote, "In the course of our lives we have all accumulated a large number of expectations about what things go together and what things do not. When such an expectation is not fulfilled, dissonance occurs." "He can even distort his perception and his information about the world around him. Changes in items of information that produce or restore consistency are referred to as dissonance-reducing changes."

   This is precisely the situation of the typical student in an introductory science courses. Students have been experimenting and observing nature since they were very young. In physics they may think that bodies need a force to keep moving contrary to Newton's first law. In introductory astronomy courses, students often think that the weather is cold in the winter because the Earth is farther away from the Sun during the winter. In introductory biology courses, students think that the biological material making up a plant has accumulated in the plant from materials already present in the soil. Students in chemistry courses memorize balancing procedures but do not connect them with the concept of the law of multiple proportions – that the relative number of atoms of each type must be the same before and after a chemical reaction.

At the same time, they have strong beliefs that knowledge is conveyed by authorities (instructor and textbook). This results in cognitive dissonance. To reduce the dissonance between their understanding and what they hear in the classroom and read in the textbook, students mishear the teacher and misread the textbook. Every time that we have given a seminar and mention about students coming up after class and stating that the instructor has said exactly the opposite of what the instructor said, everyone in the room nods their head. Cognitive dissonance causes the student to misread the textbook and mishear the teacher (Chap. 3).

3. Students can have great difficulty reading scientific texts and trying to cope with the professor in the classroom. Part of the reason for student's difficulties is that for a student taking a science gateway course, the language and epistemology of science are akin to a foreign culture. Textbooks seem to be written in students' native language and seemingly all that is required is to understand the meaning of the special scientific vocabulary. This works to the extent of going to France and being taught that chaise is the word for chair, maison is the word for house and so on, but nothing else. Without grammar, you have great difficulty communicating "where is my hotel; the Louis V?". For many students in the introductory gateway course, although individual words are understandable, the sentences appear to take the form of an unknown language. It is my contention that a student can use reflective writing to begin to analyze the material in the textbook in the manner of the modern theory of hermeneutics developed by Hans-Georg Gadamer 2004) (Chap. 4).
4. What is the students' world view, knowledge in pieces as described by diSessa or a coherent theory as described, for example, by Posner et al. (Chap. 5).
5. Chapter 6 begins with a discussion of educational models based upon philosophy of science. It then revisits the opposing view that the attitude of many students toward science is "knowledge in pieces." It continues with more details on the incommensurability of naïve theories and scientific theories.
6. Given that many students do not enter introductory science courses with a coherent view of the subject but rather a viewpoint described as "knowledge in pieces," studying philosophy of science helps them to develop a coherent view of science. What instructional supports are necessary for students to examine their own ideas and compare them to the ideas presented by peers, the textbook, and the instructor? Feyerabend 1993, p. 33) has pointed out that evaluation of a theoretical framework does not occur until there is an alternative (principle of counter induction). A scientist who is interested in maximal empirical content, and who wants to understand as many aspects of his theory as possible, will adopt a pluralistic methodology; he will compare theories with other theories rather than

with "experience," "data," or "facts." To make such comparisons, students need to develop their critical thinking skills (Chap. 7).

7. Chapter 8 relates epistemic change to conceptual change in students. Students progress through stages where they experience more and more uncertainty and, simultaneously, their way of acquiring knowledge changes from being passive to being more active and constructive. Students' change in their epistemological beliefs is related to the evolution of science philosophy and hermeneutics.
8. A coherent scientific framework is a highly ordered knowledge structure that contains a coherent set of interrelated big ideas. If students thought of science in terms of such a framework, they would, as they learn, relate new material to the material that they feel they already understand and in the process assimilate the new material within the framework. In Chap. 9, we discuss ways of getting students to view science in terms of a coherent scientific framework and also how we can get students to change the way they learn science

To deal with all of these issues, it is necessary to adopt the approach of "Joe" Redish (Teaching Physics, 2003); if we want to adopt the view that we want to teach as many as possible to our students, then we must adopt a mix of approaches and be prepared that some of them will not work for some students.

1.6 Final Thoughts

The approaches that try to attract non-science students to courses by merely writing in words the mathematical formulas ("physics for poets"), or by step-by-step detailed explanations, appear somewhat naïve. In Chap. 10, we consider some approaches to courses for non-science students. We also examine one additional activity that has been employed in those courses – the course dossier method. The course dossier method takes students beyond the reflective writing on the textbook found in Chap. 4 to the use of writing to critically explore the material presented in the class. I have used it in the most advanced undergraduate physics courses, and I have found it particularly useful in science courses designed for non-science students.

Finally in Chap. 11, we look at computer-assisted instruction. The last chapter Chap. 12 gives an overview of the book.

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